Theoretical Study of the Movement of Cotton Seed Flow along the Contour of the Rib

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Abstract

Improving the efficiency of the process of separating fiber from cotton seeds by improving the working chamber of the gin is one of the important issues. The main way to increase the efficiency of sawn gin is to increase the fiber content in the mass of seeds in the working chamber with a uniform decrease in its density. This can be achieved by using grates with a concave working surface, which serves to move the seeds away from the rotating saws and accelerate the release of bare seeds from the working chamber. The article discusses the movement of seeds on the concave surface of the grate and determines the rational parameters of their working part. The article explores the proposed grate model, consisting of four geometric shapes, provides an analytical analysis of the geometric types. The dependence of the location of the last rectilinear part of the general contour on the shape of its convexity and concavity is determined. Cotton seeds move along the contour in the form of a stream. We assume that the thickness of the flow along the contour is constant and equal. We compose a unique equation of the flow in each section of the circuit. To determine the state of the flow, we denote its velocity, density and pressure in each section, respectively. Let us determine the flow motion along the contour with respect to the arc.

Keywords

Cotton, Saw Gin, Grates, Ginning, Fiber, Seeds, Concave Surface

1. Introduction

Currently, much attention is paid to increasing the output of value-added finished products, improving the cotton industry system based on the deep processing of cotton raw materials, lowering production costs and improving the

quality of cotton products based on the re-equipment of cotton primary processing technology.

When solving these problems, increasing the efficiency of the ginning process by improving the working chamber of the gin is one of the important tasks.

Also, the main way to increase the efficiency of the saw gin is to increase the fiber content of the raw roller, accelerate the yield of bare seeds and a uniform decrease in its density [1] [2] [3] [4].

The rib-grate is one of the main parts of the working chamber of the saw gin. It serves as a free pass saw blades between the grates in the working chamber and the free output of the fibers engaged on the saw teeth after separation. Rib-grite are made by casting of cast iron grade SCh-15-32.

Working surfaces, processed on special machines, are reduced to a certain shape. The surface of the grate is hardened by he For normal operation of the saw blades, the working surface of the grate should be smooth and not rough, the distance between the grates in the working area should be 3 ± 0.2 mm, and in the lower part 4.5 - 5 mm at treatment [5] [6] [7] [8].

The number of grid-irons in the grate is one more than the number of saws on the shaft, two narrow grid-irons are installed in two extreme positions, and the rest with a normal width are intermediate. At the ginneries during the work of saw gins DP-130, the teeth of the saw cylinder, catching the fibers from the raw roller, pass between the grates and are separated from the seeds. The fibers hooked onto the saw teeth are separated by an air stream exiting the nozzle.

The surface of the grate of this gin is flat, the interaction of the raw roller and the saw cylinder is constant, the machine performance is low, energy consumption and damage are high.

Taking into account the above, we have proposed a grate with a concave profile for the rapid removal of bare seeds from the working chamber.

This rib-grate makes it possible to reduce friction with a saw cylinder and a raw roller, as a result of reducing damage to the fiber and seeds, as well as reducing energy consumption, accelerating the exit of bare seeds from the working chamber [8] [9] [10] [11] [12].

It has been proven that an increase in the productivity of gin is necessarily accompanied by an increase in the density of the seed roll. But the increase in productivity with increasing density occurs within certain limits, after the productivity decreases. This is due to a decrease in the speed of the seed roll under the influence of friction forces, it is determined that at a density of 550 - 600 kg/m^3, the process completely stops, is the reason for a negative effect on the ginning process, a decrease in the productivity and quality of the fiber. To prevent this drawback, a more perfect study of the ginning process is required, the development of other methods for removing bare seeds from the roll box. The studies carried out to date in this area have not sufficiently investigated the issue of accelerating bare seeds from the roll box of the gin by improving the design of the grate during the ginning process [5] [13] [14].

The aim of the work is to increase the efficiency of ginning by improving the

design of the grate of the saw gin stand.

Wedge-shaped depressions in adjacent grates form a tray. This tray, in the process of interaction of cotton with the saw in the contact zone, ensures their overturning and increased contact with the saw [15] [16] [17] [18].

The grate proposed by P. N. Tyutin [19], in the upper part it is made convex. This in turn leads to an increase in productivity, but to a decrease in seed and fiber quality.

The grate proposed by Sh. T. Ergashev [20], due to the better mesh of the fibers with the saw blade, is aimed at increasing productivity. The upper working surface of the grate is flat, both parts are made obliquely to each other. This ensures efficient movement of seeds on adjacent rotating saws across the width of the machine. In practice, these grates have not been used in production.

In the work of R. Sulaimanov [21], an algorithm for solving the problem of a mathematical model and dynamics of seed movement was obtained, which allows theoretically determining the optimal parameters of the distance between cantilever grates, grates and spacers when withdrawing additional seeds. On the basis of this, the distance between the saws has been reduced, and a new method and device for outputting additional seeds has been proposed.

2. Simulation of Ginning Seeds on the Control Rib-Grate

Suppose the grate outline consists of two circles and two straight lines. Cotton seeds move along the contour in the form of a stream. We assume that the thickness of the flow along the contour is constant and equal to h_0.

Let the initial grate contour be composed of an arc of a circle AB, its continuation of a straight line BC, then an arc of a circle CB and a straight line BE (**Figure 1**).
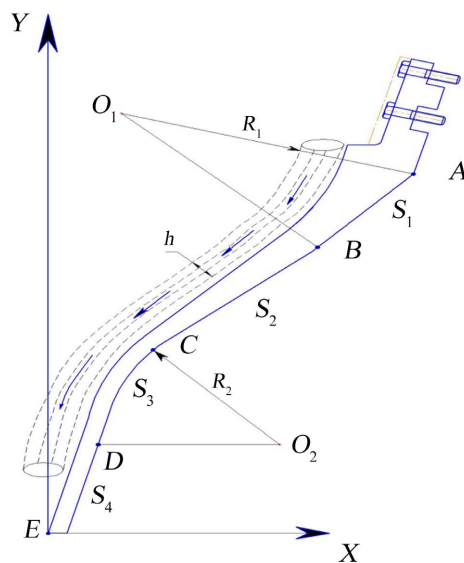

Figure 1. The movement pattern of the flow of cotton seeds along the contour of the rib-grate. AB, CD—arcs of circles, BC, DE—straight lines.

We compose a unique equation of the flow in each section of the circuit. To determine the state of the flow, we denote its velocity, density and pressure in each section, respectively, $(v_1, \rho_1, P_1), (v_2, \rho_2, P_2), (v_3, \rho_3, P_3), (v_4, \rho_4, P_4)$. Let us determine the flow motion along the contour with respect to the arc. We calculate the length of each arc from point A and let the length of each section consist of $0 < s < s_a$ (section AB), $s_{01} < s_0 + s_1$ (section BC), $s_0 + s_1 < s_0 + s_1 + s_{02}$ (section CB) and $s_{01} + s_1 + s_0 < s < s_{01} + s_1 + s_0 + s_2$ (section DE). We write the Euler equation for each section:

$$\rho_1 v_1 \frac{\partial v_1}{\partial s} = -\frac{\partial p_1}{\partial s} + \rho_1 g \left[\sin\left(\alpha_{00} + s/R\right) + f \cos\left(\alpha_{00} + s/R\right) \right]$$
$$- f \rho_1 \frac{v_1^2}{R_1}, \quad 0 < s < s_{01} \tag{1}$$

$$\rho_2 v_2 \frac{\partial v_2}{\partial s} = -\frac{\partial p_2}{\partial s} + \rho_2 g \left[\sin\left(\alpha_{00} + \alpha_{01}\right) \right.$$
$$\left. - f \cos\left(\alpha_{00} + \alpha_{02}\right) \right], \quad s_{01} < s < s_{01} + s_1 \tag{2}$$

$$\rho_3 v_3 \frac{\partial v_3}{\partial s} = -\frac{\partial p_3}{\partial s} + \rho_3 g \left[\sin\left(\alpha_{00} + s/R - s_1/R\right) - f \cos\left(\alpha_{00} + s/R - s_1/R\right) \right]$$
$$- f \frac{v_3^2}{R_2}, \quad s_{01} + s_1 < s < s_{01} + s_1 + s_{02} \tag{3}$$

$$\rho_4 v_4 \frac{\partial v_4}{\partial s} = -\frac{\partial p_4}{\partial s} + \rho_4 g \left[\sin\left(\alpha_{00} + \alpha_{01} + \alpha_{02}\right) \right.$$
$$\left. - f \cos\left(\alpha_{00} + \alpha_{01} + \alpha_{02}\right) \right], \quad s_{01} + s_1 + s_{02} < s < s_{01} + s_1 + s_{02} + s_2 \tag{4}$$

Here, *f*—is the coefficient of friction between the flow and the rib-grate, R_1, R_2 are the radii of the circles.

The coordinate origin is set at point E, the axis ox is directed to the right, the axis oy is directed up.

The coordinates of points A, B, C, D and E, the angles α_{01}, α_{02}, as well as the radii R_1 and R_2 have a certain value, for Equations (1)-(4) the lengths are determined by the following formulas.

$$s_{01} = \alpha_{01} R_1, \quad s_1 = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}, \quad s_{02} = \alpha_{02} R_2,$$
$$s_2 = \sqrt{(x_2 - x_3)^2 + (y_3 - y_2)^2}$$

In Equations (1)-(4), three unknowns participate P_i, ρ_i, v_i, $i = 1, 2, 3$, to describe them in relation to one unknown, more precisely in relation to k v_i, we use these two conditions:

The flow is stationary, then the following condition must be fulfilled

$$\rho_i \cdot v_i \cdot h \cdot L = Q_0 \tag{5}$$

Here, *Q*—is the productivity of one grate for seed flow, *L* is the width of the grate.

From Equation (5) we express the density in terms of speed:

$$\rho_i = \frac{Q_0}{v_i \cdot h_i \cdot L} \tag{6}$$

We accept the seed flow as a conjugate medium; therefore, the equation of state of the medium will be appropriate.

$$\rho_i = \rho_0 \left[1 + A \left(p_i - p_0 \right) \right] \qquad (7)$$

Here, ρ_0, p_0 —is the density and pressure in the stream before feeding to the grate; A—experimentally determined physical quantity inversely proportional to the stiffness of the medium consisting of the mass of seeds.

To determine the flux density before feeding, we define the volume between any grates and two gear discs adjacent to them.

In accordance with **Figure 2**, this volume is calculated by the following formula.

$$V = \left[\pi \beta R^2 / 2 - \left(S_1 + S_2 + S_3 + S_4 \right) \right] L$$

Here, S—the area of the triangle.

$$S_1 = 0.5 AB \sin \beta_1, \quad S_2 = 0.5 BC \sin \beta_2, \quad S_3 = 0.5 CD \sin \beta_3, \quad S_4 = 0.5 DE \sin \beta_4,$$

$$\beta_1 = \arccos \sqrt{\frac{R^2 + R_1^2 - AB^2}{R_1 R}}, \quad \beta_2 = \arccos \sqrt{\frac{R_2^2 + R_1^2 - BC^2}{R_1 R_2}},$$

$$\beta_3 = \arccos \sqrt{\frac{R_3^2 + R_2^2 - CD^2}{R_2 R_3}},$$

$$\beta_4 = \arccos \sqrt{\frac{R^2 + R_3^2 - DE^2}{R_3 R}}, \quad \beta = \beta_1 + \beta_2 + \beta_3 + \beta_4$$

In the calculations we take, $AB = s_{01}$, $BC = s_1$, $CD = s_{02}$, $DE = s_2$.

Let's say the volume V is completely filled with seeds of pieces with the same mass m.

Then the total mass of the volume is $M = N \cdot m$, and its density can approximately be calculated by the following formula.
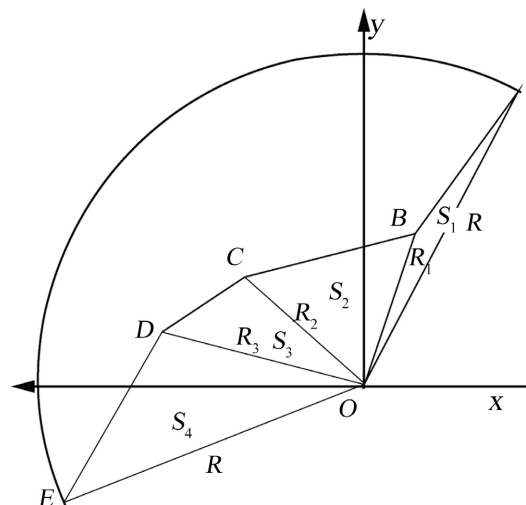
$$\rho_0 \approx N \cdot m / V$$

Figure 2. The calculated contour of the rib-grate.

Using formula (7) we find the relationship between pressure and density.

$$v_i = \frac{Q_0}{\rho_0 h_i L \left[1 + A\left(p_i - p_0\right)\right]} \tag{8}$$

From Equation (8) we determine the derivative $\dfrac{\partial p_i}{\partial s}$

$$\frac{\partial p_i}{\partial s} = -\frac{v_0}{v_i^2 A}\frac{\partial v_i}{\partial s} \tag{9}$$

Using formulas (6) and (9), Equations (1)-(4) lead to the following forms with respect to velocities v_i.

$$\frac{\partial v_1}{\partial s} = \frac{g v_1}{v_1^2 - c^2}\left(\sin\frac{s}{R_1} + f\cos\frac{s}{R_1}\right) - f\frac{v_1^3}{v_1^2 - c^2}\frac{1}{R_1}, \quad s_{00} < s < s_{01} \tag{10}$$

$$\frac{\partial v_2}{\partial s} = \frac{g v_2}{v_2^2 - c^2}\left(\sin s_{01}/R - f\cos s_{01}/R\right), \quad s_{01} < s < s_{01} + s_1 \tag{11}$$

$$\frac{\partial v_3}{\partial s} = \frac{g v_3}{\left(v_3^2 - c^2\right)v_3}\left(\sin\frac{s}{R_2} - f\cos\frac{s}{R_2}\right)$$
$$- f\frac{v_3^3}{v_3^2 - c^2}\frac{1}{R}, \quad s_{01} + s_1 < s < s_{01} + s_1 + s_{02} \tag{12}$$

$$\frac{\partial v_4}{\partial s} = \frac{g v_4}{\left(v_4^2 - c^2\right)v_4}\left(\sin s_{02}/R\right.$$
$$\left. - f\cos s_{02}/R\right), \quad s_{01} + s_1 + s_{02} < s < s_0 + s_1 + s_0 + s_2 \tag{13}$$

Here, $c = \sqrt{1/A\rho_0}$.

Equations (10)-(13) are nonlinear, we integrate numerically under the following conditions:

$$v_1 = v_{10} \quad \text{at} \quad s = s_{00} \tag{14}$$

$$v_2\left(s_{01}\right) = v_1\left(s_{01}\right) \quad \text{at} \quad s = s_{01} \tag{15}$$

$$v_3\left(s_1 + s_{01}\right) = v_2\left(s_1 + s_0\right) \quad \text{at} \quad s = s_1 + s_{01} \tag{16}$$

$$v_4\left(s_1 + s_{01} + s_{02}\right) = v_3\left(s_1 + s_{01} + s_{02}\right) \quad \text{at} \quad s = s_1 + s_{01} + s_{02} \tag{17}$$

3. Analysis of the Model for Various Values of the Parameters of the Rib-Grate

The following values are accepted in the calculations

$L = 0.16, \ R_1 = 0.107, \ R_2 = 0.1145, \ s_{01} = 0.07098120639,$
$s_1 = 0.07098120639, \ s_2 = 0.07604794422, \ s_3 = 0.07266443270,$
$s_4 = 0.082050115661, \ s_0 = 0.3017437399,$
$L = 0.00818 \text{ m}, \ m = 0.025 \times 10^{-3} \text{ kg}, \ N = 250, \ f = 0.2$

As a result, the following results were obtained, in **Figure 2** shows the calculated contour of the rib-grate.

$$\beta_1 = \alpha_1 = 0.3628444444, \ \alpha_2 = 0.6977777778, \ \alpha_3 = 0.5378122222,$$
$$\alpha_4 = 0.2485833333, \ \alpha_0 = 1.847017777, \ \beta = \alpha_0 = 105.8799999,$$
$$v = 0.00007972317841\,\text{m}^3, \ \rho_0 = 31.35850890\,\text{kg}/\text{m}^3$$

In **Figure 3** and **Figure 4** show plots of the distribution of the flow rate of the mass of seeds along the contour for various values of the angle and parameter, indicating its mechanical properties.

It can be seen from the graph that the flow velocity along the circuit is close to a linear regularity, and with increasing parameter A, the flow velocity decreases upon exiting the circuit. It is also seen that with increasing angle β_4 practically does not affect the distribution of speed.

The parameter can significantly affect the change in flux density (**Figure 4**) and with its increase, an increase in density, the formation of the mass of compacted seeds on the grate circuit is possible [12] [22] [23].
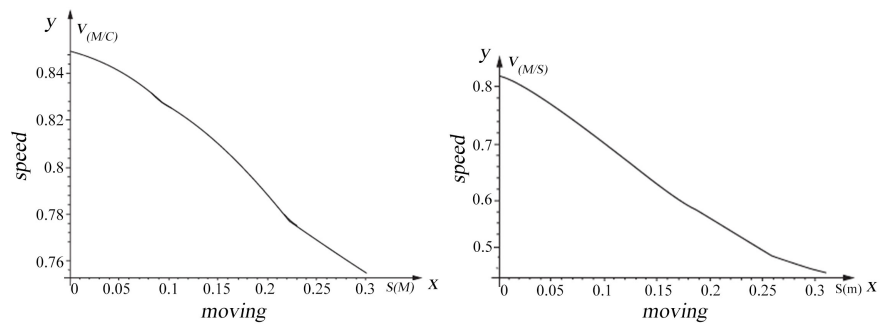

Figure 3. Graphs of the distribution of seed flow velocity along the contour for two values of the angle β_4 and parameter A. $A = 0.001 Pa^{-1}; A = 0.005 Pa^{-1}; \beta_4 = 50°$.
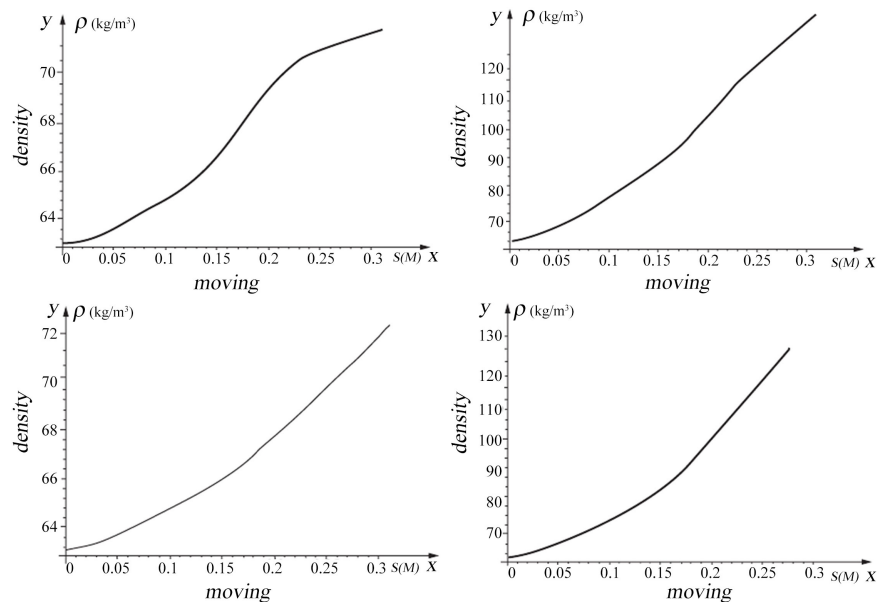

Figure 4. Graphs of the density distribution ρ (kg/m³) of the seed flow along the contour for two values of the angle and parameter. $A = 0.001 Pa^{-1}; A = 0.005 Pa^{-1}; \beta_4 = 50°$, $A = 0.001 Pa^{-1}; A = 0.005 Pa^{-1}; \beta_4 = 80°$.

4. Findings

1) A grate model consisting of four geometric forms is proposed, an analytical analysis of geometric types is presented. The dependence of the location of the last rectilinear part of the contour of the general contour on the shape of its convexity and concavity is determined.

2) A system of differential equations has been obtained to determine the law of the distribution of seed flow velocity along the contours of the proposed grate, using the law of conservation of mass and the equation of state of the medium. From the analysis of the law of the distribution of flow velocities, we observed the proximity of its distribution along the contour to a straight line, as well as a decrease in velocity along the contour.

3) The regularity of increasing the density of seed flow along the contour was determined, the possibility of increasing the density with increasing parameter (that is, with decreasing rigidity of the medium of the mass of seeds) was observed. This shows the probability of the formation of a high degree of density on the contour of the grate and in some cases the appearance of fixed zones of the medium.

Conflicts of Interest

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

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