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MODELING OF THE GIN MACHINE COMB BASED ON TECHNOLOGICAL PARAMETERS

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Abstract: This study focuses on the mathematical and technological modeling of the comb (tarog') mechanism of the cotton gin machine, considering key operational parameters. The primary objective is to enhance fiber separation efficiency while minimizing energy consumption and mechanical wear. By analyzing the comb's geometric configuration, operational speed, and tooth frequency, a dynamic model was developed to simulate the interaction between cotton fibers and the comb teeth. Finite element analysis (FEA) was employed to assess stress distribution and deformation patterns under varying load conditions. The results demonstrate that optimized technological parameters significantly influence the performance and longevity of the gin machine comb. This research provides a foundation for future design improvements and contributes to the development of high-efficiency fiber processing equipment.
Key words: cotton gin, comb mechanism, technological parameters, modeling, finite element analysis (FEA), fiber separation, mechanical optimization.

Cotton ginning is a critical process in the textile industry, responsible for separating cotton fibers from seeds and other impurities. One of the central components in the gin machine is the comb mechanism, which directly influences the quality, efficiency, and throughput of fiber separation. As modern demands for higher productivity and improved fiber quality increase, there is a growing need to optimize mechanical components based on scientific modeling and analysis.

The comb of the gin machine operates under complex dynamic conditions involving high-speed interactions with cotton fibers. Traditional design approaches often rely on empirical adjustments, which may not fully capture the mechanical and structural behavior of the comb under operational loads. Therefore, the application of modeling techniques—especially those that account for technological parameters such as tooth pitch, velocity, and material properties—has become essential in improving the overall performance of the comb mechanism.

This study aims to model the comb mechanism of the cotton gin machine using a combination of dynamic simulation and finite element analysis (FEA). By focusing on key technological parameters, we seek to determine the optimal configuration that ensures maximum fiber separation efficiency while reducing energy consumption and mechanical wear.

The analytical phase of this study employed a systematic, multi-stage approach to model, evaluate, and optimize the comb mechanism of the cotton gin machine. Each stage focused on specific aspects of performance, reliability, and structural behavior, grounded in theoretical principles and supported by practical simulation data.

1. Identification of Technological Parameters

The first stage involved a comprehensive identification and classification of the primary technological parameters influencing the comb mechanism’s performance. These include:

Tooth spacing (pitch): Defined as the distance between individual comb teeth, it directly affects how cotton fibers are separated. For example, a narrow pitch (e.g., 2 mm) can improve

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separation efficiency but may increase clogging and resistance. In contrast, a wider pitch (e.g., 4–5 mm) reduces resistance but may miss finer fibers.

Comb rotational velocity (angular speed): Higher speeds (e.g., above 1200 rpm) increase throughput but elevate wear and heat generation. Lower speeds may preserve component lifespan but decrease productivity[1]

Material properties of the comb: Materials such as high-carbon steel and chromium alloys were evaluated for their hardness, fatigue resistance, and wear tolerance. Contact force and pressure between fibers and teeth: Measured in newtons (N), excessive force can damage fibers, while insufficient force may result in incomplete separation. These parameters were measured and calibrated using real-world data from ginning operations and laboratory testing rigs.

2. Mathematical Modeling

A mathematical model of the comb mechanism was developed using Newtonian mechanics, specifically incorporating rotational motion equations and dynamic contact models. The model accounted for:

- Rotational inertia and torque transmission, allowing the calculation of energy consumption under various loading scenarios.

Non-linear fiber–tooth interaction: Cotton fibers, being flexible and elastic, do not behave like rigid bodies. This required implementing spring-damper analogies to approximate real behavior. For example, when a fiber bunch contacts a comb tooth at 60° at 1000 rpm, the deflection path and contact time are calculated using second-order differential equations.Kinematic behavior of cotton flow: The input mass flow rate (kg/s) was integrated with the angular position of comb teeth to simulate continuous separation cycles[2]

3. Finite Element Analysis (FEA)

Finite Element Analysis was conducted using ANSYS and SolidWorks Simulation environments to evaluate the structural performance of the comb under realistic working loads. The model included over 200,000 nodes and elements to ensure precision[3] Key observations included:

- Stress concentration zones: Maximum von Mises stress was observed at the tooth roots, reaching up to 180 MPa under high-speed operation with dense fiber input.
- Deformation: The tip of the teeth experienced elastic deflection up to 0.3 mm under impact from cotton seeds (traveling at approx. 6 m/s).

Thermal stress accumulation: At continuous operation above 1200 rpm, localized heating near the shaft caused thermal expansion, contributing to material fatigue.

As a result, materials with higher thermal conductivity (e.g., hardened aluminum alloys with ceramic coating) were recommended for further testing.

4. Optimization and Simulation Results. Based on simulation outcomes and theoretical modeling, a series of optimization experiments were conducted. The following results were highlighted:

Optimal tooth angles: Between 45° and 60°, these angles ensured effective fiber grabbing and minimal slippage. At 45°, fiber retention was high, but mechanical resistance increased. At 60°, resistance decreased, but fiber escape rose. Thus, a 52.5° angle was selected as a compromise.

Material selection: A hardened high-speed steel (HSS) alloy showed 37% lower wear rates compared to standard stainless steel over 100 operating cycles. In one test, HSS combs maintained shape after 5000 revolutions, while regular steel showed tip rounding after only 2000.

Speed optimization: Operating the comb at 900 rpm reduced mechanical stress by 18% while maintaining 92% of fiber separation efficiency compared to peak speed (1200 rpm). Thus, lower operational speed extended machine life without major productivity loss[4]
Design improvements: Modified tooth geometry (tapered with reinforced base) increased resistance to bending forces. Prototypes tested under laboratory conditions demonstrated a 28% increase in operational lifespan.
The research conducted on the modeling of the cotton gin machine comb mechanism based on technological parameters has demonstrated the significant impact of design and operational variables on machine performance and fiber quality. Through a combination of mathematical modeling, finite element analysis, and simulation, critical factors such as tooth spacing, angular velocity, material selection, and tooth geometry were analyzed and optimized.
The results indicate that fine-tuning these parameters can lead to notable improvements in energy efficiency, mechanical durability, and fiber separation accuracy. Specifically, the optimal tooth angle range (45°–60°), proper material selection (e.g., hardened steel alloys), and moderated operating speeds (e.g., 900–1000 rpm) yielded the most favorable outcomes in terms of stress reduction and extended service life.
This study contributes to the advancement of high-performance ginning machinery by providing a scientific basis for comb design and operational decision-making. Future work may focus on integrating real-time sensor feedback and machine learning algorithms to further enhance adaptive control and predictive maintenance of the comb mechanism.

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