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A Theoretical Study of the Separation of Raw Cotton from Air Flow Under the Influence of Centrifugal Force

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A B S T R A C T

This article is about the improvement of the separator structure, which separates the cotton from the air stream after the delivery of raw cotton to the technological processes in air ginneries, in which an effective method is proposed compared to previous analogues. This is discusses the process of separating raw cotton from air flow using centrifugal force and its mathematical laws. The trajectories of the movement of cotton in the proposed device were also determined and the corresponding graphs were obtained.

1. INTRODUCTION

In ginneries, raw cotton is transported by screw using air currents. In these cases, an important role will be played by the separation process, that is, the separation of cotton from the air stream [1].

In theoretical terms, the study of the separation process remains completely unsolved.

The authors proposed a separator device in the form of a cylindrical cone base on centrifugal force [2]. This device allows you to easily remove raw cotton from the air stream, and it is also possible to clean them from small rubbish. For the rhythmic operation of this device, it is important to study the dependence and speed of movement of raw cotton with active litter that enters the device [3].

It is known that the air flow that enters the device, the more it circulates on the wall of the separator, the more quarrels in the raw cotton are removed [4]. In addition, the effectiveness of this process depends on the speed of the incoming air flow [5].

2. A MATHEMATICAL MODEL OF THE MOVEMENT OF RAW COTTON IN THE DEVICE

The structural structure of the pneumatic separator, reduced (Fig. 1) and analyze the theoretical movement of the cotton ball in the working chamber. In this case, a lump of cotton is considered as a material point with mass - *m*.

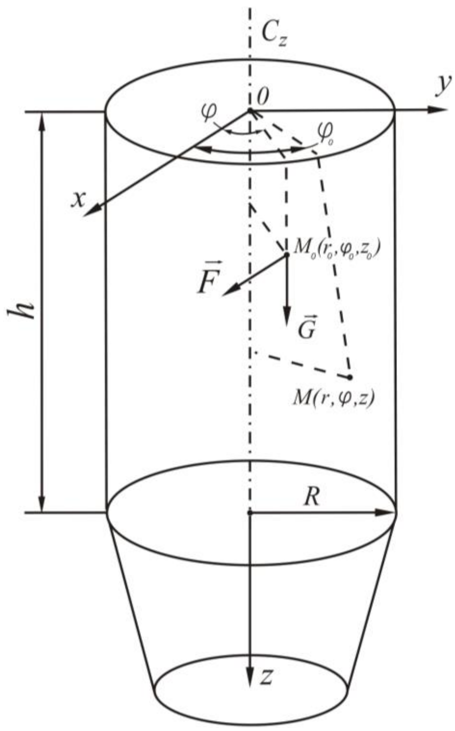


Fig. 1. Scheme of the movement of the mass of cotton in the working chamber of the separator.

Consider the movement of cotton along the inside of the working chamber of the cylinder. The axis of the cylinder is vertically directed downward. Start coordinate the position on the cylinder axis at point 0. Coordinates *x, y* - are directed along the cross sections of the cylinder sections.
The force of gravity acts on the cotton $\vec{G} = m\vec{g}$, and the aerodynamic force of the air flow $\vec{F}$.

We pass to the cylindrical coordinates:

$$x = r\cos\phi;\ y = r\sin\phi;\ z = z. \quad (1)$$

Here *x, y, z* are considered as coordinates.

We equalize the movement of cotton in the "Lagrange equation of the second kind".

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

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{\varphi}}\right) - \frac{\partial T}{\partial \varphi} = Q_\varphi \quad (2)$$

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{z}}\right) - \frac{\partial T}{\partial z} = Q_z$$

where:

T- is the kinetic energy of the material point, the expression of which is equal to:

$$T = \frac{1}{2}m\left(\dot{r}^2 + r\dot{\varphi}^2 + \dot{z}^2\right) \quad (3)$$

Q_r, Q_φ, Q_z - generalized forces.

Forces, air flow resistances acting on a material point has the following form.

$$\vec{F} = F_r \cdot \vec{e}_r + F_\varphi \cdot \vec{e}_\varphi + F_z \cdot \vec{e}_z \quad (4)$$

where:

F_r, F_φ, F_z is the correspondence of the projection force $\vec{F}$ on the coordinate axes, $\vec{e}_r, \vec{e}_\varphi, \vec{e}_z$ are unit vectors.

If the guides *α, β, γ* are the coals between the force and the form *x, y, z* are wasps, then F_r, F_φ, F_z - have the following form.

$$F_r = |F| \cdot \cos\alpha$$

$$F_\varphi = |F| \cdot \cos\beta$$

$$F_z = |F| \cdot \cos\gamma$$

Let the force air resistance be proportional to the square of the mass velocity. ($\upsilon_r, \upsilon_\varphi, \upsilon_z$ - projections of the air velocity along the axis, *r, φ* and *z*).
In this case we have:

$$|\vec{F}| = c \cdot \rho \cdot \frac{S_0}{2}\left[(\upsilon_r - \dot{r})^2 + (\upsilon_\varphi - r\dot{\varphi})^2 + (\upsilon_z - \dot{z})^2\right]$$

Then the components of the vector $\vec{F}$ along the coordinate axis are calculated by the following formulas.

$$Q_r = F_r = \frac{c\rho S}{2}\cdot(\upsilon_r - \dot{r})\cdot F_0$$

$$Q_\varphi = F_\varphi = \frac{c\rho S}{2}\cdot(\upsilon_\varphi - r\dot{\varphi})\cdot F_0 \qquad (5)$$

$$Q_z = F_z = \frac{c\rho S}{2}\cdot(\upsilon_z - \dot{z})\cdot F_0$$

here:

$$F_0 = \sqrt{(\upsilon_r - \dot{r})^2 + (\upsilon_\varphi - r\dot{\varphi})^2 + (\upsilon_z - \dot{z})^2}$$

Substitute from formula (3) - m and Q_r, Q_φ, Q_z from formula (5) (4) to (2) - formula to form the following system of differential equations of motion for determining *r*, *φ*, *z*:

$$\begin{cases} \ddot{r} = r\cdot\dot{\varphi}^2 + \dfrac{c\cdot S_0}{2\cdot m}\cdot(\upsilon_r - \dot{r})\cdot F_0 \\ \ddot{\varphi} = -\dfrac{2\dot{r}\dot{\varphi}}{r} + \dfrac{c\cdot S_0}{2\cdot m\cdot r^2}\cdot(\upsilon_\varphi - r\cdot\dot{\varphi}^2)\cdot F_0 \\ \ddot{z} = \dfrac{c\cdot S_0}{2\cdot m}(\upsilon_z - \dot{z})\cdot F_0 + g \end{cases} \qquad (6)$$

where:

r - is the radius of the cotton inlet material point on the working chamber of the aerodynamic separator, *m;*

φ - the angle of rotation of the clump of cotton around the axis - *oz*, radian;

z - horizontal axis, *m;*

$\upsilon_r, \upsilon_\varphi, \upsilon_z$ - components of the air velocity vector, *m/s;*

m - mass of cotton ball, *kg;*

g - acceleration of gravity, *m/s²;*

c - is the coefficient of resistance to air flow for a lump of cotton (calculated $c \approx 65$);

S_0 - cross-sectional area of a slow cotton lump m^2.

Using the system of equations (6), we determine the trajectory and speed of movement of the cotton mass along the inner walls of the device. To do this, we set the time when the mass of cotton reaches the inner surface of the cylinder with $t=t_0$, so that the mass of cotton $t>t_0$ moves along the wall. To do this, we compose this differential equation, the law of motion:

$$\begin{cases} \ddot{\varphi} = Q_\varphi - fQ_r \\ \ddot{Z} = Q_z - fQ_r + g \end{cases} \qquad (7)$$

Where:

$$Q_\varphi = \frac{c\rho s_0}{2m}(\upsilon_\varphi - r\dot{\varphi})F_0$$

$$Q_r = \frac{c\rho s_0}{2m}(\upsilon_r - \dot{r})F_0$$

$$Q_z = \frac{c\rho s}{2m}(\upsilon_z - \dot{z})F_0$$

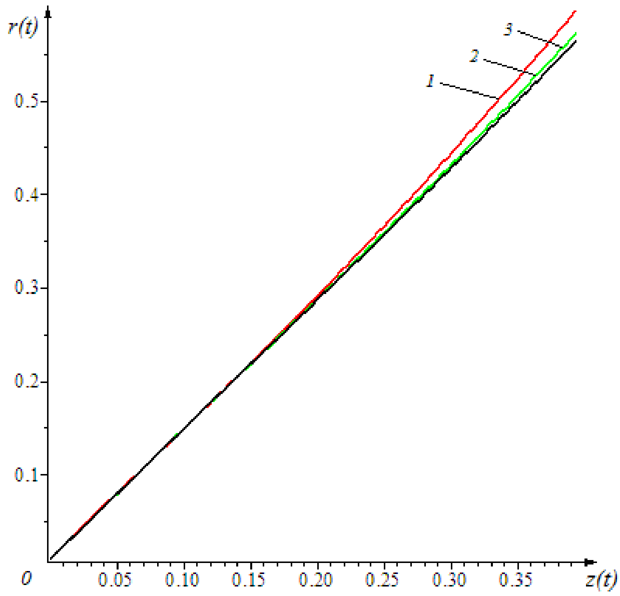
$$F_0 = F_1 = \sqrt{(\upsilon_\varphi - r\dot{\varphi})^2 + (\upsilon_z - \dot{z})^2} = \sqrt{(r\dot{\varphi})^2 + \dot{z}^2)}$$

We calculate equations (6) and (7) together using Maple-17. The total flow of air entering the device is $\upsilon_0 = \sqrt{\upsilon_r^2 + \upsilon_\varphi^2 + \upsilon_z^2}$ *m/s*. We determine the duration of the impact of the cotton ball and the air flow along the walls of the device in a perpendicular form.

3. THE METHOD OF SOLVING THE PROBLEM

To solve the problem, we performed calculations using the MAPLE-17 program. This program is designed to solve engineering problems, with the help of which there are opportunities to perform calculations in the departments of elementary mathematics, higher mathematics. Formulas (6) and (7) represent the differential equations of helical motion of a cotton ball inside a pneumatic separator [3]. These equations are solved by numerical methods in the initial conditions using the MAPLE-17 program. The corresponding results are shown in Figure 2÷9 in the form of graphs.

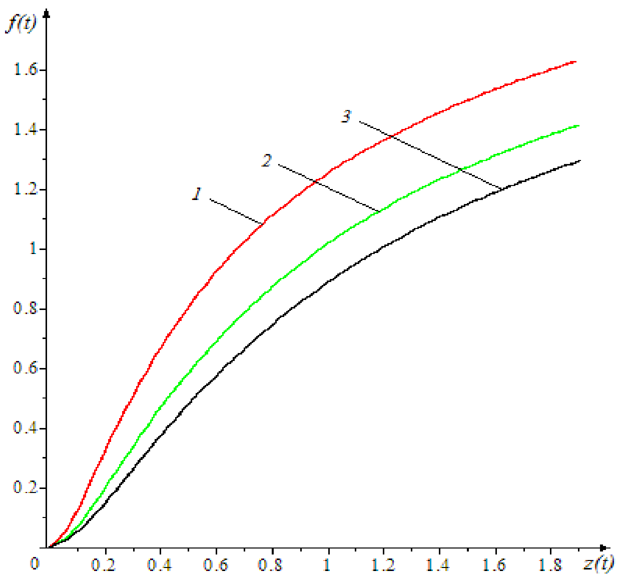
On the graphs 1÷3 (Fig. 2) shows the movement of the trajectory of cotton depending on the mass entering the pneumatic separator. In this case, clumps of raw cotton move to the base according to the law of straight lines. Lumps of raw cotton that are lighter in weight hit the inner wall of the cylinder faster than heavier masses. At an average time *t*=0,028 second, a lump of raw cotton reaches the cylinder wall.



1 - m = *0,02* kg, *2* - m = *0,04* kg, *3* - m = *0,06* kg

Fig. 2. The trajectory of raw cotton in the pneumatic separator along the radii of the cylinder, depending on the coordinates - *z*.

This impact occurs at a distance of *H*=0,35 *m* from the top of the device. After the clumps of raw cotton collide with the wall of the device, and make a circular motion along the wall and continue to move down. We can say that the greater the mass, the longer it takes to get to the wall of the device. At *H*=0,35 *m*, clumps of raw cotton hit the inner wall of the separator and continue to move down a circular path, rubbing into the cylinder wall.

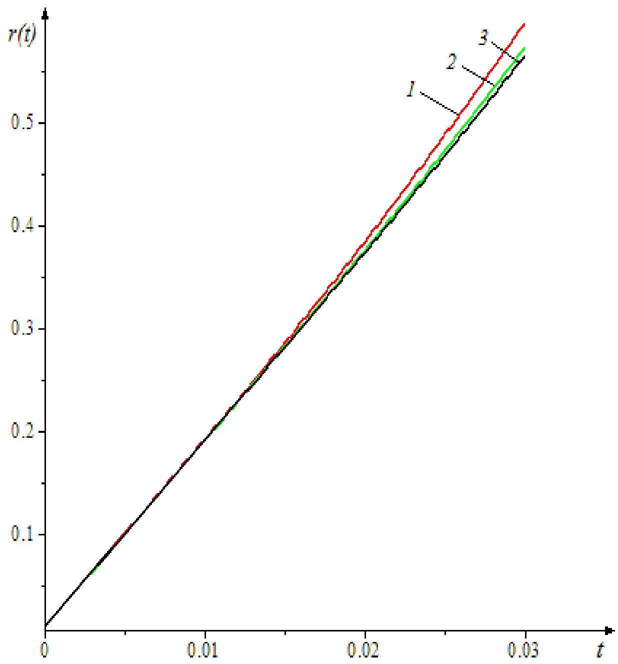


1 - m = *0,02* kg, *2* - m = *0,04* kg, *3* - m = *0,06* kg

Fig. 3. Change in the trajectory of rotation of raw cotton in a pneumatic separator with a dependence with vertical height.

As can be seen from the graphs 1÷3 in (Fig. 3), the clump of cotton makes a rotational movement, dependent on the axis of names, according to the law $\varphi=\varphi(t)$. In this case, the trajectory is described by a crooked line. The larger the mass of cotton, the smaller the angle - $\varphi(t)$ varies along the axis of the cylinder entering the cylinder - *z*.

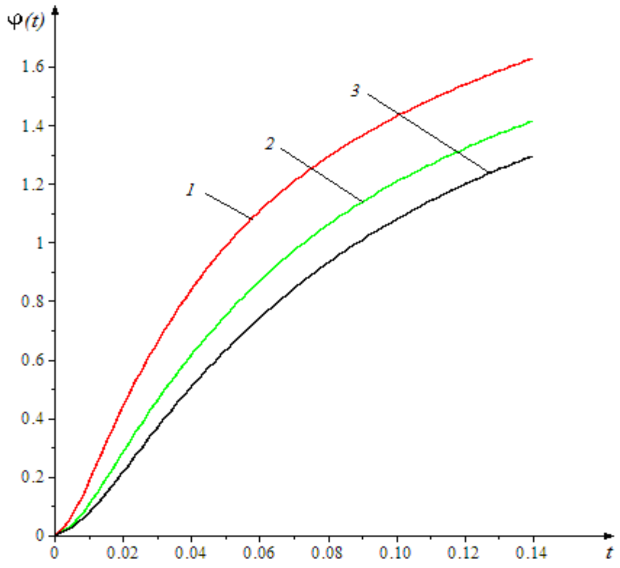
We can conclude that the larger the mass, the smaller the radial angle at which it rotates. It can be seen that the smaller the mass, the greater the radial angle of rotation of the rotational movement along the vertical axis. In just 0,14 seconds, a clump of raw cotton reaches the bottom of the device, and then proceed to the next process. During this time, clumps of raw cotton move 1,8 *m* vertically along the inner walls of the cylinder, making a rotational movement at an angle of 1,6 radians.



1 - m = *0,02* kg, *2* - m = *0,04* kg, *3* - m = *0,06* kg

Fig. 4. Dependence of the trajectory of the movement of raw cotton on time in a pneumatic separator in the direction of the radius of the cylinder.

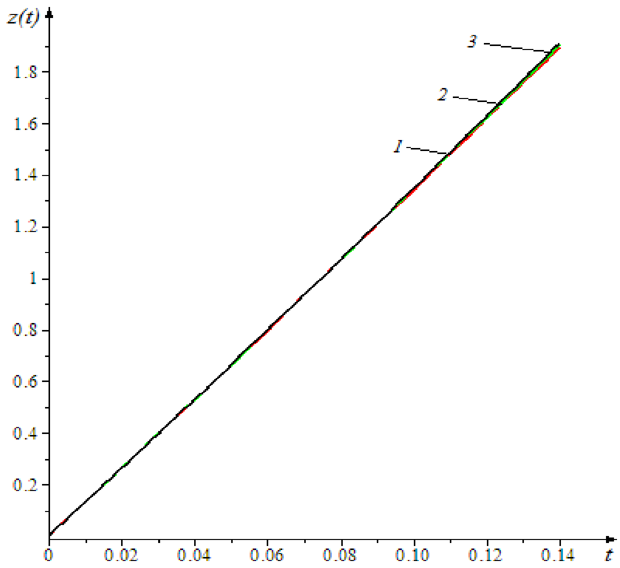
The graph in (Fig. 4) shows *t* - the time the trajectory moves along the radius, depending on the mass of cotton lumps entering the pneumatic transport. Based on this, it can be indicated that a lump of raw cotton hit the inner wall of the cylinder with a radius of t=0.035 second. In this case, light lumps of raw cotton reach the inner wall faster than the rest.



1 - m = *0,02* kg, *2* - m = *0,04* kg, *3* - m = *0,06* kg

Fig. 5. The change in the trajectory of the angular movement of raw cotton versus time in a pneumatic separator, depending on the height of the angle of rotation in the cylinder.

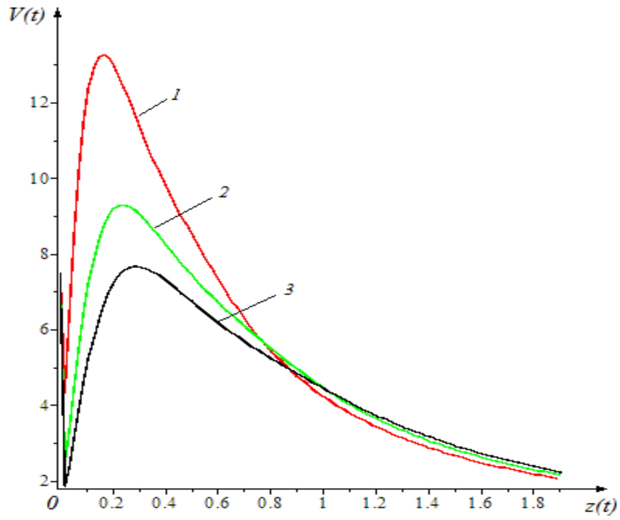
In the graph of (Fig. 5), you can see clumps of raw cotton entering the pneumatic separator depending on the size of the mass, make a trajectory of rotational motion, while light clumps of raw cotton create a more trajectory of rotational motion than heavy masses.



1 - m = *0,02* kg, *2* - m = *0,04* kg, *3* - m = *0,06* kg

Fig. 6. The change in the trajectory of the movement of raw cotton from time to time in a pneumatic separator depending on the height of the cylinder.

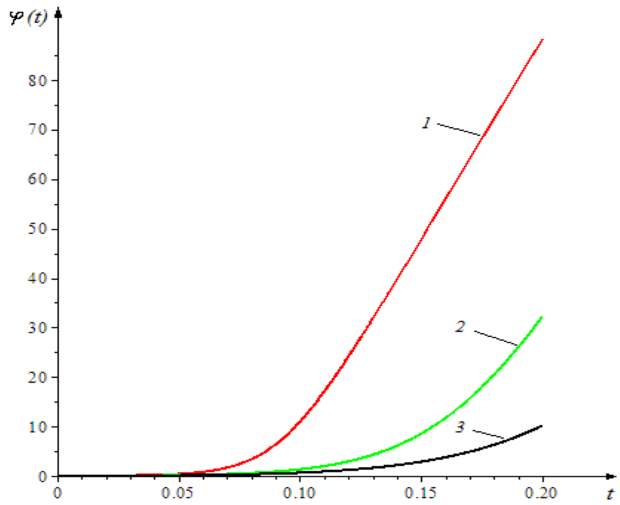
1÷6 of the graph in (Fig. 6) shows the change in the movement of the trajectory along the *z* axis with respect to time *t*, depending on the mass of lumps of raw cotton entering the transport. However, the time to reach the clump of cotton edges of the device is *t*=0,12÷0,14 seconds.



1 - m = *0,02* kg, *2* - m = *0,04* kg, *3* - m = *0,06* kg

Fig. 7. Linear trajectory of the rotational movement of the cotton ball inside the pneumatic separator depending on the vertical height.

We can say that cotton lumps follow the same trajectory during vertical movement, regardless of their mass. In the graphs in (Fig. 7) shows the trajectory of the rotational speeds along the vertical axis, depending on the mass of cotton particles entering the pneumatic separator. It can be concluded that the larger the mass, the greater its linear velocity and maximum value when the cylinder hits. Then their speed changes according to the law of decreasing.

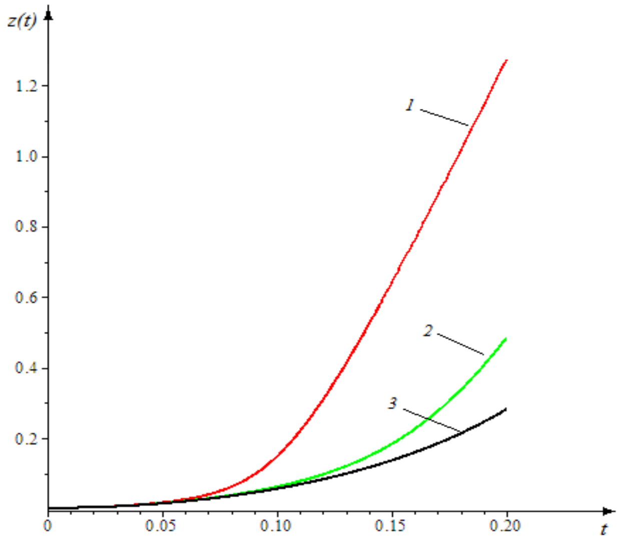


1 - m = *0,02* kg, *2* - m = *0,04* kg, *3* - m = *0,06* kg

Fig. 8. Trajectories of screw movement of cotton lumps along the inner walls of the pneumatic separator depending on the tilt time.

In the graphs in (Fig. 8) light clumps of cotton move along the inner walls of the cylinder in a circular motion 15-20 times and go to the next process.

In particular, lumps of cotton weighing m=0,02 *kg* 17 times, m=0,04 *kg* of cotton 6 times, m=0,06 *kg* and 1,5-2 times in circular motions.



1 - m = *0,02* kg, *2* - m = *0,04* kg, *3* - m = *0,06* kg

Fig. 9. Trajectories of the clump of cotton from top to bottom in the vertical direction along the inner walls of the pneumatic separator.

As can be seen from the graphs in (Fig. 9), light lumps of cotton move along the inner walls of the cylinder in a vertical direction from top to bottom, and heavy cotton lumps of a 3-line move slowly and go to the next process.

4. CONCLUSIONS

1. A pneumatic separator is proposed for separating air from cotton and a theoretical study is made of the movement of raw cotton.
2. Differential equations that were generated using a mathematical model of the rotational motion of raw cotton inside the device were solved numerically using the MAPLE-17 software.
3. Graphs of the trajectory of the rotational movement were obtained, depending on time along the radius of the cylinder of the device, as well as the angle of rotation.
4. The time of impact of the clumps of raw cotton on the cylinder wall was determined, and the vertical motion of the fall along the direction along the axis of the cylinder was calculated.
5. Specifically, the time the cotton ball gets on the cylinder wall of the device and the time of the vertical direction along the axis of the cylinder.
6. It was found that the separation process is easier when the lump of cotton in the device is around the corner $\alpha = 20^0$, and not horizontally.
7. The centrifugal separation method of cotton raw materials is more effective than previous technological processes, preventing damage to seeds and fibers, thereby preserving their natural characteristics.
8. Calculations show that light-mass quarrels move along the inner surface of the cylinder according to a helical law. This, in turn, allows the separation of small quarrels from cotton and with the help of a mesh surface is separated from the cotton.

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