DEVELOPMENT OF A MATHEMATICAL MODEL FOR AEROMECHANICAL CLEANING OF COTTON FIBER

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Introduction. In the primary processing of cotton, efficient cleaning of the fiber from mechanical impurities is a crucial stage that determines the quality of the final textile product. In modern textile manufacturing, improving the cleaning process, implementing energy-saving technologies, and minimizing the human factor are important scientific and practical objectives. The aeromechanical method of cleaning cotton fibers is based on separating impurities through the action of an air stream. This method ensures high cleaning efficiency with minimal mechanical damage to the fiber. This thesis presents the development of a mathematical model of the aeromechanical cleaning process, focusing on the optimization of airflow parameters, drum speed, and their influence on cleaning efficiency.

Physical and Mechanical Principles of Aeromechanical Cleaning

The aeromechanical cleaning process is based on the difference between two main forces. Aerodynamic force (F_d) — lifts and separates impurities, Holding force (F_s) — keeps the fiber on the cleaning drum surface.

For efficient separation of impurities, the following condition must be satisfied:

$F_i < F_d < F_s$

where:

F_i — adhesion force of impurities to the fiber,

F_d — aerodynamic lifting force,

F_s — fiber holding force.

The aerodynamic force acting on an impurity particle is given by:

$F_d=1/2C_d \rho Av^2$

where:

C_d-drag coefficient,

ρ -air density,

A- projected area of the impurity,

v-airflow velocity.

From this expression, it follows that the separation efficiency depends on the airflow velocity, air density, impurity size, and shape factor C_d. To achieve high cleaning efficiency without damaging fibers, an optimal velocity range must be determined experimentally.

Relationship Between Airflow Velocity and Drum Rotation Speed

In aeromechanical cleaning devices, two key operational parameters are interrelated:

Airflow velocity (v)

Drum rotational speed (n)

Stable cleaning performance requires coordination between these two parameters. Empirically, their relationship can be expressed as:

$v=k_1 \cdot n^{\alpha}$

where: k_1 — machine-specific constant, α — empirical coefficient (0.6–0.8),
n — drum speed (rpm).

If the drum speed is too low, impurities remain unseparated; if too high, fibers may be carried away with the airflow. Therefore, the optimal drum speed is determined as:

$$n_{opt} = (\frac{V_{opt}}{k_1})^{1/a}$$

This equation enables synchronization between mechanical and aerodynamic parameters for stable and efficient cleaning.

Mathematical Model for Aerodynamic Separation of Impurities

An impurity particle will be lifted and removed from the fiber surface when the aerodynamic lifting force equals or exceeds its gravitational force:

$F_d \geq m\, g$

Substituting the aerodynamic force equation:

$$\frac{1}{2} C_d\, \rho A v^2$$

Solving for critical airflow velocity:

$$v_{crit} = \sqrt{\frac{2\, mg}{C_d \rho A}}$$

This represents the minimum airflow velocity required to separate impurities of mass mmm. Based on experimental observations:

Light leaf fragments: v_{crit} = 4–6 m/s, Fine dust and sand: v_{crit}= 9–12 m/s

Heavy stalk and shell pieces: v_{crit}= 14–18 m/s.

Hence, the cleaning system must provide adjustable airflow velocity to target different impurity types effectively.

Model of Fiber Retention Force on the Drum Surface

The fiber's retention force on the drum surface is expressed as:

$F_s = \mu N$

where:

μ — coefficient of friction between fiber and drum surface,

N— normal pressure applied by the drum elements.

To prevent the fiber from being carried away by airflow:

$F_d < F_s$

This condition defines the design requirements for the drum surface material, its roughness, and the shape of gripping elements. Optimizing these parameters ensures the fiber remains stable during cleaning.

Conclusion. The development of a mathematical model for the aeromechanical cleaning of cotton fiber is a significant contribution to improving the efficiency and quality of cotton pre-processing technologies. The proposed models allow determination of the optimal airflow velocity, drum speed, and aerodynamic force balance, ensuring minimal fiber damage and maximum cleaning performance. Furthermore, the dynamic model provides a foundation for designing automated control systems that adapt to variations in raw cotton properties. In conclusion, the integration of mathematical modeling, experimental optimization, and intelligent control can lead to the creation of energy-efficient, high-performance, and sustainable cotton cleaning systems, contributing to the advancement of textile technology in Uzbekistan and beyond.

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