THEORETICAL ANALYSIS OF THE WORKING PARTS OF A NEW DESIGN FOR SEPARATING COTTON FROM WASTE

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Abstract
This article investigates the issue of raw cotton being lost into waste streams during the cotton cleaning process, which remains one of the most pressing challenges in primary cotton processing enterprises today. A new grate design for a regenerator device is proposed, and the motion of cotton particles on the grate is first examined theoretically.

Keywords: Cotton, regenerator, waste, fiber, raw materials, technology, sawing drum, knife, efficiency.

Introduction

According to the International Consultative Committee on Cotton and Statistics (ICAC), "the top five cotton fiber exporters are the United States, India, Australia, Brazil, and Uzbekistan, while the top five importers are Bangladesh, Vietnam, China, Turkey, and Indonesia." The dynamic and sustainable development of the cotton ginning industry, the introduction of modern equipment at industry enterprises, and the efficient and rational use of production capacities are the basis for increasing competitiveness in the global cotton market. In this regard, the global cotton industry pays special attention to providing cotton ginning enterprises with new innovative equipment and technologies that operate with high efficiency, as well as to creating resource-saving designs for their working parts [1].

Large-scale scientific research is being conducted worldwide to improve the techniques and technologies used in the primary processing of raw cotton. In this direction, it is envisaged to develop effective technology for cleaning raw cotton from impurities, to create effective and resource-saving devices for the purpose of designing working parts and driving mechanisms of cotton ginning units, to optimize their modes, and the parameters of these units are of particular importance.In the cotton processing industry, cotton cleaning machines are selected based on the type of impurities in the cotton composition, and the cleaning process is carried out.

Foreign impurities contained in raw cotton by origin:
- Organic impurities (cotton leaves, capsules, parts of weeds)
- Mineral impurities (stones, sand, clods, soil)

By size:
- Small (less than 10 mm)
- Large (more than 10 mm)

Contamination content in raw cotton by adhesion:
- Active impurities
- Passive impurities

Active impurities are impurities that are bound to the inside of raw cotton.
Passive impurities are impurities that are loosely bound to the outer part of the raw cotton. The classification of cleaning machines in cotton cleaning enterprises is selected depending on the type of the above impurities in cotton.
One of the current problems in technological processes is that during the cleaning of raw cotton from various impurities, there are cases when large amounts of cotton pieces are found in the waste [2]. Regeneration devices are widely used to separate cotton particles from impurities released as a result of these processes. However, due to their low efficiency in separating cotton particles, the working elements of this device have been improved as a result of our research work. First, the movement and forces acting as a result of the movement of cotton particles in the working elements of the existing and newly proposed devices were studied theoretically.

Materials and Methods

Before developing the design drawings and structures of the new device for separating cotton particles from impurities, the working parts of the device used in the process of cleaning raw cotton from large impurities were analyzed. The working parts of this device are identical to the working parts of the regenerative device, and before developing new working parts for the regenerative device, the movement of the cotton flow under the action of the sawing drum and the grate located under it was studied [3-4].
First, let us define the types of saw drums, which are the main working parts of the technological machines used in the process of cleaning raw cotton from large impurities, and their effect on raw cotton: saw drums have a steel saw band consisting of single or arc segments. A solid saw band is attached to the drum, and a saw band in the form of an arc segment is attached to the slats with a screw.
The quality indicators of the resulting product are taken into account in the design of each technological machine and its working parts. During the loosening of raw cotton by the teeth of the saw drum, mechanical damage occurs under the influence of various forces [7].
In this case, the following forces act on a piece of cotton: $N = Q\cos\beta \qquad S = Q\sin\beta$ (1)

$$\operatorname{tg}\alpha = \frac{f\cdot\omega^2\cdot R - Rg}{\omega^2\cdot R - g} \tag{2}$$

α the rational value of the angle is determined from the condition:

$$\operatorname{tg}\alpha \geq \frac{m - R\cdot f\cdot C_0}{f\cdot m - R\cdot C_0} \tag{3}$$

where: m – mass of a piece of cotton.
R is the radius of the drum.
f is the friction coefficient, $f = 0,3$.
C_0 – experimental coefficient $c = 3\cdot 10-5(kgs^2)/m^2$
C_0 was first determined by Prof. Miroshnichenko G.I..

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$$C_0 = C_1 \cdot \frac{V}{2g} \cdot f_m \qquad (4)$$

here: C_1 – resistance coefficient, $C1 = 1$, well-distributed cotton per piece $C1 = 1{,}5$;
f_m- modular cotton surface,

$$f_m = 9{,}2 \cdot 10^{-4}\ m^2$$

$V = \omega R$– cotton passage speed

In order to study the influence of the brush drum on the inclusion of cotton particles in the waste during the process of cleaning raw cotton from impurities, their interaction was analyzed. A special brush drum is used in the cleaning machine to separate cotton from the saw drum. Let's calculate its main indicators. Fig. 1 shows a diagram of the relative positions of the brush drum and the saw drum.

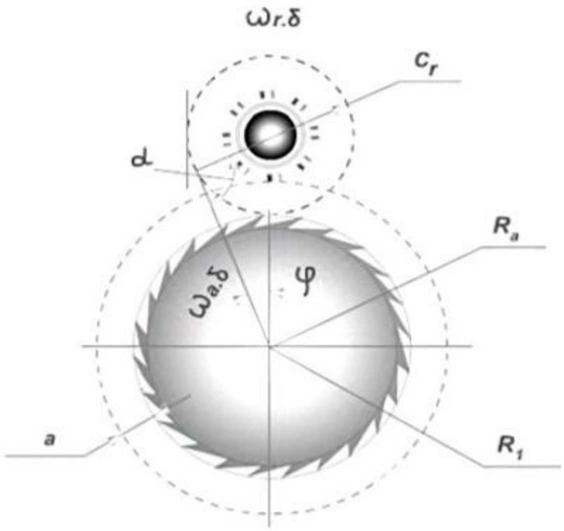

Figure 1. Saw drum with brush drum diagram of their relative positions

R_{ch} – brush drum radius;
R_a-is the radius of the saw drum;
z – number of slats;
n– number of revolutions of the saw drum per minute;
P3 – impact force;
ωsb – angular velocity of the brush drum;
ωab– angular velocity of the saw drum;
G – amount of cotton per brush bar

The number of revolutions of the brush drum per minute is determined by the following formula:

$$n_r = \frac{2\pi n_a}{z \cdot arcsin\frac{R_r}{R_r + R_a}\sqrt{1 - \left[\frac{R_r^2 + (R_a + a)^2 - (R_r - R_a)}{2R_r(R_a + a)}\right]}}$$

$$R_1 = R_a + a \qquad (5)$$

The impact force is determined as:

$$P_3 = \frac{S}{\Delta t} = \frac{G}{g \cdot \Delta t}\,(1 + K)(V_r + V_a) \qquad (6)$$

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The amount of cotton per brush bar is determined by the following formula.

$$G = \frac{Q}{60n_a} = \frac{300}{60\cdot400\cdot12} = \frac{1}{24} = 0{,}04 \text{ kg} \qquad (7)$$

where: z – number of brush strips (around the circumference)
n is the number of revolutions (of the saw drum)
G is the productivity, kg/s.

The improved cotton regenerator shown in Figure 1 works as follows: cotton waste enters the device through the waste chute (1). The cotton waste is captured by the sawing drum (2), and as the drum rotates, a fixed brush in the device securely captures the cotton waste on the drum teeth. The cotton waste on the teeth of the drum is pre-cleaned by an intermediate passage of knives (3), and pieces of cotton remain on the teeth. In addition, the pieces of cotton remaining on the teeth of the drum are cleaned of impurities by passing through hexagonal grates (4) and tetrahedral grates (5) [6-7-8]. After the brush drum (6) in the device cleans the cotton waste again, the impurities are directed down through the mesh surface (7) to the screw conveyor (11). The first brush drum (6) transfers the cotton pieces to the lower saw drum (8), where the cleaning process is carried out in the second stage. The cleaned cotton pieces from the teeth of the second sawing drum are sent to the outlet chute (10) of the device by the upper brush drum (9). In this way, the cotton particles are separated from the cotton waste and regenerated.

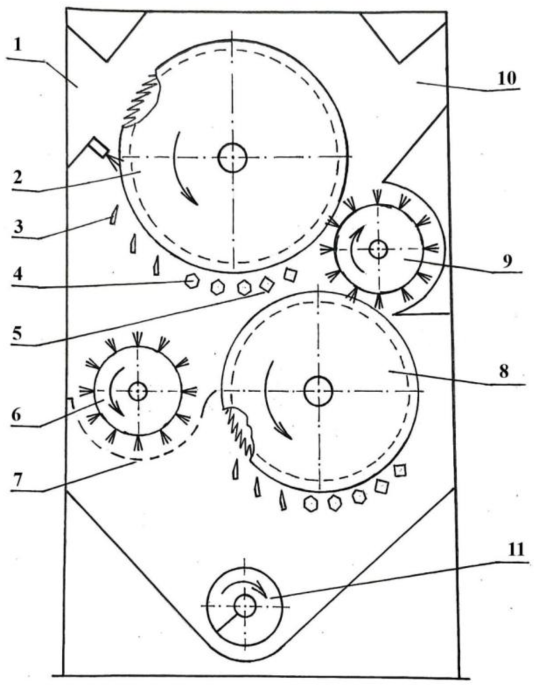

Figure 2. Process diagram of the improved cotton regenerator

1-waste shaft, 2-sawing drum, 3-knife, 4-hexagonal grate,
5-tetrahedral grate, 6-brush drum, 7-mesh surface, 8-sawing drum, 9-brush drum, 10-cotton piece outlet, 11-screw conveyor

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Research methods

According to the research, the main working parts of the device for separating cotton particles from waste in existing regenerative machines are the saw drum, knives, and grate, whose location, shape, and interaction affect the efficiency of cleaning. In existing devices, the grates are cylindrical in shape with a diameter. During the operation of the device, when extracting cotton pieces from the waste, the cotton pieces mixed with the waste, which pass continuously, are captured by the saw teeth with the maximum possible efficiency, which depends on the geometric shape of the grates and the location of the knives [9]. New working parts for the regenerative device have been proposed, taking into account the movement of waste mixed with cotton particles in existing grates under the action of the saw drum and factors affecting it. The movement of cotton particles in it and the processes of their separation from waste have been theoretically analyzed (Fig. 3).

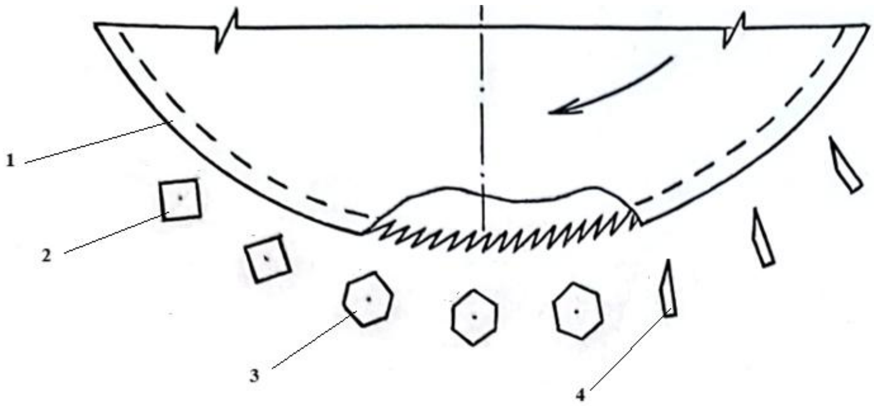

Figure 3. New proposal for a regenerator with replaceable working parts

1-saw drum; 2 - tetrahedral grate bars;
3-hexagonal grate bars; Knives 4

It should be noted that the basis of regeneration is the high-performance extraction of cotton pieces from the grate as a result of the saw teeth grabbing the waste and dragging it across the surface of the grate. To study the process of separating cotton pieces with saw teeth, the movement of the waste flow along a curve in the form of a module formed by a concentric arc of a circle was considered.

Let us consider the movement of cotton pieces captured by the saw teeth: We will determine the position of the teeth on the surface of the saw drum using certain indicators: the location of teeth B or B_1, in the diagram OB=R, the height of tooth BC=h_0, and the angle of inclination of tooth OBC (Fig. 4).

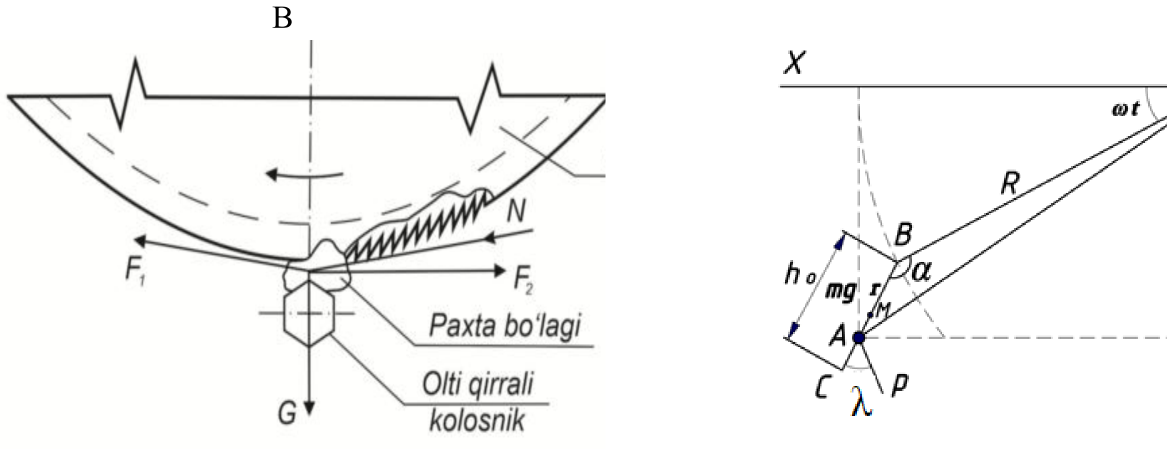

Figure 4. Movement of cotton fluff along the teeth of the saw drum

When extracting cotton particles from waste mixed with cotton particles, the cotton particles are affected by gravity and friction. Under the action of gravity and pressure, the force is determined. The distance BA=r is taken as a generalized coordinate, and Lagrange's equation of the second kind is used to determine the movement of cotton fluff along the teeth of the saw drum, which is the main working part of the device. Let us assume that at the time of rotation t=0, the teeth of the saw drum are in the position r=r_0, with the radius OB lying along the horizontally oriented axis OX, and the axis OY perpendicular to it. The center of the saw drum is designated as the origin of coordinates [11].
The location of the mass of cotton pieces in the saw teeth in coordinates is recorded as follows:

$$x = R\cos\omega t + r\cos(\alpha - \omega t)$$
$$y = R\sin\omega t + r\sin(\alpha - \omega t) \qquad (8)$$

m To determine the kinetic energy of a piece of cotton in the mass, we take the derivative of the equation of motion with respect to time from equation (8) and obtain:

$$T = \frac{m}{2}(\dot{x}^2 + \dot{y}^2) = \frac{m}{r}(R^2\omega^2 + r^2 + r^2\omega^2 + 2R_{\omega\dot{r}}\sin\alpha - 2R_{\omega^2}r\cos\alpha) \quad (9)$$

Using the second-order Lagrange equation, we obtain the partial derivative from equality (9):

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{r}}\right) - \frac{\partial T}{\partial r} = Q_r \qquad (10)$$

(10) From the equation, we determine the generalized forces of external forces acting on the flow of cotton particles on the surface of the saw teeth of the sawing drum, and calculate the general and particular solutions of the inhomogeneous equation.

$$m\ddot{r} = m\omega^2(r - R\cos\alpha) + Q_r \qquad (11)$$

where: Q_r – the generalized force is found using the formula:

$$Q_r = \Sigma X_i \frac{\partial x}{\partial r} + \Sigma Y_i \frac{\partial y}{\partial r} \qquad (12)$$

Research results

X_i, Y_i –OX andOY the projection of external forces on the axis is equal to: $Y_i = mg\sin(\alpha - \omega t)$ $X_i = 0$ We obtain an equation of the dependence of the gravitational force of a piece of cotton, the friction force on the weight with the Coriolis force.

$$F_{TP} = -f \cdot m \cdot g\cos(\alpha - \omega \cdot t) + f \cdot F_{kor} \qquad (13)$$

Here, the Coriolis force arises when the delint breaks away from the saw tooth.

$F_{kor} = -2 \cdot \omega_e \cdot \dot{r}_r \cdot \sin\alpha$ (14)

Here, angle α is the angle between the translational acceleration and the relative velocity of the cotton particle, force P is the pressure force, force G is the gravitational force of the cotton particle, and angle λ is the angle between the surface of the saw tooth.

$P = S \cdot p \sin\lambda$ (15)

Here, S is the area of contact between the cotton particle and the tooth, λ is the angle between the gravitational force and the area of the saw tooth.

$\lambda = \arcsin\frac{R\ \sin\alpha}{\sqrt{R^2+h_0^2\ -2Rh_0\ \cos\alpha}}$ (16)

Taking this into account, the total force of the connection between the delint and the tooth is determined by the formula:

$$Q_r = mg\sin(\alpha-\omega t) + fmg\cos(\alpha-\omega t) + 2mfr\omega\cos\alpha + P\sin\lambda,$$

$(\frac{\pi}{2} < \alpha < \pi)$ (17)

The non-homogeneous second-order differential equation for determining the motion of a cotton particle under the action of a saw tooth of a saw drum is as follows:

$\ddot{r} - \omega^2 \cdot \dot{r} + 2 \cdot f \cdot$

$r\omega \cdot \cos\alpha = -\omega^2 \cdot R \cdot \cos\alpha - g[\sin(\alpha - \dot{\omega}t) - f\cos(\alpha - \omega t)] + (\frac{Q}{\rho\cdot\vartheta} - \vartheta_0) \cdot P \cdot \sin\lambda$

(18)

Here: at t=0, taking r= r_0 (r)̇=0, we find the initial condition for the movement of a piece of cotton along the teeth of the saw blade of the sawing drum:

$$\omega^2 r_0 - \omega^2 R\cos\alpha - g(\sin\alpha - f\cos\alpha) + \overline{P}\sin\lambda > 0 \qquad (19)$$

From this, we can select the angle α that satisfies the condition of the movement of the cotton piece along the tooth at t=0. Suppose that for a small mass of the cotton piece and the condition of the movement of the cotton piece at t=0 corresponds to the inequality sin √λ>0, where the condition 0<λ<π is satisfied. When h_ (0) <<R, we can assume λ≈α. Then, assuming equation (2.19) as, we obtain:

$$\omega^2 r_0 + \omega^2 R\cos\overline{\alpha} - g(\sin\overline{\alpha} + f\cos\overline{\alpha}) - \overline{P}\sin\overline{\alpha} > 0$$

$$\omega^2 r_0 + (\omega^2 R + fg)\cos\overline{\alpha} + (\omega^2 R - \overline{P})Sin\alpha > 0 \qquad (20)$$

We will add the following description to this.

$$Cos\beta = \frac{\overline{P}-g}{\sqrt{(\overline{P}-g)^2 + (\omega^2 R + fg)^2}}$$

$$q = \frac{\omega^2 r_0}{\sqrt{(\overline{P}-g)^2 + (\omega^2 R - fg)^2}} \qquad (21)$$

r_0 < В R получаем уравнение относительно α:

$$\sin\overline{\alpha}\cos\beta - \cos\overline{\alpha}\sin\beta < q \qquad (22)$$

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(2.22) using the equation for the angle of inclination of the saw tooth: $\sin(\overline{\alpha}-\beta)<q$ from this $\overline{\alpha}<\beta+\arcsin q$ or:

$$\overline{\alpha}<\overline{\alpha}_0=\arccos\frac{\overline{P}-g}{\sqrt{(\vec{P}-g)^2+(\omega^2R-fg)^2}}+\arcsin\frac{\omega^2 r_0}{\sqrt{(\overline{P}-g)^2+(\omega^2R-fg)^2}} \quad (23)$$

$\alpha=\pi-\overline{\alpha}$ taking into account the dependence, . $\alpha>\alpha_0=\pi-\overline{\alpha}_0$

$$m\cdot\ddot{x}+c\cdot x=N+F_1+F_2 \quad (24)$$

(24) from which we obtain the following equation.

$$\ddot{x}+\frac{c}{m}\cdot x=\frac{N+F_1+F_2}{m} \quad (25)$$

Let us solve this second-order differential equation.

$x=e^{k\cdot t}$ We introduce the designations and derivatives of the first and second orders $\dot{x}=k\cdot e^{k\cdot t}$ and $\ddot{x}=k^2\cdot e^{k\cdot t}$ and substitute them into (25).

We obtain the following equation.

$x^2+\frac{c}{m}=0$ The solution to the resulting equation is expressed in complex numbers.

$$k_1=\sqrt{\frac{c}{m}}i \text{ va } k_2=-\sqrt{\frac{c}{m}}i$$

Let us write down the solution as follows.

$$x_1=a\cdot\sin\sqrt{\frac{c}{m}}t+b\cdot\cos\sqrt{\frac{c}{m}}t \quad (26)$$

Solution (25) is the solution to the homogeneous part of equation (26). Now let's find the solution to the inhomogeneous part and from this solution we find A and B [12]. Substitute the first and second order derivatives into equation (27).

$0+\frac{c}{m}At+\frac{c}{m}B=\frac{F_1+F_2+N}{m}$ in here $\frac{c}{m}A=0,\ \frac{c}{m}B=\frac{F_1+F_2+N}{m}$

$$A=0,\ B=\frac{F_1+F_2+N}{c}$$

$$x_2=\frac{F_1+F_2+N}{c}$$

General solution $x=x_1+x_2=a\cdot\sin\sqrt{\frac{c}{m}}t+b\cdot\cos\sqrt{\frac{c}{m}}t+\frac{F_1+F_2+N}{c}$

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Analysis of research results. Using the obtained differential equations, we express the pressure forces acting on the cotton pieces separated from the waste composition using knives, tetrahedral and hexagonal grates (Figs. 5, 6, 7) in graphs.

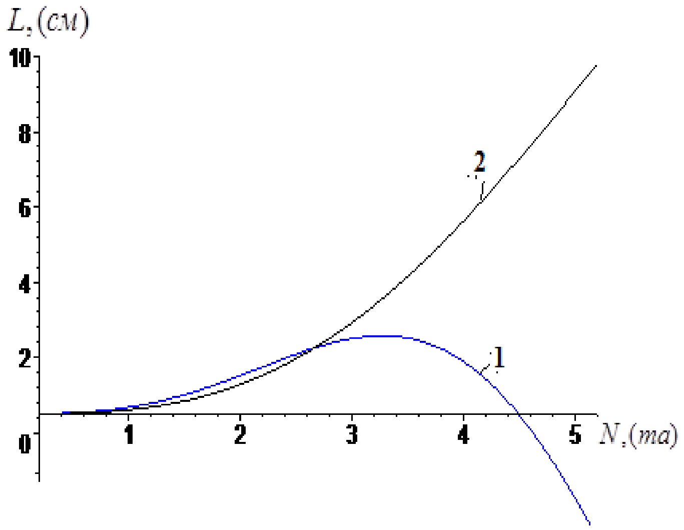

Figure 5. Pieces of cotton separated from the waste composition graph of dependence on the knife
1-dirt, 2-cotton

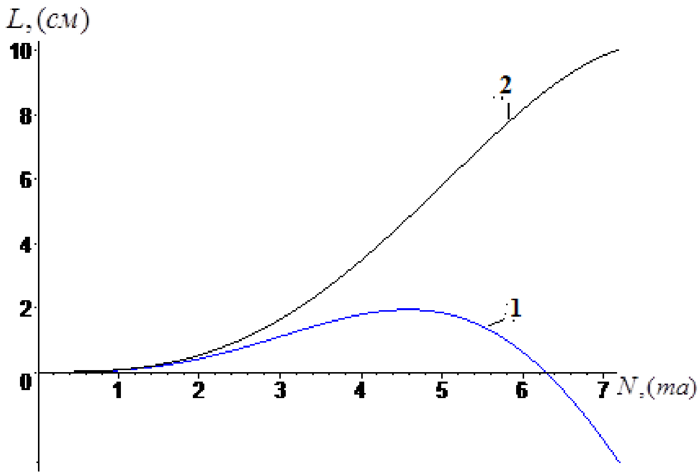

Figure 6. Cotton pieces separated from the waste composition graph depending on the tetrahedral grate
1-dirt, 2-cotton

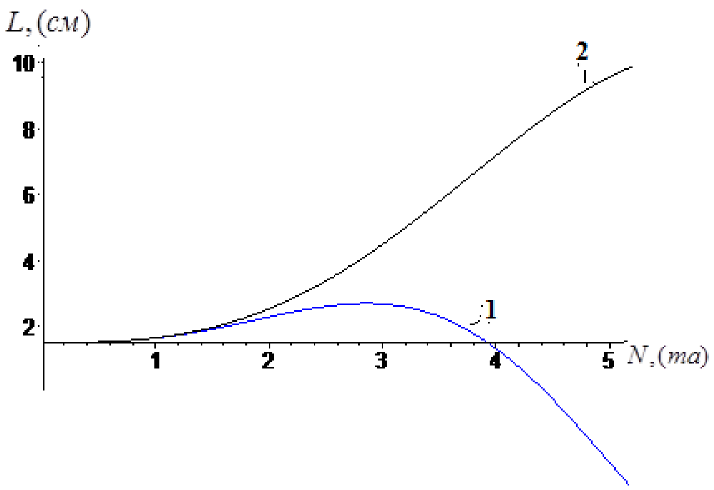

Figure 7. Pieces of cotton separated from the waste composition graph depending on the hexagonal grate
1-dirt, 2-cotton

The results of the experiments showed that the dynamic load of the technological load on the rod of the cotton cleaner grate is calculated as the load passing through the radial direction of the saw drum. The results of the experimental studies show that the technological load is distributed along the length of the grate rod.

$$q_1 = \int S \cdot \sin\frac{\pi x}{L}\frac{dx}{dl} \qquad (27)$$

According to the law, vibration load manifests itself in the form of forced oscillations of the grate bar.

$$q(x)\sin\theta t \qquad (28)$$

According to the law, the grate bar with a new geometric shape can be considered in the first approximation as a uniformly distributed beam supported by five supports [13]. When compiling the equations, the following are not taken into account: the equation of motion, shock loads on the rod perpendicular to the radial direction, the influence of vibrations of other rods of the grate, and axial loads on the rod.

Conclusions

1. The movement of cotton and various impurities in the inlet and working chamber of the regenerative unit, as well as the forces acting on them, have been determined.
2. As a result of the analysis of the existing working parts of the regenerative unit, the influence of their geometric shape on the cleaning efficiency has been studied.
3. The main working parts of the device are the saw drum, knives, and grate, the location, shape, and interaction of which affect the cleaning efficiency.
4. Polygonal grates with the highest efficiency are proposed, with the determination of conditions for the separation of waste mixed with cotton pieces in existing processes.
5. The movement of the working parts of a new type of regenerative device relative to each other and the movement of cotton particles in them during the separation of cotton particles from impurities have been theoretically investigated.
6. When capturing cotton particles moving along the surface of polygonal grates, the coordinate location of their mass in the saw teeth is determined.

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