Optimization of gin saws for sustainable and eco-friendly cotton processing

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Abstract. The growing attention to environmental responsibility in the textile and apparel industry necessitates the development of innovative and sustainable manufacturing technologies. This study presents an energy-efficient processing technology aimed at improving cotton processing efficiency, focusing on optimizing the design of ginning saws. Using a comprehensive design methodology, key processing parameters, such as cutting speed, feed rate, tool-material interaction, and machine dynamics, were carefully optimized to meet sustainability goals. To ensure improvements that minimize energy consumption and environmental impact, the behavior of cotton fibers and the influence of environmental conditions on processing performance were considered. A new method for modeling and generating an optimized ginning saw tooth profile is presented, resulting in improved cutting efficiency, reduced fiber damage, and increased tool life. The results demonstrate that this method not only improves productivity but also facilitates the adoption of more environmentally friendly manufacturing practices by reducing resource consumption and improving manufacturing sustainability. This research contributes to the development of environmentally responsible production strategies in the textile and clothing industry, thereby contributing to the achievement of broader environmental goals.

1 Introduction

Cotton gins in many countries are manufactured using outdated technology for separating raw cotton from fiber. This technology includes the sequential operations, such as impressing, discs to a diameter of 320 mm with an internal bore of 61 mm, transferring the blanks to a cutting machine, forming the teeth, sharpening and conditioning the functional edges of the saw teeth, and final blade sharpening on a press-cutting unit. The overall procedure is highly time-cons and labor-intensive, requiring substantial capital investment [1]. Therefore, determining the enhanced power performance of the working saws is essential, given, that

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service life of saw blade in a roller box range from 72 to 80 hours To achieve this, it is necessary to improve the saw's properties and replace the material with a stronger one [2]. The study is conducted using the following Euler formula:

$$P_K = \frac{\pi^2 E J_{min}}{(\mu \cdot l)^2} \quad (1)$$

The critical stress σ_k is the amount of the stress that occurs in a rod's cross-section when the compressive force reaches the point of criticality. If the critical stress stays below the proportionality limit, Euler's formula (1), is applicable. The rod's slenderness λ which is determined by formula (2), is typically utilized to indicate the requirement for the applicability of Euler's formula (2).

$$\lambda = \frac{\mu \cdot l}{i_{min}} \quad (2)$$

where I_{min} is the lower point of inertia, and l is the length of the saw or rod.

2 Materials and methods

The results of the research allowed us to determine the ideal normal cutting load for various saw spacings and to elucidate the geometric properties of saws and spacers. It was found that complex geometric interactions, such as the connection between saws and spacers, affect the strength and stability of saws, in addition to their size. For example, Figure 1 shows how saw spacing affects stability when using different steel grades. Results demonstrated that at 45°C, the highest stability occurred when the distance between saw teeth was 2.9 mm (Figure 1). Among the materials tested, R9 tool steel exhibited the highest critical strength stability index [3].

Figure 1 clearly shows that an increase in the minimum moment of inertia is associated with an increase in the stability (critical force) of the saw blade. Therefore, the ellipse of inertia concept was used to evaluate stability from any point along the ellipse, which allowed for a thorough stability assessment under various loads [4]. We conducted experiments with saws and spacers at different distances from each other, and optimal gap parameters were established based on geometric characteristics to ensure saw blade stability under dynamic loads [5]. Utilizing these findings, it is possible to simulate improved working parts for the gin, effectively doubling the service life of the saws [6]. This research has enabled the identification of suitable materials and design parameters to significantly increase the operational hours of saw disks within the roll box, extending their service life from 100 hours onwards.

Table 1. Geometric characterization of saw tooth profiles.

Option	H=3,46	t=3.59	a=20	b=40	r=0.2	Z=280
1	2,2	2,35	30	40	0,5	320
2	2,2	2,97	35	55	0,5	360

The geometric characterization of saw tooth profiles used in cotton ginning equipment is shown in Table 1. A collection of geometric characteristics, including tooth height (H), thickness (t), tooth angle (a), base width (b), tip radius (r), and the total number of teeth per saw (Z), is used in the table to compare two different saw tooth designs. The baseline structure is established by maintaining the same tooth height (H = 3.46 mm) and thickness (t = 3.59 mm) in both choices. Variations can be seen in the total number of teeth (Z), base width (b), and tooth angle (a). Variant 1 is characterized by a lower tooth density (Z = 320) due to a

smaller tooth angle (a = 30°) and a narrower base width (b = 40 mm). Variant 2, on the contrary, is characterized by a higher tooth density (Z = 360) with a larger tooth angle (a = 35°) and an increased base width (b = 55 mm). In experiments, theoretically, these geometric variations have a direct impact on how saw teeth and cotton fibers interact throughout the ginning process. Although it may improve fiber grip, a narrower angle (Option 1) tends to penetrate deeper into the cotton locks, increasing friction and the chance of fiber breakage. On the other hand, a wider base and a greater angle (Option 2) provide smoother handling of fibers and better durability, while the higher teeth count improves uniformity and processing capacity. Cutting efficiency and less mechanical wear are balanced by the uniform tip radius (r = 0.5 mm) in both variants, which guarantees controlled contact between the saw teeth and fiber bundles. Since saw design directly affects gaining efficiency, fiber quality, energy consumption, and mechanical lifespan, a comparative investigation of these factors is essential.

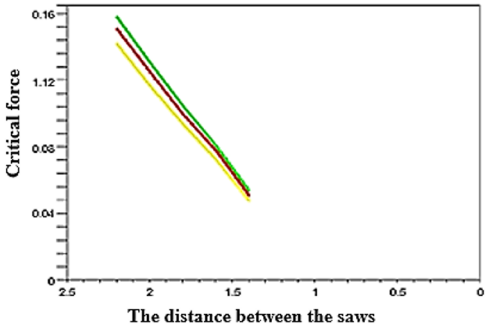

Fig. 1. Interaction of the relationship between the critical force and different sizes of valve.

3 Results and discussions

However, current saw manufacturing technologies complicate the production of tool steels and accelerate wear. Using these materials for saw blades will extend the service life of saws and lead to significant cost and resource savings. The manufacture of dies and punches for tooth-cutting machines requires the use of advanced laser and hydroprocessing technologies for tool steel.

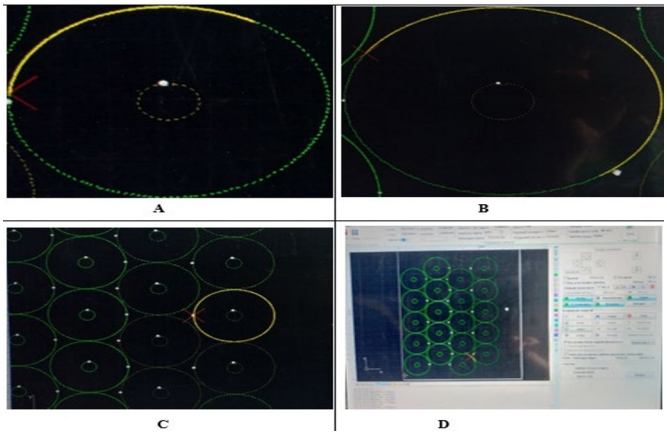

Fig. 2. The impact of saw teeth distance on critical force p_k, indicates elastic fragility.

Since one tooth is 2.2 mm high, 4 mm wide, and 1mm thick, the laser will increase the heating of the tooth when used sharply and complicate the polishing process shown in Figure 2.

In the present study, we have selected water treatment technology as the primary focus of investigation due to its critical importance in environmental engineering and sustainable resource management. Within this framework, particular attention is directed toward the analysis of the critical force P_k, which signifies the point of loss of stability in the elastic stage of material deformation. Comprehending the behavior of P_k is critical to maintaining the mechanical integrity and operational reliability of components used in water treatment systems. To facilitate a thorough evaluation, we investigate the effect of variations in the spacing between saw teeth (or sawtooth elements) on the magnitude of the critical force. By methodically adjusting these spacings, we aim to describe the influence of the geometric configuration on the stability thresholds. The results of critical load calculations for various materials under specified operating conditions are presented in detail below. As shown in Table 1, the U8 material demonstrated a relatively average critical load capacity when evaluated at a temperature of 45 °C in a roll box, resulting in a critical load value of P_k = 0.148 MPa. In contrast, the 12Kh1MF material demonstrated above-average critical load characteristics when exposed to a higher operating temperature of 450 °C in a roll box, achieving a critical load value of P_k = 0.151 MPa. Furthermore, it highlights the exceptional critical load performance of P9 high speed steel, which at a working temperature of 45 °C achieved a critical load value of P_k=0.156 MPa, making it the highest among the evaluated materials [7].

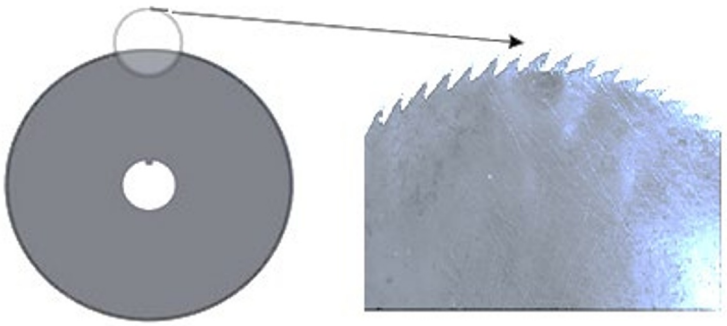

Fig. 3. Determining the most efficient machining parameters in Solid CAM.

The obtained results indicate that high-speed steel (P9) and heat-resistant steel (12Kh1MF) exhibit the highest critical load capacity under specific operating conditions. This underscores their suitability for applications requiring high mechanical strength and reliability under critical loads.

This machining methodology requires a complex decision-making system operating in real time, which requires the continuous evaluation and adjustment of various operating parameters. In particular, the selection of the optimal machining mode is crucial, as it must dynamically adapt to changes in material properties, tool wear, and other process factors [8]. Figure 3 illustrates the most efficient machining parameters in Solid CAM. Furthermore, this methodology emphasizes the importance of optimizing the toolpath throughout the machining process. This ensures cutting force stability throughout the process, preventing fluctuations that can negatively impact workpiece quality and cutting tool life. The ability to maintain a constant cutting force is crucial both for improving the overall efficiency of the machining process and for enhancing the accuracy of the final product. This real-time optimization not only improves process stability and predictability but also helps reduce energy consumption and minimize tool wear. Numerous studies have confirmed the

effectiveness of this approach in achieving these goals, highlighting its potential for the development of machining technologies [9]. The front saw configuration with improved tooth design is shown in Figure 4.

Fig. 4. Introduced front saw configuration with improved tooth design.

To characterize saw teeth, the data set includes profile geometry points, machining commands, and toolpath coordinates. The set of measurements presented in each row is defined by Cartesian coordinates (X, Y), circular interpolation commands (G2, G3), and linear interpolation commands (G1). These parameters determine the precise tooth shape and cutting path of the saw blade [10].

The table presents two sets of saw profiles: the original saw profile (C90) and the new saw profile (OG659). Other measurement codes (G17, G54, G99, etc.) are also compared. To ensure that the manufactured saw teeth meet design specifications, critical measurements such as radii, angles, and coordinate positions were recorded. Tool paths and documented coordinates allow for precise reconstruction of saw tooth geometry, allowing for the determination of deviations in thickness, height, and curvature. This data is essential for predicting saw performance in cotton ginning, verifying design tolerances, and assessing manufacturing accuracy.

4 Conclusions

The results of this study demonstrate that using waterjet cutting technology to manufacture saws with an innovative tooth profile using Solid CAM software can significantly improve productivity. Specifically, this advanced method demonstrated the potential to reduce machining time by up to 60% compared to traditional machining methods.

This significant reduction in machining time highlights the potential for significant improvements in production efficiency. Furthermore, the use of high-quality tool steels facilitates the development of new saws that are energy-efficient and resource-saving. These advances lead to significant cost reductions in both material procurement and metalworking, thereby increasing the overall cost-effectiveness of the production process. The innovative saw tooth profile is also expected to improve cotton fiber extraction productivity by 15–20%.

This innovation is expected to increase productivity while maintaining or even improving the quality of the extracted cotton fiber. Furthermore, the use of these advanced tool steel saws, particularly in single-chamber, dual-cylinder gins, is expected to significantly improve the productivity and efficiency of the ginning process. The exceptional durability and performance of these new saws will likely lead to a significant increase in ginning capacity, further optimizing cotton processing. In light of these results, it is clear that the widespread adoption of energy-efficient technologies in the cotton processing sector offers significant opportunities for both economic and environmental benefits. The adoption of these innovative saw designs and advanced processing methods represents a significant technological advancement that could lead to cost savings, increased productivity, and greater sustainability in cotton processing.

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