Theoretical analysis of cotton movement in cleaning equipment

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Abstract. The article explores the supply of cotton in the cleaning of cotton from fine impurities, the laws of movement under the influence of the pile cylinder, the possibility of increasing the level of friction. The main conditions of the movement of cotton in continuous components, the shortcomings of the influencing factors are analyzed. Using the experience of foreign countries, a cotton transfer option was proposed, which allows for additional grinding and disassembly in pile cylinders. The focus of the work was to determine at what angle the cylinder pegs would strike them so that the cotton pieces could move along the required trajectory. Experiments were carried out using the obtained solutions and the developed algorithm, the results of which were analyzed and appropriate conclusions were developed. During the experiments, taking into account the geometric dimensions of the cotton pieces, the effect of their values on the movement parameters was determined. The obtained results allow to determine the coordinates of the mutual position of the pile cylinders with the supply rollers.

1. Introduction
1.1. The state of the problem
Contamination and defective compounds in the fiber have a negative impact on the efficiency of spinning equipment due to the decline in the quality and grade of fiber produced in ginneries. The residues in the fiber are mainly small impurities, and in Uzbekistan, the United States, China and other countries, pile cylinder cleaners with similar geometric and technological parameters are used to clean cotton [1, 2].

A number of researchers [3,4,5,6] have based their findings on the cleaning efficiency and fiber quality of pile cylinders, which are greatly influenced by a flat transfer of cotton in a shredded state.

In the United States and China, this problem was resolved to some extent in two variants [7, 8, 9].

The first is that at the beginning of the transfer of cotton to the technological processes are installed cotton feeders, which transmit the cotton in a flat unit of time in a shredded state.

The second is that the air-supplied cotton cleaning cylinders are transferred to the top of the pile cylinders, and with the help of piles, they are further crushed and cut into small pieces and transferred to the cleaning zone - the mesh surface zone (figure 1).

The process of cotton technology US and Chinese there are no cotton supplier at the beginning of the technological process, cotton is transported in pneumatic tubes in a cyclic form in a single state in technology of Uzbekistan [10].

The cotton ginning equipment is located in the process stream and is equipped with 6 (or 10) pile cylinders at the beginning.
Figure 1. Air separation and cleaning equipment for cotton. 1-pneumatic tube, 2-pile cylinder, 3-mesh surfaces, 4-air thrust tube, 5-cotton outlet hole

They are fitted with two supply rollers for 2 cotton conveyors and a supplier consisting of a rectangular shaft. However, the cotton falling from these supply rollers to the pile cylinder is in a ball-shaped position and the cotton is transferred directly to the mesh surface zone, even before passing through the pile cylinders, due to high movement speed, it does not completely separate into small pieces.

Therefore, using the experience of the United States and China, we proposed to transfer the cotton to the top of the pile cylinder first, and then to the additional grinding zone, i.e. to the bottom different surface zone (figure 2).

Preliminary experiments on this proposal [11, 12, 13, 14] found that the relative position of the pile cylinders with the rollers to ensure that the cotton is shredded and separated into components, and the distance between the pile cylinders and the top wall of the cleaner have a significant effect.

During the movement of the cotton pile cylinders at the top, as a result of the impact of the piles, it crumbles and breaks into its constituent parts, its volume density decreases, and small impurities are released in it [15].

Figure 2. Technological scheme of the pile cleaner.

The more piles the cotton is exposed to, the more it will break and break into pieces. To do this, a piece of cotton moving in the air from the impact of the cylinder peg must fall on the surface of the next cylinder. If you move over it, the friction efficiency will decrease. Alternatively, the cotton swab may
move with or without touching the top wall of the cleaner as it moves after the pile blow. When a piece
of cotton meets the top wall, its movement slows down, and at this moment the cotton coming from
behind it can reach it and reduce the level of friction. It is therefore advisable to move the cotton pieces
without touching the top wall.

Based on the analysis, we consider the movement of the cotton pieces.

2. Materials and methods

2.1. Movement of cotton on top of pile cylinders
It is known that the suspended supply is equal to the shortest distance between two pegs in a horizontal
position. This means that the width of the cotton pieces falling vertically from the supplier may be equal
to or even larger if the cotton piece passes through the gap between the supplier piles (figure 3).

When the first and second grinding and cleaning cylinders are stopped from moving in the position
shown in figure 1, the shortest distance between their horizontal piles is $\xi_1(0) = 25 \, mm$. The shortest
distances $\xi(\beta)$ between the ends of the remaining piles $\xi_1$ will be much larger.

For example, the shortest distance between the ends of the second pile is $\xi_2(30) = 78.53 \, mm$, the
third is $\xi_3(60) = 224.8 \, mm$, and the fourth is $\xi_4 = 425 \, mm$, where $\beta$ is the angle formed between
the direction of the pile seen and the horizontal axis. As the cylinders rotate during operation, the angles
and distances formed by their piles can be equal to the arbitrary values obtained from the intervals $0 \leq \beta \leq \frac{\pi}{2}$
and $25 \leq \xi \leq 425 \, mm$, respectively. Numerical experiments have shown that this angle assumes
a value of $38^\circ < \beta < 39^\circ$ in the range of $\xi(\beta) = 110 \, mm$.

When the first piles on the horizontal axis rotate at the initial time, the shortest distances between
their ends $\beta$ the algorithm for estimating the change in the arbitrary values of the angle $0 \leq \beta \leq \frac{\pi}{2}$
has the following appearance.

$$
\xi_i = \xi_{i-1} + (R_C + h_p)(1 - \cos \sum_{i=1}^n \beta_i) = \xi_{i-1} + 200(1 - \cos \sum_{i=1}^n \beta_i) \tag{1}
$$

Where, $0 \leq \sum_{i=1}^n \beta_i \leq \frac{\pi}{2}$, $\xi_{i-1}$ is the value before step $i$ of the algorithm.

If the calculation step does not change, expression (1) takes the following form

$$
s_i = s_{i-1} + (R_C + h_p)(1 - \cos i \Delta \beta) = s_{i-1} + 200(1 - \cos i \Delta \beta) \tag{2}
$$

Where,
Thus, pieces of cotton with a width of \( b = 110 \text{ mm} \) and less falling vertically in the feeder collide with the ends of the pegs forming a horizontal axis \( 38^\circ < \beta < 39^\circ \) angle of the second cleaning cylinder. Because the size of such fragments is small, they do not collide with the pegs of the cylinder forming an angle of \( \beta \geq 39^\circ \).

The cotton pieces struck from the pegs forming an angle of \( \alpha = 0 \) with the horizontal axis move upwards with an initial velocity of \( y'_2(0) = v_C, x'_2(0) = 0 \) where \( v_2 \) is the linear velocity of rotation of the second cylinder. Such a piece of cotton collides with the next piece of cotton moving vertically downwards, and as a result, between the first and second cylinders, the pieces of cotton will be more. If a piece of cotton is struck at an angle with a vertical arrow, it

\[
y'_2(0) = v_C \sin \alpha, x'_2(0) = v_B \cos \alpha \tag{3}
\]

The initial velocity moves along a curved trajectory, where \( \alpha \) is the angle between the vertical axis and the direction of the pile striking the cotton piece (figure 1).

If the values of the angle \( \alpha \) increase from 0 to \( \frac{\pi}{2} \), the horizontal axis projection of the amount of movement of the cotton piece decreases and the vertical axis projection increases.

Compared to the above calculation results, on existing machines, most of the cotton pieces falling vertically from the supplier are hammered from the pegs forming an angle \( \alpha > 51^\circ \) with the vertical axis, and as a result move at a relatively large speed along the vertical axis and relatively small along the horizontal axis. Pieces of cotton moving according to this law rise a great distance along the vertical axis and, as a result, touch the stationary wall of the machine, changing its trajectory of motion and causing the above-mentioned defects.

In most theoretical studies in this area, a moving piece of cotton considered a material point. The following is a method of taking into account the average values of the dimensions of the cotton pieces moving in the cleaning machine.

2.2. The theory of curvilinear motion of a piece of cotton around a second cylinder

The differential equations written in the form of projections on the horizontal and vertical axes of such motion are as follows.

\[
m \frac{d^2x_2}{dt^2} = m \frac{d^2y_2}{dt^2} = 0, m \frac{d^2x_2}{dt^2} = m \frac{d^2y_2}{dt^2} - mg \tag{4}
\]

By reducing the right and left sides of these differential equations to mass \( m \) and integrating them once in time, we obtain the following equations:

\[
u_{y2} = c_1, v_{y2} = -gt + c_2 \tag{5}
\]

Here we determine the integral constants \( c_1 \) and \( c_2 \) from the following initial conditions.

At the beginning of the curvilinear movement, i.e. while \( t = 0 \), the piece of cotton:

- curvilinear velocities (3) satisfy the initial conditions;
- \((x_2, y_2)\)The displacements of the curvilinear motion at 0 coordinates are equal to 0.

Substituting the initial conditions for the above equations (4), we obtain the following equations

\[
dx_2 \over dt_2 = v_2C \cos \alpha, dy_2 \over dt_2 = v_2C \sin \alpha - gt \tag{6}
\]

Integrating the generated expressions again, we obtain the following results

\[
x_2(t) = v_2Ct \cos \alpha, y_2(t) = v_2Ct \sin \alpha - gt^2 \over 2 \tag{7}
\]
Using the obtained solutions we determine the analytical expression of the function of the trajectory of the curvilinear motion of the cotton mass \( y_2 = y_2(x_2) \)

\[
y_2 = x_2 t g \alpha - \frac{g x_2^2}{2 u_c^2 \cos^2 \alpha}
\]

This solution allows you to determine the values of \( y_2 \) functions that correspond to the arbitrary values of the \( x_2 \) argument.

2.3. Consider the geometric dimensions of the cotton pieces

In the above study, the mass of moving cotton pieces was considered to be a material point equal to \( m \). In fact, cotton pieces have different mass, density, composition and geometric dimensions. The geometric dimensions of the pieces change (shrink) as a result of the interaction of the cylinders with the sweaters. Therefore, large-sized cotton pieces move mainly around the second cylinder.

Assume that the cross section of the piece of cotton in question consists of a rectangle with width \( b \) and height \( h \) (figure 4).

Numerous experiments were performed to theoretically evaluate the effects of the geometric dimensions of the cotton pieces on the movement inside the vibrating cylinder. Tables 1 and 2 show the parameters of movement of cotton pieces with a height of \( h = 50,75,100,125 \ mm \) in the ripping area.

![Figure 4. Section of a piece of cotton with height \( h \).](image)

The main purpose of the experiments was to determine at what angle when the cotton pieces were struck by the second cylinder pegs with a horizontal axis, the movement would touch the top wall of the machine and fall on the third cylinder without changing the trajectory. Based on this, the following conditions were taken into account when selecting the values of the “input” and “output” parameters included in the calculation algorithm. That is, so that the piece of cotton falls to the intended coordinate of the third cylinder under the influence of the second cylinder peg stroke:

In the horizontal direction must cross the distance:

\[
(x_2)_{\text{MAX}} = L_{OM} = 425 \ mm
\]  

In the vertical direction without touching the fixed wall at the top of the machine required to move in the interval.

\[
0 < (y_2)_{\text{MAX}} \leq L_{TT} = 150 \ mm
\]  

We determine the parameters that ensure that the trajectory of impact action given by the second
cylinder peg to the vertically falling cotton piece is based on these requirements.

3. Results and discussion

3.1. Experimental results and their analysis

In all of the initial values in Table 1, the trajectory of the cotton pieces (10) is in the conditional range. That is, pieces of cotton with heights \( h = 50 \text{ mm} \) and \( h = 75 \text{ mm} \) move without touching the top wall of the grinding machine until they have covered a distance of \( x_2 = 425 \text{ mm} \).

In the data in Table 2 (10) there are cases of violation of the conditions. For example, if a piece of cotton with a height of \( h = 100 \text{ mm} \) is struck at an angle of \( \alpha = 12^\circ \), it will increase in distance when it reaches \( y_2 = 149.26 \text{ mm} \) in the horizontal direction. At subsequent values, a piece of cotton touches the top wall, changing the trajectory of the movement.

When a piece of cotton of height \( h = 125 \text{ mm} \) is struck at an angle of \( \alpha \geq 8^\circ \), the upper layers of the piece of cotton change the trajectory of motion by touching the fixed wall long before it reaches the third cylinder.

When the data from Table 2 reach the third cylinder, i.e., when the distance \( x_2 = 425 \text{ mm} \) is traversed, the cotton pieces are forged

- \( \alpha = 8^\circ \) in the vertical direction when given at an angle of \( y_2 = 152.53 \text{ mm} \);
- \( \alpha = 10^\circ \) in the vertical direction when given at an angle of \( y_2 = 167.20 \text{ mm} \);
- \( \alpha = 12^\circ \) indicates that it is moving at a distance of \( y_2 = 181.98 \text{ mm} \) in the vertical direction when given at an angle.

Thus, if the tattoo is given to cotton pieces with geometric dimensions \( 100 \leq h \leq 125 \text{ mm} \) at an angle of \( \alpha \geq 10^\circ \), they will change the trajectory of motion by touching the top wall, and the above-mentioned defects in the work of the machine will appear.

Table 1. Dependence of the trajectory of movement of cotton pieces on the direction of impact of the cylinder ripping.

| \( x_2 \text{ mm} \) | \( h = 50 \text{ mm} \) | \( h = 75 \text{ mm} \) |
|-----------------|------------------|------------------|
|                 | \( \alpha = 8^\circ \) | \( \alpha = 10^\circ \) | \( \alpha = 12^\circ \) | \( \alpha = 8^\circ \) | \( \alpha = 10^\circ \) | \( \alpha = 12^\circ \) |
| 220             | 72.271            | 80.043            | 87.890            | 97.271            | 105.04            | 112.89            |
| 240             | 73.439            | 81.909            | 90.458            | 98.439            | 106.90            | 115.45            |
| 260             | 74.465            | 83.631            | 92.879            | 99.465            | 108.63            | 117.87            |
| 280             | 75.348            | 85.208            | 95.153            | 100.34            | 110.20            | 120.15            |
| 300             | 76.089            | 86.641            | 97.282            | 101.08            | 111.64            | 122.28            |
| 320             | 76.687            | 87.929            | 99.264            | 101.68            | 112.92            | 124.26            |
| 340             | 77.142            | 89.074            | 101.10            | 102.14            | 114.07            | 126.10            |
| 360             | 77.454            | 90.074            | 102.79            | 102.45            | 115.07            | 127.79            |
| 380             | 77.624            | 90.930            | 104.33            | 102.62            | 115.93            | 129.33            |
| 400             | 77.651            | 91.641            | 105.73            | 102.65            | 116.64            | 130.73            |
| 420             | 77.536            | 92.208            | 106.98            | 102.53            | 117.20            | 131.98            |
| 440             | 77.278            | 92.632            | 108.08            | 102.27            | 117.63            | 133.08            |
Table 2. Dependence of the trajectory of movement of cotton pieces on the direction of impact of the cylinder ripping.

| $x_2$ mm | $\alpha = 8^\circ$ | $\alpha = 10^\circ$ | $\alpha = 12^\circ$ | $\alpha = 8^\circ$ | $\alpha = 10^\circ$ | $\alpha = 12^\circ$ |
|----------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|          | $h = 50$ mm        | $h = 75$ mm        |                    |                    |                    |                    |
| 220      | 122.27             | 130.04             | 137.89             | 147.27             | 155.04             | 162.89             |
| 240      | 123.43             | 131.90             | 140.45             | 148.43             | 156.90             | 165.45             |
| 260      | 124.46             | 133.63             | 142.87             | 149.46             | 158.63             | 167.87             |
| 280      | 125.34             | 135.20             | 145.15             | 150.34             | 160.20             | 170.15             |
| 300      | 126.08             | 136.64             | 147.28             | 151.08             | 161.64             | 172.28             |
| 320      | 126.68             | 137.92             | 149.26             | 151.68             | 162.92             | 174.26             |
| 340      | 127.14             | 139.07             | 151.10             | 152.14             | 164.07             | 176.10             |
| 360      | 127.45             | 140.07             | 152.79             | 152.45             | 165.07             | 177.79             |
| 380      | 127.62             | 140.93             | 154.33             | 152.62             | 165.93             | 179.33             |
| 400      | 127.65             | 141.64             | 155.73             | 152.65             | 166.64             | 180.73             |
| 420      | 127.53             | 142.20             | 156.98             | 152.53             | 167.20             | 181.98             |
| 440      | 127.27             | 142.63             | 158.08             | 152.27             | 167.63             | 183.08             |

4. Conclusion
Theoretical research and experimental tests performed. The results made it possible to determine the dimensions of the cotton piece on the trajectory of movement, the impact angle of the cylinder piles relative to the horizontal axis, the distances between the top wall of the pile cylinder cleaner. Depending on the size of the cotton pieces to be cleaned, the top of the cleaner based on the conditions of movement with or without touching the wall.

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