

DETERMINATION OF ENERGY CONSUMPTION CHANGES AND DISTRIBUTION IN COMPONENTS OF AN IMPROVED COTTON REGENERATOR DEVICE USING ELECTRONIC SENSORS

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Abstract

This article investigates the performance of newly designed working elements in a regenerator device used to separate residual cotton fibers (linters) from waste generated during raw cotton cleaning at ginneries. The study focuses on changes in energy consumption and its distribution within the device, which were measured using electronic sensors and oscillographic analysis. Experimental results show the effects of comb geometry on airflow dynamics and energy efficiency, highlighting the potential for improved fiber recovery and reduced energy loss.

Keywords: Cotton, regenerator, fiber separation, energy efficiency, electronic sensors, vibration analysis, saw drum, comb geometry, airflow dynamics.

Introduction

Cotton fiber is one of the core raw materials in the global textile industry. Scientific research in the field of primary cotton processing is increasingly focused on preserving fiber quality, improving resource efficiency, and reducing energy consumption. Priority is given to technological innovations that enhance the cleaning of raw cotton from fine and coarse impurities, improve equipment performance, and develop energy-efficient processing systems. Particular attention is being paid to the development of technical solutions that eliminate problems and improve the efficiency of all technological processes [1]. Many leading research centers and universities around the world with developed textile industries have conducted a range of scientific studies to develop and improve cotton cleaning technologies for removing various impurities.

Scientists such as R. M. Sutton, J. T. W. Baker, P. A. Boving, V. G. Arude, S. K. Shukla, and T. S. Manojkumar have researched and improved cotton cleaning methods and production technologies abroad [3].



Materials and Methods

In this study, an advanced sensor-based approach was applied to assess the performance of a regenerator device designed to separate linters from waste. An oscilloscope-based analysis was used to monitor dynamic processes within the system. These methods allowed the evaluation of mechanical properties, angular velocities, and energy consumption during operation. It is difficult to determine whether the energy consumption of the device has changed compared to a feeder shaft—a lint drum that agitates the cotton waste—since changes to the combs will likely impact the saw drum system.

The shape of the comb has a significant impact on the aerodynamics of the flow. While blades create laminar flow, square and hexagonal combs create turbulent flow. These flow characteristics can be determined using the Navier-Stokes equations and graphical analysis. This information is important for improving energy efficiency and optimizing the device [4].

Research Methods

The effect of comb geometry on airflow was analyzed through experimental setups using vane (triangular), quadrangular (rectangular), and hexagonal cross-sections. Each shape impacts flow differently, altering turbulence and energy consumption.

To analyze the effect of vane, quadrangular, and hexagonal combs on flow, it is necessary to consider their geometric characteristics. A vane has a triangular cross-section, which creates both laminar and turbulent flows. A quadrangular comb has a rectangular cross-section, which can enhance turbulent flows in the corners. A hexagonal comb has a hexagonal cross-section, which can complicate the flow.

The Navier-Stokes equations are used to analyze flow aerodynamics. These equations describe the motion of liquids or gases and the pressure distribution.

$$\rho \left(\frac{du}{dt} + (u \cdot \nabla)u \right) = -\nabla p + \mu \nabla^2 u + f$$

Here: ρ - liquid density, u - velocity vector, t - time, p - pressure, μ - dynamic viscosity, φ - external force vector.

The flow around the blade is primarily laminar. However, with increasing speed, turbulent flow occurs.

The edges of the tetrahedral comb increase flow turbulence. For a tetrahedral comb, the pressure distribution in the flow is more complex. The more edges of the hexagonal comb, the greater the flow turbulence. The aerodynamic properties of the geometric shape affect the energy efficiency of the flow. For example, the turbulent flow of a hexagonal comb can increase energy consumption [5-6]. However, this turbulence is of great importance when separating cotton from waste. Experimental observations will be conducted to determine these changes.

To study the instantaneous angular velocity generated in the belt drive section (shaft) of the saw and brush drum systems, a device was constructed that generates a small electromotive force (EYUK) based on the laws of special induction [7]. The value (EYUK) generated by this device is directly proportional to the angular velocity of the shaft. The results (EYUK) can be loaded into a calculator using an oscilloscope and then analyzed on a graph.

EYUK, induced in an inductive sensor, varies according to the function law: EYUK: $\varepsilon = \varepsilon_m \sin(\omega t + \varphi)$. Here,



$$\omega = \frac{\alpha}{t} = \frac{2\pi}{t} \quad (\text{rad/s}).$$

However, it is clear that the graph's pattern does not always follow the laws of harmonics. This is due to the influence of the saw shaft load on the shaft's inertia, which requires a device capable of recording changes in the micro- and nanosecond range. It is advisable to carry out such monitoring using an oscilloscope.

Research Results. Theoretical analysis shows that the geometric shapes of the blades and combs, and their influence on the aerodynamics of the flow, play a significant role in improving energy efficiency. A detailed study of these properties using experimental or simulation methods provides the necessary information for optimizing energy consumption in the cotton separation process [8]. This not only increases energy efficiency but also improves the overall economic efficiency of the production process.

Work was conducted to measure and evaluate the vibration magnitude of the rotating shaft and other vibrating parts of the saw drum system. During the measurements and observations, a plan was developed for determining the frequency, amplitude, and strength of vibrations generated in the device based on signals generated by the Rigol-DS2202A oscilloscope strain gauge [9-10].

The general requirements for vibration measurements using these electronic technologies are as follows:

- on directly rotating shafts;
- when assessing the vibration state of machines;
- when monitoring changes in machine motion;
- in the presence of excessive dynamic loads;
- when monitoring radial clearances in bearings.

The table of technical specifications for the selected strain gauge indicates that the ohmic resistance at the input and output is 1000 ± 10 Ohms, and the output voltage at an excitation voltage of 10 V is $1 \text{ mV} \pm 15\%$ [11]. Taking steps to eliminate signals (noise) generated without precision and low-noise filters, using mathematical methods or electrical filters, effectively impacts the characterization of the saw drum system. Using the above information, strain gauges, inductive sensors, and photoresistors were placed as electronic data sensors on the parallel section of the saw drum shaft, on the section perpendicular to the shaft, and underneath the device. To accurately determine the vibration level in the electronic devices used in the saw drum system, forces of known magnitude and the resulting vibrations were determined and used as a reference. Only after calibration was completed were the sensors installed in the device as data detectors, and the results obtained.

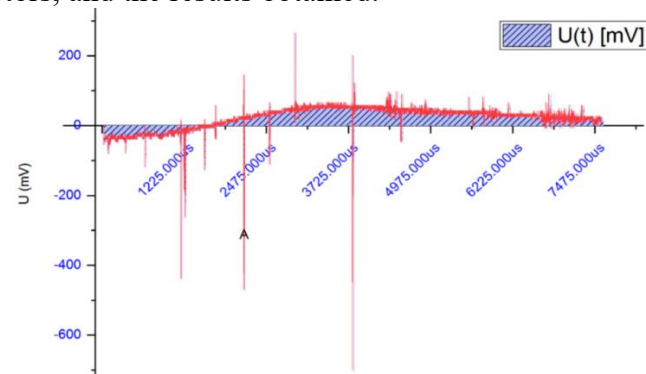


Figure 1. An oscillogram obtained during startup shows strain gauge readings

Which are essentially a graphical representation of the changes in saw shaft strain and stress at point A. In this graph, the x-axis represents time in microseconds, and the y-axis represents stress. These values can be converted to strain values based on established reference values [12].

However, our goal is to determine the magnitude of strain caused by vibration, depending on the changes made to the device, and this is sufficient for comparing the graphs. The values shown in the oscillogram typically reflect the results of stress and strain measurements taken by strain gauges on the material. Using this data, we can determine the strength, elasticity, and other mechanical properties of the material [13].

Analysis of Study Results

Oscillogram analysis provides a deeper understanding of how the material changes under loading and what values it displays under which conditions. This is particularly important for the cotton linter separator, as it helps determine the properties of materials during storage and potential problems. For example, knowing how they respond to strong vibrations or how they tolerate deformation stresses is important for future design and development processes [15].

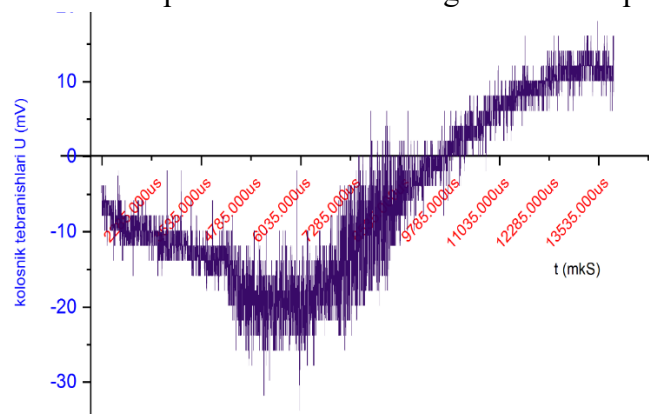


Figure 2. Analysis of instantaneous vibration values generated by a sensor mounted on hexagonal rods, based on data obtained on an oscilloscope

Figure 2 shows a graphical representation of the data analysis of the operating state of the device for a hexagonal grid during the processing of a product at a voltage in millivolts and a time in microseconds. The deformation amplitude can be varied in 30 mV increments [16].

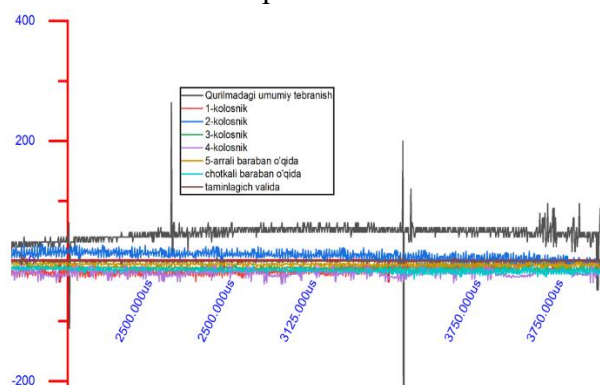


Figure 3. Vibration values obtained over time as vibrations occurred on the rails and at fixed points on the device.

Figure 3 shows a summary view of all oscillograms obtained by the device for separating cotton linters from waste generated during cotton cleaning. The graph shows the device's operation and the efficiency of cotton linter detection.

X-axis: Time (μs) – This axis displays changes over time. Changes over time allow for the analysis of process dynamics [83].

Y-axis: Dynamic characteristics (e.g., vibration level or voltage) – This axis displays dynamic parameters during the cotton linter separation process.

The graph displays the following information:

Oscillograms: The graph combines oscillograms obtained at different points in time. Each oscillogram displays the dynamic changes that occurred during the separation of cotton linters from waste. Differences between oscillograms allow for the analysis of the device's performance in different modes.

Display of peaks and valleys: The graph shows how the dynamic characteristics change over time. For example, it shows how the vibration level changes during the process and how quickly cotton linters are detected and separated. Control Points: Control points on the graph, such as peak and trough points, help evaluate the efficiency of the device and the stability of the process [17]. These points serve as the basis for studying the device's performance and making necessary adjustments.

The data obtained from the graph clearly demonstrates the operation of the device separating cotton linters from waste during cotton raw material cleaning. Combining the oscillograms allows for an assessment of the overall efficiency of the cotton linter separation process and identifies opportunities for improvement.

This graph allows for a more in-depth analysis of the dynamics of the cotton linter separation process and the efficiency of the device. All data displayed on the graph serve as the basis for improving the process's refinement and quality.

Conclusions

Practical experiments were conducted to study the components of waste separated during cotton raw material cleaning, the amount of cotton linters contained in them, and the technology for their separation. As a result, a regenerator device with a new design of working elements was proposed. Based on the recommended parameters, an experimental mesh sample was manufactured. It consisted of a knife and hexagonal and tetrahedral rods made of grade 45 steel. The mesh was installed in an existing regenerator unit designed to separate cotton pieces from waste generated during cotton cleaning. The following conclusions were reached during the experiments under production conditions:

1. To determine the optimal parameters for the working elements of the newly designed regenerator unit, optimization experiments were conducted using a unique and combined method with various input factor values to ensure the efficient operation of the unit.
2. To evaluate the significance of the polynomial regression coefficients, the Student's t-test was used, with the same confidence interval initially assigned to all regression coefficients.
3. The experiments revealed that the optimal range for the distance between the drum and the grate is 13–18 mm, and the optimal range for drum rotation speed is 275–300 rpm.

4. Modern software was used to determine the strength of the proposed working elements of the regenerator and to design them. As a result, grates with blade, hexagonal, and tetrahedral cross-sections were manufactured from grade 45 steel.

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