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JUSTIFICATION OF THE PARAMETERS OF THE CONICAL PERFORATED SURFACE IN A CENTRIFUGAL GRAIN SEPARATOR

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Abstract. *A theoretical study of the separation process of grain material on a conical perforated surface of a vibro-centrifugal separator is presented. The paper analyzes current approaches to pneumatic-centrifugal and vibro-centrifugal grain separation, highlighting the key factors that determine the efficiency of separating heterogeneous grain mixtures. A mathematical model describing the motion of an individual particle along a rotating conical surface has been developed, taking into account the influence of centrifugal, gravitational, and frictional forces. The corresponding differential equations of motion are derived to characterize the kinematic behavior of particles under various operational conditions. The results of this study provide a theoretical basis for optimizing the design and technological parameters of vibro-centrifugal grain separators aimed at improving separation accuracy and energy efficiency.*

Key words: *separation, grain mixture, terminal velocity, conical screen, vibro-centrifugal separator*

Modern grain cleaning and post-harvest processing technologies increasingly demand higher precision and efficiency in separating grain mixtures into uniform fractions according to their size, mass, and aerodynamic characteristics [1, 3, 5]. Despite notable progress in the design of pneumatic and centrifugal separators, their performance remains limited when it comes to achieving consistent classification of grain masses into primary and fine fractions. Conventional pneumatic-centrifugal separators are primarily effective in removing light impurities; however, they often fail to provide the necessary uniformity and accuracy of separation. In industrial practice, sieve-type cleaning machines are commonly employed to address this issue [2, 4, 6]. Nevertheless, such systems are characterized by several operational drawbacks, including relatively low throughput, high energy consumption, and accelerated wear of the working elements, which collectively reduce overall process efficiency.

In view of these limitations, research efforts have increasingly focused on developing innovative methods and designs that combine aerodynamic, vibrational, and centrifugal effects to enhance separation quality. The scientific relevance of this work lies in establishing a methodological framework that integrates analytical modeling of particle dynamics with the optimization of structural and kinematic parameters of the separator. This approach enables more accurate control of the particle motion trajectory, thereby improving both separation selectivity and energy efficiency.

Earlier theoretical investigations [3, 4] analyzed the motion of particles on conical surfaces under the combined influence of gravitational and centrifugal forces. The equations of motion, expressed in polar coordinates, allowed researchers to determine equilibrium conditions and critical velocities at which particles are able to pass through perforations in the conical surface. These models serve as an important theoretical foundation for describing the complex particle flow behavior within centrifugal and vibro-centrifugal separators, as they take into account the cone geometry, the inclination angle of its generatrix, the coefficients of friction, and the initial kinematic conditions of particle movement.

Building upon these findings, this study proposes a new configuration of a vibro-centrifugal separator equipped with a conical perforated surface designed to improve the efficiency of grain fractionation. The theoretical analysis focuses on the motion of an individual grain particle of mass m along a rotating perforated conical surface spinning around a vertical axis at a constant angular velocity ω. The adopted coordinate system originates at the cone apex [1, 2]. This formulation serves as the basis for developing differential motion equations and defining optimal operating parameters that ensure effective and energy-efficient separation of grain materials.

We consider the motion of a single grain particle of mass mmm on the inner surface of a thin-walled, perforated right circular cone whose axis is vertical [1]. The cone rotates about its vertical axis with constant angular speed ω. Let sss denote the distance measured along the cone generatrix from the cone apex to the particle (fig. notation), and let θ be the particle angular coordinate relative to the cone (i.e. the particle’s angular coordinate in the body-fixed frame). The cone half-angle (angle between the generatrix and the axis) is β.

$$\frac{d^2\rho}{dt^2} - \rho sin^2(\beta)\left(\omega - \frac{d\varphi}{dt}\right)^2 + \frac{Nf}{mV}\frac{d\rho}{dt} + g\sin(\omega t)sin(\beta) = 0$$

$$\rho\frac{d^2\varphi}{dt^2} - \frac{2\rho}{dt}\left(\omega - \frac{d\varphi}{dt}\right) + \frac{Nf\rho}{mV}\frac{d\varphi}{dt} - g\cos(\omega t) = 0$$

The particle velocity on the working surface is given by [1, 11, 14-16]:

$$V = \sqrt{\left(\frac{d\rho}{dt}\right)^2 + \left(\rho\frac{d\varphi}{dt}sin(\beta)\right)^2}$$

The solution of the derived differential equations makes it possible to determine the velocity of a particle relative to the conical separating surface and the distance it travels along the cone generatrix [12, 15]. However, to ensure the reliable passage of grain particles through the perforations, it is essential to establish the conditions that provide a favorable alignment between the particle trajectories and the separating apertures, as well as to verify that the residence time of particles near the separation surface is sufficient for penetration through the openings [2, 7].

The fundamental prerequisites for the passage of particles through the separator apertures are as follows:

– the presence of a force acting on the particle in the direction normal to the conical surface [2];

– continuous contact of the particle with the working surface [13];

– the existence of relative motion of the particle along the conical surface [9].

At the same time, the velocity of the grain particle relative to the conical surface must not exceed a specific critical value beyond which stable separation cannot occur.

To determine the required length of the conical section at which the separator achieves its steady operating mode, the relationship between the particle velocity and its displacement along the generatrix is employed, yielding the following analytical dependence [1, 10, 14]:

$$\rho_p = \frac{\sqrt{V_{pr}^2 - \left(\frac{d\varphi}{dt}\right)^2}}{\frac{d\varphi}{dt}\cdot\sin(\beta)}$$

The obtained calculation results made it possible to construct graphical dependencies illustrating the variation of the critical velocity of particle passage through openings of different diameters on the conical surface. This, in turn, allows determining the rational length of the active zone in the grain mixture separation process according to the geometric dimensions of the particles (Fig. 1).

The analysis of the derived expression and the constructed graphs indicates that as the size of the passing particles increases, the length of the conical generatrix required to achieve the limiting velocity of particle penetration through the perforations decreases. Consequently, the separation process of the grain material completes over a shorter segment of the working surface [8].

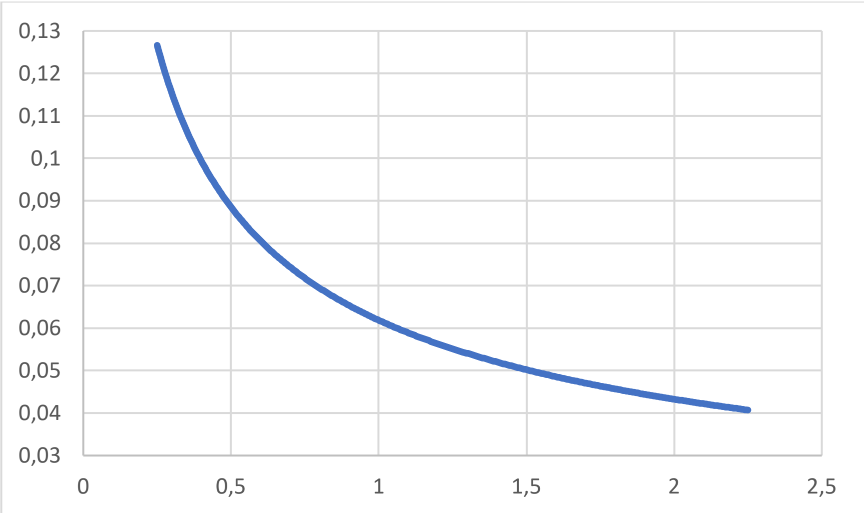

Figure 1 – Dependence of the working surface length on the size of the passing particle ($d = 3\ mm, \omega = 105\ s^{-1}$).

As the diameter of the perforations increases, the length of the conical generatrix over which the passage of particles occurs also increases [9, 11, 13]. However, despite the improved throughput of the conical separating surface, excessive enlargement of the holes leads to violations of the requirements regarding the content of coarse particles in the final product [12, 15–17].

It has been established that increasing the cone inclination angle enhances the velocity of particles along the generatrix [10, 14], while simultaneously reducing the normal component of the centrifugal force, which governs the ability of particles to pass through the perforations of the working surface.

Theoretical justification of the conditions for particle passage through the apertures of a rotating perforated conical surface has been performed. Based on the equations of particle motion under the combined influence of centrifugal, gravitational, and frictional forces, the dependence of the critical velocity of particle passage on the geometric parameters of the separating surface (apex angle, perforation diameter) and the kinematic parameters of rotation (angular velocity, rotation frequency) was established.

Analytical expressions were obtained that allow determination of the length of the working surface of the cone over which the separation process is completed. The solution of the governing equations demonstrated that the rational length of the generatrix is a function of rotation frequency, perforation diameter, cone angle, and the size of passing particles. These dependencies provide a basis for the design of working components in vibro-centrifugal separators.

The results of this study can be applied to improve the design of vibro-centrifugal and combined grain cleaning machines. The derived analytical expressions and graphical dependencies provide an engineering foundation for further modeling, optimization of working element parameters, and enhancement of the efficiency of grain separation processes.

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