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# Theoretical Features of the Process Cleaning Zone between Sections of Raw Cotton from Weed Impurities

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## Abstract

The article proposes to use the Euler equations to describe the motion of a stationary stream in the cleaning zones, which allows us to determine the laws of the distribution of pressure, density and speed along the arc of contact of the moving layer of raw cotton with the surface of the mesh during impact with spikes on the pulp. It was found that the pressure, density and flow velocity along the cleaning arc as a result of the hammer spikes change stepwise with decreasing pressure and density and increasing flow velocity along this arc.

## Keywords

Friction Force, Cotton Mass, Dry Friction Force, Feed Rollers, Density, Angular Velocity, Element Motion, Elastic Element, Detail

## 1. Introduction

Cleaning of raw cotton is a fairly complex process, which occurs by shock and shock-shaking effects on the material from the working body, which often performs a rotational movement. The nature of the process depends mainly on the nature of the material supply [1]. The process of feeding material for processing often occurs unevenly, in the form of portions of different sizes, and the process is probabilistic and the description of its movement is much more complicated and it is difficult to get close to the real value [2] [3] [4]. However, this is the main disadvantage of the feed processes, which leads to many problems, such as deterioration of the original quality of the material, loss of material, increased energy and material costs for processing raw materials, etc. [5]-[10]. To eliminate such shortcomings, based on the results of research, many scientists have proposed developments that provide for achieving a continuous and uneven supply of material to the processing process. This process is also convenient for mathematical description.

For continuous and uniform flow, the process is continuous, and it can be written as a continuous process using the laws of motion of continuous media, such as Euler's Equations for a continuous, stationary flow.

## 2. Mathematical Description of the Process of Cleaning Cotton from Weed Impurities

It is proposed to use equations to determine the amount of selected impurities both in packings between the pegs and between the sections of the cleaning zone. It is proposed to use the model of A.G. Sevostyanov [11] to describe the process of cleaning raw cotton from weed impurities. It was established that the largest amount of emitted impurities is released in the areas between the first and third pegs, then its slight decrease occurs in the areas between the next pegs. This circumstance should be taken into account when choosing the length of the contact zones of the raw material with a mesh surface. Taking into account the loosening of the flow during the transition from the cleaning section to the second section, we infer the Euler shape:

$$\rho_j v_j \frac{\mathrm{d}v_j}{\mathrm{d}\alpha} = -\frac{\mathrm{d}p}{\mathrm{d}\alpha} + \rho_j gR\left(\cos\alpha - f\sin\alpha\right) - f\rho_j v_j^2 \tag{1}$$

where

$$\rho_j = \rho_j\left(\alpha\right),\ \ v_{\ j} = v_j\left(\alpha\right)\ \text{ and }\ p_j = p_j\left(\alpha\right) \tag{2}$$

through functions $\alpha_{j-1} \le \alpha \le \alpha_j$ the density and speed of raw cotton in the sector are given

Equation (2) contains 3 unknowns: $p$, $\rho$ and $v$, and. To close it, we use the equation of state of a compressible medium, establishing a relationship between pressure $p$ and density $\rho$:

$$\rho = \rho_c\left[1 + A\left(p - p_c\right)\right] \tag{3}$$

and mass conservation condition for stationary flow motion

$$\rho v S_0 = Q_0 \tag{4}$$

Here $S_0 = k_0 L h$ is the cross-sectional area of the flow layer, $h$ is the thickness of the layer, $L$ is the length of the drum, $k_0$ is the coefficient characterizing the decrease in the contact area of the raw material with the surfaces of the pegs. $Q_0$ is the capacity of the purifier, $\rho_c, p_c$ is the density and pressure upon receipt of the raw material on the surface of its contact with the stick, $A$ is the constant characterizing the compressibility of the raw material. When $A \ll 1$ (4) we determine the speed

$$v = v_c\left[1 - A\left(p - p_c\right)\right] \tag{5}$$

Under the impact of the flashing on the raw material at the contact of the flow particle, it acquires speed $v_c = \beta v_k$, where $v_k$ is the linear speed of the splitting, $\beta < 1$ is the rate reduction coefficient determined experimentally, in [2] the average flow rate in the cleaning zone is adopted $v_{cp} = 0.5 v_k$. Assuming in the formula (5) $v = v_c$, we find the density of the raw materials on the surface contact with the stick

$$\rho_c = \frac{Q_0}{S_0 v_c}$$

To determine the pressure $p_c$, we assume that the pressure $p_0$ density of the feedstock $p_0$ in the feed zone is known. Then, lying $p = p_0$ and $\rho = \rho_0$ using formula (3), we find

$$p_c = p_0 - (\rho_0/\rho_c - 1)/A \tag{6}$$

From the requirement that there is no separation of raw materials from the surface of the splitting $p_c > 0$, it follows that means $\frac{\rho_0}{\rho_c} < 1 + p_0 A$. On the other hand, the condition of rarefaction of raw materials in the treatment zone $p_c < p_0$, which gives $\frac{\rho_0}{\rho_c} > 1$. Thus, to implement the process of rarefaction of raw materials without breaking contact with the pick, it is necessary that the ratio of the densities satisfy the inequality $1 < \frac{\rho_0}{\rho_c} < 1 + p_0 A$. Limitation on the magnitude of the pressure $p_0$ (or speed of the pick) from the condition that there is no damage to the seeds during impact interaction of the pick with the feed. If we denote by $P_k$ the ultimate impact force at which damage to the seeds occurs, then assuming in formula (6) $p_c < P_k/S_0$, we obtain $p_0 < P_k/S_0 + (\rho_0/\rho_c - 1)/A$. We introduce a new variable by the formula (6) $\alpha = s/R$ ($\alpha$ -the central angle, *R*-the radius of the drum). In view of (2) and (4), we write the equation for pressure *p*.

$$a\frac{\mathrm{d}p}{\mathrm{d}\alpha} = R\rho g(\sin\alpha - f\cos\alpha)\left[1 + A(p - p_c)\right] - \bar{Q}_0 f\left[1 - A(p - p_c)\right]$$

We bring the last equation to the form:

$$\frac{\mathrm{d}p}{\mathrm{d}\alpha} = F_1(\alpha)p + F_2(\alpha) \tag{7}$$

where

$$F_2(\alpha) = \frac{A\left[R\rho_0 g F_1(\alpha) + \bar{Q}_0 f v_0\right]}{a},$$

$$F_4(\alpha) = \frac{(1 - Ap_c)F_1(\alpha)R\rho_0 g - \bar{Q}_0 v_0 f(1 + p_c A)}{a}$$

$$F_1(\alpha) = \sin\alpha - f\cos\alpha, \quad a = 1 - \bar{Q}_0 v_c A, \quad \bar{Q}_0 = \frac{Q_0}{S_0}.$$

A solution of Equation (5) satisfying the condition $p(0) = p_c$ is represented in quadratures

$$p = F_3(\alpha)\left[\frac{p_{0c}}{F_3(0)} + \int_0^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)}\mathrm{d}\alpha\right] \tag{8}$$

where $F_3(\alpha) = \exp\left[\int F_2(\alpha)\mathrm{d}\alpha\right]$

We use formula (8) to determine the pressure $p$ in each section.

The contact of the flow of raw cotton in the first section with the mesh surface occurs in four sections $0 < \alpha < \alpha_0$, $\alpha_0 < \alpha < 2\alpha_0$, $2\alpha_0 \le \alpha < 3\alpha_0$ and $3\alpha_0 \le \alpha < 4\alpha_0$ the Solution in each section, taking into account the change in contact pressure according to formula (8), due to the impact of each prick, is written as:

$$p = p_1 = F_3(\alpha)\left[\frac{p_c}{F_3(0)} + \int_0^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)}\mathrm{d}\alpha\right] \quad \text{at} \quad 0 < \alpha < \alpha_0 \tag{9}$$

$$p = p_2 = F_3(\alpha)\left[\frac{p_{1c}}{F_3(\alpha_0)} + \int_{\alpha_0}^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)}\mathrm{d}\alpha\right] \quad \text{at} \quad \alpha_0 < \alpha < 2\alpha_0 \tag{10}$$

$$p = p_3 = F_3(\alpha)\left[\frac{p_{2c}}{F_3(2\alpha_0)} + \int_{2\alpha_0}^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)}\mathrm{d}\alpha\right] \quad \text{at} \quad 2\alpha_0 < \alpha < 3\alpha_0 \tag{11}$$

$$p = p_4 = F_3(\alpha)\left[\frac{p_{3c}}{F_3(3\alpha_0)} + \int_{3\alpha_0}^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)}\mathrm{d}\alpha\right] \quad \text{at} \quad 3\alpha_0 < \alpha < 4\alpha_0 \tag{12}$$

Similarly for the second section we have

$$p = p_5 = F_3(\alpha)\left[\frac{p_{4c}}{F_3(0)} + \int_0^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)}\mathrm{d}\alpha\right] \quad \text{at} \quad 0 < \alpha < \alpha_0 \tag{13}$$

$$p = p_6 = F_3(\alpha)\left[\frac{p_{5c}}{F_3(\alpha_0)} + \int_{\alpha_0}^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)}\mathrm{d}\alpha\right] \quad \text{at} \quad \alpha_0 < \alpha < 2\alpha_0 \tag{14}$$

$$p = p_7 = F_3(\alpha)\left[\frac{p_{6c}}{F_3(2\alpha_0)} + \int_{2\alpha_0}^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)}\mathrm{d}\alpha\right] \quad \text{at} \quad 2\alpha_0 < \alpha < 3\alpha_0 \tag{15}$$

$$p = p_8 = F_3(\alpha)\left[\frac{p_{7c}}{F_3(3\alpha_0)} + \int_{3\alpha_0}^{\alpha} \frac{F_4(\alpha)}{F_3(\alpha)}\mathrm{d}\alpha\right] \quad \text{at} \quad 3\alpha_0 < \alpha < 4\alpha_0 \tag{16}$$

where

$$p_{1c} = p_1(\alpha_0) - \left[\frac{\rho_1(\alpha_0)}{v_c} - 1\right]\Big/ A, \quad p_{2c} = p_2(2\alpha_0) - \left[\frac{\rho_2(2\alpha_0)}{v_c} - 1\right]\Big/ A,$$

$$p_{3c} = p_3(3\alpha_0) - \left[\frac{\rho_3(3\alpha_0)}{v_c} - 1\right]\Big/ A, \quad p_{4c} = p_4(4\alpha_0) - \left[\frac{\rho_4(4\alpha_0)}{v_c} - 1\right]\Big/ A,$$

$$p_{5c} = p_5(\alpha_0) - \left[\frac{\rho_5(\alpha_0)}{v_c} - 1\right]\Big/ A, \quad p_{6c} = p_{26}(2\alpha_0) - \left[\frac{\rho_6(2\alpha_0)}{v_c} - 1\right]\Big/ A,$$

$$p_{7c} = p_7(3\alpha_0) - \left[\frac{\rho_7(3\alpha_0)}{v_c} - 1\right]\Big/ A$$

For calculation, the reduced coefficient of friction between the net and the raw cotton was used according to the formula $f = f_0(1-n)$, where $n = S/S_0$, $S$ is the area of the grid occupied by open areas, $S_0$ is the total area of the grid.

Consider the process of separation of weed impurities from the composition of raw cotton when it moves along a mesh surface. Following [3], the relationship between the mass of raw cotton entering the cleaning zone and its density is presented in the form

$$\frac{\mathrm{d}m}{m} = \lambda \frac{\mathrm{d}\rho}{\rho}$$

where $\lambda = 1/(1+a)$, $a > 0$ is the proportionality coefficient. I integrate the last equation that satisfies the conditions $m = m_9$ ($m_0$ is the mass of raw cotton entering the zone between the first and second peels of the peeling zone of the raw cotton per unit time), $\rho = \rho_c$ at $\alpha = 0$ for the cleaning zone between the first and second peaks, we obtain

$$\frac{m_1}{m_0} = \left(\frac{\rho_1}{\rho_c}\right)^{\lambda}$$

Given the dependence (3), we have

$$\frac{m_1}{m_0} = \left[1 + A\left(p_1 - p_c\right)\right]^{\lambda} \quad \text{at} \quad 0 < \alpha < \alpha_0$$

The mass of the selected impurities referred to the mass $m_0$ between the first and second, second and third, third and fourth pegs and after exposure to the fourth peck is determined by the formula

$$\varepsilon_1 = \frac{m_0 - m_1}{m_0} = 1 - \left[1 + A\left(p_1 - p_{0c}\right)\right]^{\lambda} \quad \text{at} \quad 0 < \alpha < \alpha_0$$

$$\varepsilon_2 = \varepsilon_1\left(\alpha_0\right)\left(\frac{\rho_2}{\rho_c}\right)^{\lambda} = \varepsilon_1\left(\alpha_0\right)\left[1 + A\left(p_2 - p_{1c}\right)\right]^{\lambda} \quad \text{at} \quad \alpha_0 < \alpha < 2\alpha_0$$

$$\varepsilon_3 = \varepsilon_2\left(2\alpha_0\right)\left[1 + A\left(p_3 - p_{2c}\right)\right]^{\lambda} \quad \text{at} \quad 2\alpha_0 < \alpha < 3\alpha_0$$

$$\varepsilon_4 = \varepsilon_3\left(3\alpha_0\right)\left[1 + A\left(p_4 - p_{3c}\right)\right]^{\lambda} \quad \text{at} \quad 3\alpha_0 < \alpha < 4\alpha_0$$

Similarly, for the second cleaning zone, we have

$$\varepsilon_5 = \varepsilon_4\left(4\alpha_0\right)\left[1 + A\left(p_5 - p_{4c}\right)\right]^{\lambda} \quad \text{at} \quad 0 < \alpha < \alpha_0,$$

$$\varepsilon_6 = \varepsilon_5\left(\alpha_0\right)\left[1 + A\left(p_6 - p_{5c}\right)\right]^{\lambda} \quad \text{at} \quad \alpha_0 < \alpha < 2\alpha_0$$

$$\varepsilon_7 = \varepsilon_6\left(2\alpha_0\right)\left[1 + A\left(p_7 - p_{6c}\right)\right]^{\lambda} \quad \text{at} \quad 2\alpha_0 < \alpha < 3\alpha_0$$

$$\varepsilon_8 = \varepsilon_7\left(3\alpha_0\right)\left[1 + A\left(p_8 - p_{7c}\right)\right]^{\lambda} \quad \text{at} \quad 3\alpha_0 < \alpha < 4\alpha_0$$

where the pressure $p_i\left(i = 1, 2, 3, \cdots, 8\right)$ is determined using formulas (9)-(16). The total mass of weed impurities (referred to the total mass of raw cotton on the surface of the net) from the two cleaning zones is presented as the sum

$$M = \sum_{i=1}^{4} \int_{(i-1)\alpha_0}^{i\alpha_0} \varepsilon_i \mathrm{d}\alpha + \sum_{i=1}^{4} \int_{(i-1)\alpha_0}^{i\alpha_0} \varepsilon_{4+i} \mathrm{d}\alpha$$

## 3. Analysis of the Results

There are graphs (**Figure 1**, **Figure 2**) of the distribution of density, speed and mass of the selected impurities (referred to the mass of raw cotton) on the arc of contact between the cotton and the net surface of the first cleaning zone for two values of the productivity of the cleaning machine. In the calculations accepted when the cleaning machine's performance is 8 - 10 t/hour. The calculation is accepted: $R = 0.2$ m, $\omega = 50$ s$^{-1}$, $v_s = 3.8$ m/s; $h = 0.018$ m; $L = 1.7$ m, $\alpha = 45^\circ$, $k_0 = 0.8$, $S_0 = k_0 hL = 0.02448$ m$^2$, $f = 0.1$, $\rho = 40$ kg/m$^3$, $p_0 = 2500$ Pa, $A = 7 \times 10^{-4}$ 1/Pa.

From the analysis of the graphs it follows that as a result of the impact of the pegs in the places of impact, the density and velocity in the sections of the flow layer change abruptly. During the transitions to the sections between the protrusions, the density practically does not change, and the speed increases significantly, which is noticeable at high machine productivity (**Figure 1**).

The graphs of the mass distribution of trash impurities extracted from the flow (referred to the mass of the untreated mass of raw cotton), presented in **Figure 2**, show that a high cleaning effect is observed in the region between the first and second separation. Then a decrease in the mass of trash impurities is observed, and, moreover, a significant decrease in trash impurities occurs in the areas between the second and third pegs is observed at high performance values $Q_0$.

It can be seen that an increase in the parameter $\lambda$ value leads to an increase in the mass of weed impurities. According to the calculations, the total mass of weed impurities isolated from the treatment zone was calculated. **Table 1** and **Table 2** show the amounts of weed impurities in the areas between the pegs and their total mass (referred to the mass of raw cotton) at different values of the parameter $\lambda$ and two performance values $Q_0$.

From the analysis of the tabular data it follows that the total mass of the released impurities can increase significantly with large values of the parameter $\lambda$. At the same time, intensive separation of weed impurities occurs in the areas between the first and second grate.

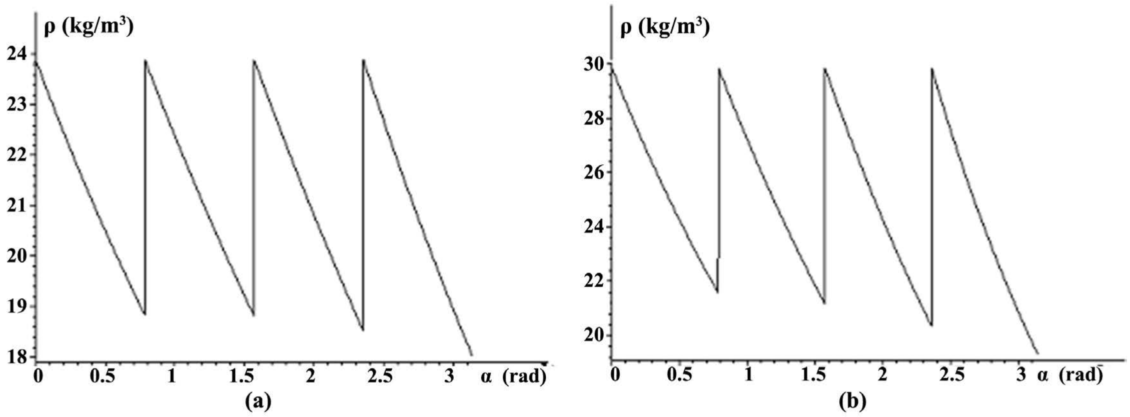

**Figure 1.** Density distribution ($\rho$) of raw cotton in the area of the first cleaning section for two performance values $Q_0$. (a) $Q_0 = 8$ t/hour; (b) $Q_0 = 10$ t/hour.

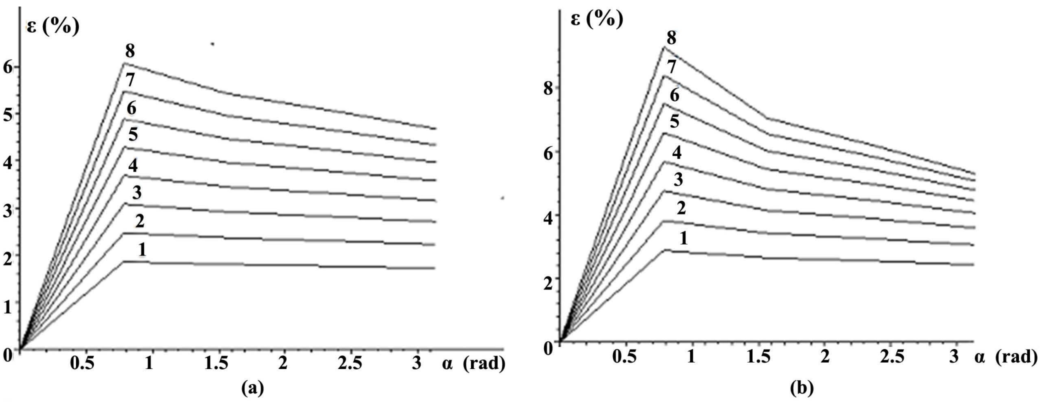

**Figure 2.** The mass distribution of the selected weed impurities (referred to the mass of raw cotton of raw) $\varepsilon$ (in percent) in the first section of the cleaning at two values of performance $Q_0$. Different parameter values $\lambda$: 1- $\lambda = 0.06$, 2- $\lambda = 0.08$, 3- $\lambda = 0.1$, 4- $\lambda = 0.12$, 5- $\lambda = 0.14$, 6- $\lambda = 0.16$, 7- $\lambda = 0.18$, 8- $\lambda = 0.2$. (a) $Q_0$ = 8 t/hour; (b) $Q_0$ = 10 t/hour

**Table 1.** The values of the mass of the separated weeds between the pegs and their total mass (relative mass of raw cotton raw cotton, in %) in the first section of the cleaning zone at $Q_0$ = 8 t/hour and for different values of the parameter $\lambda$.

| $\lambda$ | 0.06 | 0.08 | 0.1 | 0.12 | 0.14 | 0.16 | 0.18 | 0.2 | 0.2 | 0.24 |
|---|---|---|---|---|---|---|---|---|---|---|
| $0 < \alpha \le \alpha_0$ | 0.731 | 0.972 | 1.211 | 1.448 | 1.685 | 1.920 | 2.153 | 2.385 | 2.615 | 2.844 |
| $\alpha_0 < \alpha \le 2\alpha_0$ | 1.438 | 1.901 | 2.356 | 2.803 | 3.242 | 3.674 | 4.098 | 4.515 | 4.925 | 5.328 |
| $2\alpha_0 < \alpha \le 3\alpha_0$ | 1.400 | 1.833 | 2.251 | 2.653 | 3.041 | 3.415 | 3.775 | 4.120 | 4.453 | 4.772 |
| $3\alpha_0 < \alpha \le 4\alpha_0$ | 1.369 | 1.780 | 2.169 | 2.239 | 2.888 | 3.219 | 3.532 | 3.828 | 4.107 | 4.369 |
| $M_k = \sum_{i=1}^{4} M_{ik}(\%)$ $k = 1, 2, 3, \cdots, 10$ | 4.937 | 6.485 | 7.987 | 9.444 | 11.29 | 12.23 | 13.56 | 14.85 | 16.10 | 17.31 |

**Table 2.** The values of the mass of separated weeds between the pegs and their total mass (relative mass of raw cotton raw cotton, in %) in the first section of the cleaning zone at $Q_0$ = 10 t/hour and for different values of the parameter $\lambda$.

| $\lambda$ | 0.06 | 0.08 | 0.1 | 0.12 | 0.14 | 0.16 | 0.18 | 0.2 | 0.2 | 0.24 |
|---|---|---|---|---|---|---|---|---|---|---|
| $0 < \alpha \le \alpha_0$ | 0.731 | 0.972 | 1.211 | 1.448 | 1.685 | 1.920 | 2.153 | 2.385 | 2.615 | 2.844 |
| $\alpha_0 < \alpha \le 2\alpha_0$ | 1.438 | 1.901 | 2.356 | 2.803 | 3.242 | 3.674 | 4.098 | 4.515 | 4.925 | 5.328 |
| $2\alpha_0 < \alpha \le 3\alpha_0$ | 1.400 | 1.833 | 2.251 | 2.653 | 3.041 | 3.415 | 3.775 | 4.120 | 4.453 | 4.772 |
| $3\alpha_0 < \alpha \le 4\alpha_0$ | 1.369 | 1.780 | 2.169 | 2.239 | 2.888 | 3.219 | 3.532 | 3.828 | 4.107 | 4.369 |
| $M_k = \sum_{i=1}^{4} M_{ik}(\%)$ $k = 1, 2, 3, \cdots, 10$ | 4.937 | 6.485 | 7.987 | 9.444 | 11.29 | 12.23 | 13.56 | 14.85 | 16.10 | 17.31 |

Increasing the efficiency of cleaning cotton has a positive effect on the processes of further processing of cotton and its processed products [12] [13].

## 4. Conclusions

1) It has been found that the use of the Euler equation to describe the flow of

cotton in the cleaning zones of cotton ginning machines makes it possible to correctly describe the laws of distribution of pressure, density and velocity along the arc of contact of a moving layer of raw cotton with a mesh surface, which is fully consistent with the logical representation of events in zone of interaction of cotton with pegs and mesh surface.

2) It has been established that the pressure, density and second mass of cotton along the cleaning arc as a result of the blows of the splitter change abruptly, and there is a gradual decrease in pressure and density and an increase in the flow rate along this arc. This indicates a significant loosening of the cotton flow during the transition from the first cleaning section to the second, and there is a slight change in their values in other cleaning sections.

3) To describe the process of cleaning raw cotton from trash impurities together with the Euler equations, it is proposed to use the model of A.G. Sevostyanova, who even more accurately describes the process of separating weeds from the cotton flow. It shows that the greatest amount of trash impurities is released in the areas between the first and third pegs, then the weight of the excreted litter decreases and the cleaning effect will be low in subsequent areas. This circumstance should be taken into account when choosing the length of the contact zones of the raw material with the mesh.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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