Separating grain thrower for processing grain material

S S Yampilov¹,³, Zh B Tsybenov¹, S Zh Gylykova¹, I O Onkhonova¹ and N I Moshkin²

¹Department of Biomedical Engineering, East Siberian State University of Technology and Management, Ulan-Ude, 670013, Russia,
²Buryat State University, Ulan-Ude, 670000, Russia,
³E-mail: yampilovss@mail.ru

Abstract. Research is underway to develop a grain separator. This device performs processing of grain material including cleaning, drying and cooling of grain. The device is able to perform all these operations. Currently, such machines do not exist. Known machines are able to perform only one process. The proposed device differs from all known machines in that it is able to perform the entire complex of works on the processing of grain material. The device consists of a rotating drum, where separating and other elements are installed, allowing to carry out the flight of the grain material into the air stream. The purpose of the research is to study the influence of the main parameters of the separating grain thrower on the processing efficiency of grain material. The geometrical parameters of the device are calculated using differential equations analytically describing the movement of grain in the drum of the device. Experimental setup was made for laboratory research and confirmation of theoretical studies. The tests confirmed the theoretical conclusions.

1. Introduction

Grain processing companies need modern, versatile machines that are capable of processing grain material in a single step. At present, all known grain processing machines process grain in stages, with each stage using a relevant specialised machine. This technology of processing grain material in stages is energy and resource intensive. An example of staged processing is cleaning drying complex ZAV-40 (figure 1) [1]. High cost of complexes for stage-by-stage processing of grain material is one of the reasons for which not all farms grow grain crops. Now, in Central Russia alone, about half of the total area of agricultural land is unused [2].

The analysis of existing grain processing equipment has shown that there are currently no machines capable of carrying out the entire range of work on the processing of grain material autonomously. Specialized machines are known to be able to carry out only one process.

There is an ongoing research on the development of a separating grain picker. Separating machine is able to carry out all operations on a step-by-step grain processing (figure 1). Depending on the requirements of the finished product, processing of grain material involves the following operations: cleaning from impurities (light and heavy impurities, large and small, long and short), drying of grain to basic conditions, cooling of grain after drying, fractionation of grain. Developed device performs all these operations in one process. One machine replaces the complex of machines installed, for example, in the cleaning drying complex ZAV-40 (figure 1).
This machine is able to meet the growing needs of grain-producing companies. Conducting theoretical and laboratory research to determine the basic design parameters of the separating grain picker is an urgent task.

2. Simulation of particle motion

Theoretical studies were carried out to establish the basic geometric parameters of the device and were calculated using differential equations to describe analytically the movement of particles in the drum of the device.

Let’s consider motion of particles on separating surface. Main mass of particles slides on surface. External forces acting on the particle are centrifugal force, Coriolis force, gravitational force and frictional force (figure 2).

Differential equation of acting forces:

\[ m \frac{d^2 S}{dt^2} = F_c \cos \alpha - F_f + G \sin(\beta - \alpha), \]

where
- \( m \) – particles mass, kg;
- \( \omega \) – angular velocity, rad/s;
- \( N \) – the support reaction force, N;
- \( S \) – is the distance from the center to the particle, m;
- \( f \) – is the coefficient of friction;
- \( F_f = fN \) – friction force;
- \( F_c = mS\omega^2 \) – centrifugal force;
- \( F_K = 2m\omega \frac{ds}{dt} \) – Coriolis force;
- \( G = mg \) – the force of gravity.

Equation of particle equilibrium on the separating surface:

\[ N - F_K - F_c \sin \alpha - G \cos(\beta - \alpha) = 0, \text{ or } \]
\[ N = F_K + F_c \sin \alpha + G \cos(\beta - \alpha) \]

Given the equilibrium equation of the particle on the separating surface, the differential equation of the acting forces will be as follows:

\[ m \frac{d^2 S}{dt^2} = F_c \cos \alpha - fF_K - fF_c \sin \alpha - fG \cos(\beta - \alpha) + G \sin(\beta - \alpha) \]

Dividing the resulting equation by the mass \( m \), we find the following equation:

\[ \frac{d^2 S}{dt^2} = S\omega^2 \cos \alpha - 2f \omega \frac{dS}{dt} - f S\omega^2 \sin \alpha - f g \cos(\beta - \alpha) + g \sin(\beta - \alpha) \]
By substituting $dt = d\phi/\omega$ into the resulting equation, i.e. $\omega = d\phi/dt$ - angular velocity, we obtain the following equations:

$$\omega^2 \frac{d^2S}{d\phi^2} + 2f \omega^2 \frac{dS}{d\phi} - S\omega^2 (\cos \alpha - f \sin \alpha) = g(sin(\beta - \alpha) - f \cos(\beta - \alpha)),$$

$$\frac{d^2S}{d\phi^2} + 2f \frac{dS}{d\phi} - S(\cos \alpha - f \sin \alpha) = \frac{g}{\omega^2}(sin(\beta - \alpha) - f \cos(\beta - \alpha)).$$

The equation of motion of the particle was obtained taking into account its sliding on separating surface without detachment from it. The equation has constant coefficients and belongs to inhomogeneous linear equations of the second order [3].

3. Methods and materials

Experimental setup (figure 3) was made according to patents [4,5]. The basic design geometrical parameters were calculated using differential equations analytically describing the movement of grain in the drum of the device and sign of separation of grain material particles [6].

![Figure 2. Acting forces.](image1)

![Figure 3. The experimental installation.](image2)

The experimental installation of the separating grain thrower consists of the drive. The drive contains an electric motor, an electric motor speed controller, a worm gearbox and a V-belt transmission. The drive drives the shaft, which rotates the drum containing the separating devices for cleaning the grain material. The drum is installed in a cylindrical outlet casing.

The grain material, namely, its cleaning, drying, fractionation, cooling and transport, if necessary, is handled by the rotating drum.

The grain material is fed to the rotating drum by a storage hopper. The hopper regulates the grain feed by means of a flap.

The grain in the rotating drum is transported by centrifugal forces to the separators, where it is cleaned of impurities.

The grain material at the periphery of the rotating drum is ejected through the drum's outlet channels onto the cylindrical surface of the outlet hood.

Then, through the outlet channel, the grain material is inertially flown into the air stream, where it is dried, cooled, fractionated by specific gravity and cleaned from light impurities.

All movements of the grain material in the device are shockless, which prevents injury to the grain material [7].
The investigations made on the experimental installation (figure 3) showed high efficiency of grain material processing and confirmed the theoretical studies describing analytically the movement of particles in the drum of the device.

Laboratory studies of the effect of the main parameters of the separating grain thrower on the flight range of the grain material particles were conducted. For this purpose, used wheat variety "Mironovskaya 79" with a moisture content of 13%. The feed of grain material is 5 tons per hour.

4. Results and discussion
Preliminary studies have shown that at an angle of inclination of the drum outlet to the horizon of 45°, the flight range of the granular material particles is the greatest. At this inclination angle the effect of the initial velocity of the particles on the flight range was investigated (figures 4, 5, 6, 7).

Dependence of distribution frequency \( Q \) on flight range \( l \) of the grain particles at initial velocity of 8 meters per second (figure 4).

![Figure 4. Flight speed 8 m/s.](image)

Dependence of the distribution frequency \( Q \) on the flight range \( l \) of the grain particles at an initial velocity of 10 meters per second (figure 5).

![Figure 5. Flight speed 10 m/s.](image)

Dependence of the distribution frequency \( Q \) on the flight range \( l \) of the grain particles at an initial velocity of 12 meters per second (figure 6).
5. Conclusion
The derived differential equations analytically describing the movement of particles in the drum of the device allowed to determine the rational basic design, kinematic and technological parameters of the separating grain picker. Laboratory tests confirmed theoretical studies that analytically describe the movement of particles in the drum of the device, as well as the high efficiency of treatment of grain material.

The tests were conducted at different angles of inclination of the drum outlet to the horizon. The greatest efficiency of treatment of grain material is observed at an angle of inclination of the outlet spigot and the flight of grain material of 45°, which is confirmed by theoretical studies. At this angle of flight, the maximum flight range of grain material is achieved and was 7 meters with initial flight speed of 14 meters per second (figure 7).

As a result of these investigations the dependencies of frequency distribution Q on range l of particles of grain material at its initial velocity of flight were obtained. (figure 4,5,6,7). High efficiency of grain material processing at initial velocity of 14 meters per second was observed (figure 7).

Thus, laboratory tests of the separating grain picker have shown high efficiency of processing grain material. It is necessary to conduct comprehensive field tests in grain-producing farms.

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