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# THEORETICAL PRINCIPLES OF PNEUMO-MECHANICAL COMBINATION OF GRANULATION IN TRANSFERRING HAIRY SEED TO MESH SURFACE

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**Abstract:**

Pneumo-mechanical seed sorting systems are critical in enhancing the efficiency and precision of separating hairy cotton seeds based on their aerodynamic and mechanical properties. Conventional sorting machines often face limitations in seed permeability and damage control due to inadequate tooth-disc design and feed mechanism parameters. There is a lack of comprehensive theoretical modeling that considers the dynamic movement of hairy seeds along various disc tooth geometries, especially under different angular speeds and bevel angles. This study aims to theoretically analyze the movement of hairy seeds along the surface of toothed discs to determine optimal conditions that minimize mechanical damage and improve transfer efficiency. A differential motion equation was developed to describe seed behavior on the tooth surface, integrating parameters like centrifugal force, tooth inclination, and angular speed. Simulation results showed that at 45–55° bevel angles and 45 rpm disc speed, optimal permeability with minimal damage was achieved. The work presents an original mathematical model describing hairy seed dynamics on rotating toothed surfaces and verifies the results through simulation using Maple software. Findings provide a scientific basis for improving sorting machine design, offering practical insights for engineering optimized feeder components to enhance sorting efficiency and reduce seed damage.

**Keywords:** Disks, types of teeth, mesh surface, pneumomechanical, colosnik, adjustable wall, hair seed.

## 1. Introduction

In a pneumatic-mechanical sorting machine, seeds with high scattering are mainly sorted well. The degree of fluffiness differs in the amount of fluffiness when passing through the sieve holes. Therefore, the sorting efficiency is increased by improving the design of the system to ensure uniform discharge onto the sieve surface at the optimal level of fluffiness and by using devices and guides to create a uniform seed layer on the sieve surface [1].

In the agricultural engineering sector, the sorting and processing of seeds particularly cotton hairy seeds play a crucial role in the efficiency and quality of downstream production. Pneumo-mechanical sorting machines are widely employed due to their ability to sort based on physical and aerodynamic properties. These machines combine airflow and mechanical movement to separate seeds based on weight, shape, and surface characteristics. However, the growing demand for increased throughput and reduced seed damage has necessitated deeper exploration into the mechanical dynamics involved in the seed transfer process, especially along toothed feeder discs[2].

Specifically, the movement of hairy seeds on the toothed surface of a rotating disc has a direct impact on the efficiency of their sorting. Factors such as centrifugal force, friction, bevel angle of the disc teeth, and angular velocity govern the motion trajectory and interaction of seeds with the mesh surface. Despite their importance, these variables have not been thoroughly integrated into a theoretical framework to model seed dynamics. Studies have generally focused on empirical optimization of feeder parameters or qualitative assessments of seed damage, leaving a critical gap in predictive modeling and precise control of seed flow in mechanical sorting machines[3].

Several prior works have attempted to enhance seed transfer systems by adjusting physical components like the angle of inclination and the spacing between disc teeth. For instance, researchers have proposed mechanical modifications to the feeder housing or the use of guiding elements to increase uniformity of seed distribution on the mesh. However, most of these studies lacked mathematical rigor and did not account for dynamic interactions under varying operational conditions. Moreover, they have not fully explored the application of mathematical simulation tools to predict seed movement across different tooth profiles, angular speeds, and structural designs[4].

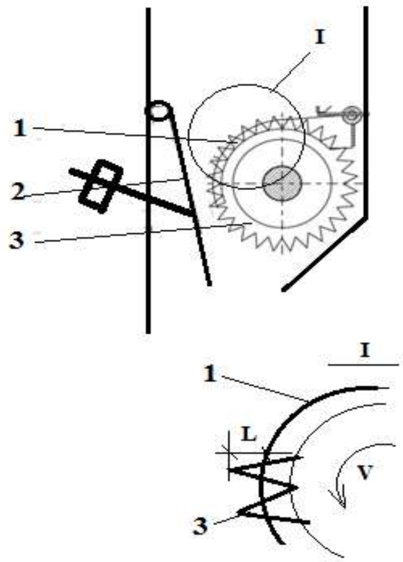
To address this gap, the present study develops a detailed mathematical model using second-order non-homogeneous differential equations that describe the movement of hairy seeds along toothed disc surfaces. It considers forces such as normal compression, centrifugal acceleration, and frictional interactions. Using Maple software, graphical analyses are performed to determine optimal conditions under which seed damage is minimized and transfer efficiency maximized. The influence of angular speeds and bevel angles on seed motion and damage is investigated through simulation[5].

The findings of this study provide a significant step forward in the theoretical understanding of seed dynamics in pneumatic-mechanical sorting machines. By identifying the conditions that minimize seed damage while maintaining high permeability, the study offers practical implications for the design and operation of efficient feeder systems. Furthermore, the research contributes to the development of precision agricultural technologies that align with modern demands for productivity and sustainability[6].

## 2. Materials and Methods

The main working elements of the pneumatic-mechanical sorting machine are the feed shaft, grate and toothed disk.

Figure 1 illustrates a feeder mechanism comprising toothed disks used in a seed transfer system. The diagram shows the interaction between the rotating toothed disk (1), guiding element (2), and seed path (3), which ensures uniform seed delivery. The arrows indicate rotational direction and motion trajectory within the transfer mechanism.




**3.**

Figure 1. The scheme of the feeder consisting of toothed disks in the seed transfer system.

*a) the fierst column, the second adjustable wall, the third toothed disk.*
*b) Scheme of movement of colosniks between disc teeth.*

In order to further increase the efficiency of the transfer of hairy seeds from the feeder, it is possible to lower the grates and raise the disk teeth to allow more seeds to be transferred, and it is also possible to increase the efficiency by sliding the front wall of the feeder with a toothed disk, but by sliding the wall and opening the distance between the disk teeth and the front wall, the seed adhesion decreases and, as a result, the permeability of the seeds through the holes of the sorting mesh decreases. This negatively affects the quality of sorting. Therefore, we will consider a theoretical analysis of the movement of seeds along different types of teeth in order to increase the grain size without changing the distance between the disk teeth and the front wall.

Figure 2 above shows the parameters affecting the hairy seeds from the disc teeth, where ω is the angular velocity of the saw disc; $F_{mk}=m\omega^2 r$ - centrifugal force of hairy seeds; R – saw cylinder radius; r – sawtooth length; 2mωx- Caryolis force; $F_{ish}$ - friction force; N- normal compressive strength; m – mass of hairy seed; f – coefficient of friction; α- bevel angle of the saw tooth. (Fig. 2)[7].

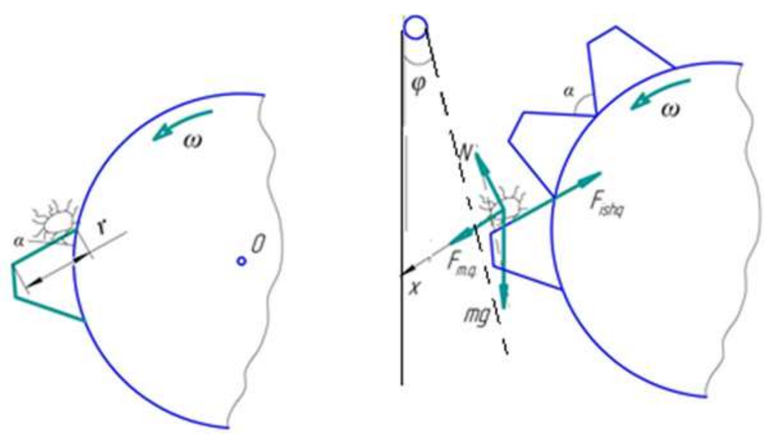



Figure 2. Scheme of movement of hairy seeds along the disc teeth**.**

## 4. Results

We will compare the situation of using different teeth to reduce the damage of the hairy seed in smooth transmission jams caused by the movement of the hairy seed on the disc tooth surface. We construct the differential equation of motion on the surface of the disc tooth of the saw-tooth cylinder[8].

$$\begin{cases} m \cdot \ddot{x} = F_{m.q} - F_{ish} \cdot \cos\beta + m \cdot g \cdot \cos\alpha \\ m \cdot \ddot{y} = N + F_{ish} \cdot \sin\beta + m \cdot g \cdot \sin\alpha \end{cases} \quad (1)$$

$$\begin{cases} m \cdot \ddot{x} = m \cdot \omega^2 \cdot r - f \cdot N \cdot \cos\beta + m \cdot g \cdot \cos\alpha \\ m \cdot \ddot{y} = N - f \cdot N \cdot \sin\beta + m \cdot g \cdot \sin\alpha \end{cases} \quad (2)$$

From equation (2), the motion of the hairy seed is from the plane motion along the OU axis be $\ddot{y} = 0$. As a result:

$$m \cdot \ddot{y} = N + 2 \cdot m \cdot \omega \cdot \dot{x} - f \cdot m \cdot g \cdot \sin\beta + m \cdot g \cdot \sin\alpha$$

$$N = -2 \cdot m \cdot \omega \cdot \dot{x} + f \cdot m \cdot g \cdot \sin\beta - m \cdot g \cdot \sin\alpha \quad (3)$$

Equation (3) is the normal compressive force acting along the surface of the disc tooth of hairy seeds [3, 4]. Substituting this equation into equation (2), we analyze the movement of hairy seeds along the OX axis[9].

$$m \cdot \ddot{x} = m \cdot \omega^2 \cdot r - f \cdot (-2 \cdot m \cdot \omega \cdot \dot{x} + m \cdot g \cdot \sin\beta - m \cdot g \cdot \sin\alpha) + m \cdot g \cdot \cos\alpha \quad (4)$$

(4) We divide the equation by m to obtain a second-order non-homogeneous differential equation:

$$\ddot{x} - 2 \cdot f \cdot \omega \cdot \dot{x} = \omega^2 \cdot r - f \cdot g \cdot \sin\beta + f \cdot g \cdot \sin\alpha + g \cdot \cos\alpha \quad (5)$$

(5) we calculate the homogeneous part of the equation:

$$\lambda^2 - 2 \cdot f \cdot \omega \cdot \lambda = 0$$

We look for the general solution of the equation in the form $x_1 = C_1 \cdot e^{\lambda_1 \cdot t} + C_2 \cdot e^{\lambda_2 \cdot t}$ and determine the particular solution[10].

$$\lambda_1 = 2 \cdot f \cdot \omega\,; \; \lambda_2 = 0$$

$$x_1 = C_1 \cdot e^{2 \cdot f \cdot \omega \cdot t} + C_2 \quad (6)$$

We look for the general solution of the differential equation $x = x_1 + x_2$ here in the form $x_2 = a \cdot \cos\omega \cdot t + b \cdot \sin\omega \cdot t$ and we can derive from this equation in terms of time. Here, $\alpha = \omega \cdot t$ is the angle of rotation of the gear disk[11].

$$\dot{x}_2 = -a \cdot \omega \cdot \sin\omega \cdot t + b \cdot \omega \cdot \cos\omega \cdot t$$

$$\ddot{x}_2 = -a \cdot \omega^2 \cdot \cos\omega \cdot t - b \cdot \omega^2 \cdot \sin\omega \cdot t \quad (7)$$

We substitute equation (7) into equation (5) to find the values of a and b.

$$-a \cdot \omega^2 \cdot \cos\omega \cdot t - b \cdot \omega^2 \cdot \sin\omega \cdot t + 2 \cdot f \cdot \omega^2 \cdot a \cdot \sin\omega \cdot t - 2 \cdot f \cdot \omega^2 \cdot b \cdot \cos\omega \cdot t =$$

$$= f \cdot g \cdot \sin\alpha + g \cdot \cos\alpha$$

We determine the constant values by equating the corresponding coefficients[12].

$$a = \frac{g \cdot (2 \cdot f^2 - 1)}{\omega^2 \cdot (1 + 4 \cdot f^2)}\,; b = \frac{-3 \cdot f \cdot g}{\omega^2 \cdot (1 + 4 \cdot f^2)}$$

We set the determined constant values a and b to $x_2 = a \cdot \cos\omega \cdot t + b \cdot \sin\omega \cdot t$ .

$$x_2 = \frac{g \cdot (2 \cdot f^2 - 1)}{\omega^2 \cdot (1 + 4 \cdot f^2)} \cdot \cos\omega \cdot t - \frac{3 \cdot f \cdot g}{\omega^2 \cdot (1 + 4 \cdot f^2)} \cdot \sin\omega \cdot t \quad (8)$$

The general form of the differential equation for the movement of hairy seeds along the OX axis on the surface of a disc saw tooth is as follows:

$$x = C_1 \cdot e^{2\cdot f\cdot \omega \cdot t} + C_2 + \frac{g\cdot(2\cdot f^2 - 1)}{\omega^2 \cdot (1+4\cdot f^2)} \cdot \cos\omega \cdot t - \frac{3\cdot f\cdot g}{\omega^2 \cdot (1+4\cdot f^2)} \cdot \sin\omega \cdot t \qquad (9)$$

(9) using the initial condition to determine the constant values of $C_1$ and $C_2$ in equation, $t = 0$ да $x = 0$; $\dot{x} = \vartheta_0$ we define:

$$C_1 + C_2 = -\frac{g\cdot(2\cdot f^2 - 1)}{\omega^2 \cdot (1+4\cdot f^2)}$$

$$C_1 = \frac{\vartheta_0}{2\cdot f\cdot\omega} + \frac{3\cdot g\cdot f}{2\cdot\omega^2\cdot(1+4\cdot f^2)}; \quad C_2 = -\frac{g\cdot(2\cdot f^2 - 1)}{\omega^2 \cdot (1+4\cdot f^2)} - \frac{\vartheta_0}{2\cdot f\cdot\omega} - \frac{3\cdot g\cdot f}{2\cdot\omega^2\cdot(1+4\cdot f^2)}$$

Putting the determined constant values into the equation (9), we form the equation of motion of the hairy seeds on the surface of the teeth of the cylinder[11].

$$r = \left(\frac{\vartheta_0}{2\cdot f\cdot\omega} + \frac{3\cdot g\cdot f}{2\cdot\omega^2\cdot(1+4\cdot f^2)}\right) \cdot e^{2\cdot f\cdot\omega\cdot t} - \left[\frac{g\cdot(2\cdot f^2-1)}{\omega^2\cdot(1+4\cdot f^2)} + \frac{\vartheta_0}{2\cdot f\cdot\omega} + \frac{3\cdot g\cdot f}{2\cdot\omega^2\cdot(1+4\cdot f^2)}\right] + \frac{g\cdot(2\cdot f^2-1)}{\omega^2\cdot(1+4\cdot f^2)} \cdot \cos\alpha - \frac{3\cdot f\cdot g}{\omega^2\cdot(1+4\cdot f^2)} \cdot \sin\alpha \qquad (10)$$

Equation (10) describes the movement of hairy grains on the surface of various disk teeth in a disk cylinder[13].

## 5. Discussion

In order to ensure the smooth transmission of hairy grains on the disk teeth and thereby reduce their damage, it is important to correctly select the parameters of the gear disk. In reducing the damage of hairy grains on the surface of the disk teeth, the centrifugal force acting on the hairy grains, the bevel angles of the disk teeth, and the angular speeds of the gear cylinder are mainly important, where the number of rotations of the supply shaft is set to 30, 45, 60 rpm, and the angle of inclination in the direction of movement of the teeth is set to 45°, 55°, 65°. We use the Maple program to construct graphs to analyze the effect on the effectiveness of reducing damage.

Figure 3. The time-dependent graph of the angular speed of the disc teeth at different values ω1=30 rev/min, ω2=45 rev/min, ω3=60 rev/min during transmission of hairy seeds on the tooth surface of the disc[14].

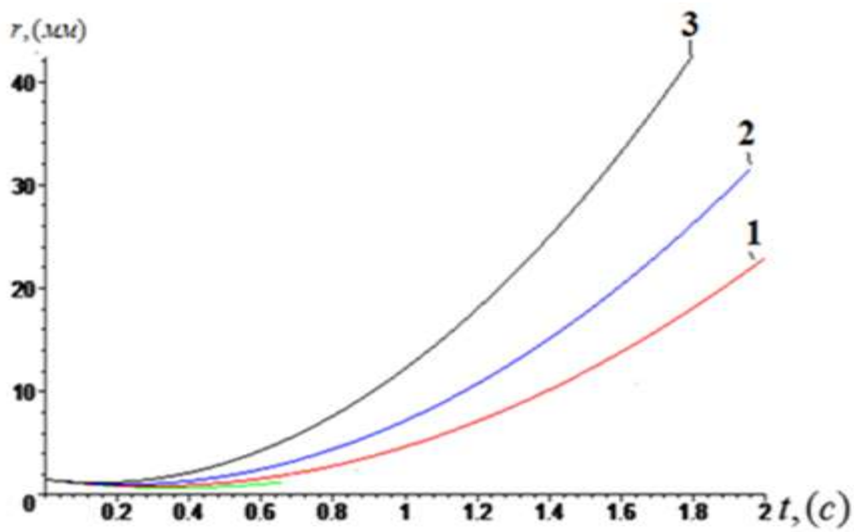



Figure 3. Displacement curves of toothed disks

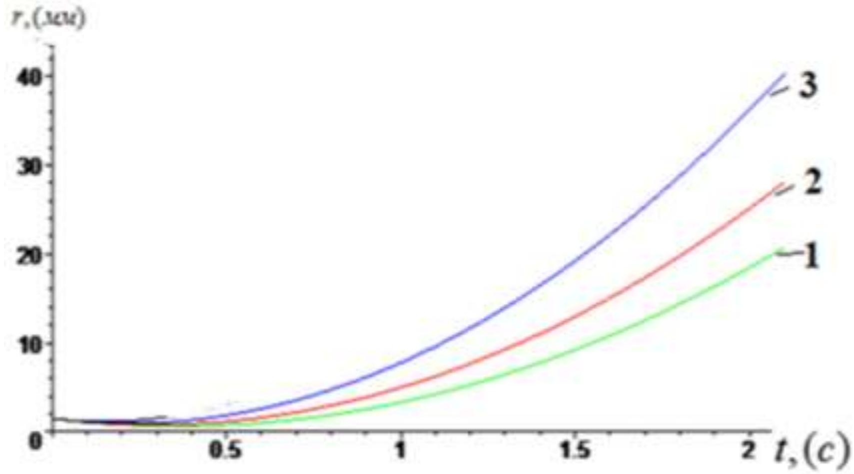



*Figure 4. The time-dependent graph of tooth inclination angles at different values a1=450, a2=550, a3=650 during transmission of hairy seeds on the tooth surface of the disk*[15].

Figure 4. Effect of tooth angle on seed displacement

It can be noted from the graphs that in order to reduce mechanical damage when conveying hairy seeds in a straight line, we can see that the centrifugal force acting mainly on the hairy seeds, the bevel angles of the disc teeth, and the angular speeds of the supply roller are of great importance. With an increase in the bevel angle of the teeth of the supply roller, the area of the grain catch also increases, but the mechanical damage of the grain also increases as the blunt side of the tooth decreases and becomes pointed[16].

## 6. Conclusion.

The theoretical and experimental analysis of the movement of hairy cotton seeds along the toothed surfaces of a pneumomechanical sorting machine has demonstrated that seed motion and damage are significantly influenced by angular speed and tooth bevel angle. The study found that optimal seed permeability with minimal mechanical damage is achieved when the supply roller operates at 45 rpm with a bevel angle of 45° to 55°, as confirmed through mathematical modeling and simulation in Maple. These findings not only provide a robust theoretical framework for improving the performance of sorting machines but also offer practical design parameters for engineers seeking to enhance seed handling efficiency. The implications of this research extend to the broader field of agricultural processing, where precision and reduced product loss are critical. Future research should focus on expanding the model to three-dimensional simulations, incorporating real-time sensor feedback, and testing other seed types under variable environmental conditions to further refine the sorting mechanism.

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