Study of the movement of raw cotton on the surface of an inclined peg

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Abstract. The article presents a study of the raw cotton movement on the surface of a throwing drum with inclined spikes of a saw gin. The considered system consists of two separate sections. The interaction of cotton with actuating tools in the first section takes place on the surface of the spike of the throwing drum, and in the second section, it occurs with separation from the spikes of the throwing drum until it hits the blade of the saw cylinder. It was determined that with an increase in ω, the path and time for the passage of raw cotton along the surface of the spike of the throwing drum decreased while the angle and height of the cotton hit on the surface of the saw cylinder increased. As a result of studying the kinematics and size of the saw gin throwing drum using the raw cotton movement, the relative velocity of cotton in the falling zone was 0.2667 m/s at an angle of 114º relative to the drum.

1 Introduction

In modern conditions of development of machinery and technology for raw cotton processing, the issues of resource saving, improving product quality, and reducing production costs for the full cycle of processing raw materials are of particular importance.

A common distinguishing feature of saw gins produced in the U.S. firms from domestic technologies is the absence of seed tubes in working chambers and throwing drums in peeling chambers, as well as the use of saw blades of a diameter of 406 mm. In this regard, the problem of developing a saw gin with a seed tube and a throwing drum with saw blades of a diameter of 320 mm is very relevant.

In [1], the movement of raw cotton on the surface of the spike of the throwing drum was studied and its diameter (210 mm), frequency of rotation (62.83 s^{-1}), productivity (1587 kg/h) and the angle of fall of cotton on the surface of the spike of the throwing drum (φ_o =60º), which provide improved loosening, cleaning and uniform supply of raw cotton to the saw cylinder were determined. However, the use of these results leads to an increase in the size and weight of the working chamber, and high-power consumption.

The studies by A. Juraev and K.Kh. Abdullaev [2] contain data on the development and substantiation of the parameters of the spike drum of the gin feeder in order to increase the

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efficiency of loosening and cleaning the fiber material due to the monotonous pattern of the impact; the studies define the interaction of the (inclined) spike and raw cotton pappus.

To reduce the size and the weight of the working chamber, and power consumption, a throwing drum with inclined spikes can be used [3]. To do this, it is necessary to study the trajectory of the movement of raw cotton, the kinematics (rotation frequency and diameter) of the throwing drum, and its location relative to the saw cylinder, the movement of the mass of raw cotton on the surface of the spike of the throwing drum and with separation from it until it hits the teeth of the blades of saw cylinders. The saw cylinder consists of a shaft, saw blades, and saw gaskets, which are assembled by tightening washers and nuts on both sides [4-6].

2 Materials and methods

The calculated schemes of the considered system consist of two separate sections. The interaction of cotton with the working bodies in the first of them (Figure 1) takes place on the surface of the spike of the throwing drum, and in the second section (Figure 2), it occurs with separation from the spike of the throwing drum until it hits the saw cylinder blade.

The calculated scheme of the raw cotton movement on the surface of the drum spike (see Figure 1) consists of mass *m* located on the surface of a spike drum rotating at a constant angular velocity, which has radius *R* and initial angle φ_o, and displacement *S* relative to it in time *t*.

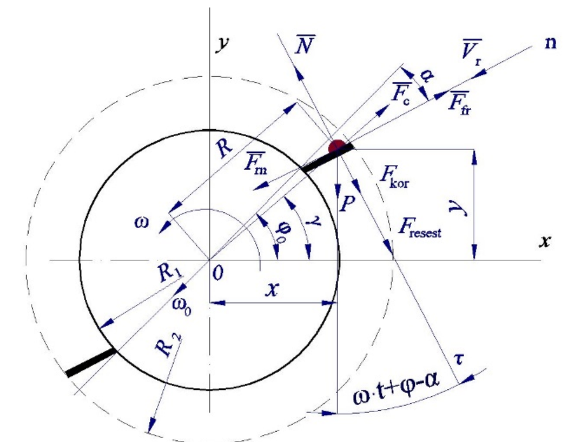

Fig. 1. Calculated scheme of cotton movement on the surface of the drum spike.

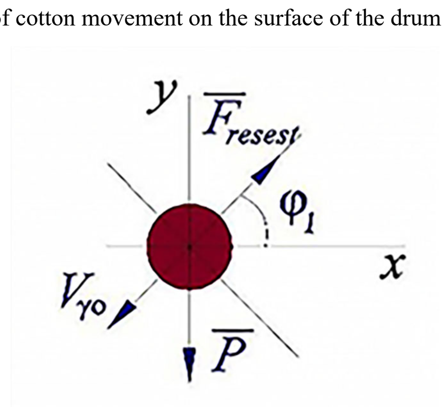

Fig. 2. Calculated scheme of cotton movement with separation from the drum spike.

Let us denote the angle of the cotton gripping by the spike drum by φ_o, and the angle of falling - by φ_1. We assume that the mass of raw cotton in the process of movement changes insignificantly, and the amount of litter and weedy impurities removed with the air can be ignored due to their smallness (the number of impurities of raw cotton of I–III varieties is 3–5%).

We choose a fixed coordinate system with the origin at point O and denote it by XOY. The moving and relative coordinate systems are selected with the origin at point O_1 on the drum. The $O_1\tau$-axis is directed along a tangent line 90º-α to the diameter (α is the angle of inclination of the spike relative to the radial axis). Clockwise rotation is taken as a positive direction, the O_1n-axis is perpendicular to the $O_1\tau$-axis, of the coordinate system $\tau\ O_1\ n$, rigidly connected to the drum and, therefore, rotated with it at a constant angular velocity ω.

The mass of cotton lying on the spike of the drum is considered a solid rectangle with sides $S_{rect}= l_{work}\times L$, where l_{work} – is the working length of the drum; L is the height of the spike. It is assumed that it is concentrated in the center of the rectangle and, depending on the productivity, the thickness of the cotton layer, which was chosen for Π = 1200 kg/h, Δ_{av} = 0.0166 m (it depends on the density of raw cotton and the overall dimensions of the gin) changes.

The following forces act on the cotton mass [1]: $P=m\cdot g$ – cotton weight, N; $F_c=m\cdot R\cdot\omega^2$ – centrifugal force, N; $F_{fr}=K_{fr}\cdot N$ – friction force of cotton on the surface of the spike, N; N - normal reaction force, H; $F_{resist\ r}=K^*\cdot v^2$ – air flow resistance force, N; where $v=\omega\cdot R$ – is the absolute air flow velocity, m/s; $\omega=\pi\cdot n/30$ - angular velocity of the spike drum, rad/s; $n=30\cdot\omega/\pi$, min^{-1} – frequency of rotation of the spike drum; K^* – coefficient of proportionality; $K_{fr}=0,3$ – coefficient of friction between raw cotton and spike drums; $V_s=0,6\cdot V_{air}$ – hovering velocity, m/s; V_{ro} - relative velocity of the spike drum and cotton before falling onto the spike of the drum, m/s [7-8].

Let us derive the equation of dynamics of a material point

$$m\cdot\overline{W}=\overline{F_{fr}}+\overline{P}+\overline{F_{ц}}+\overline{F_{resist}}+\overline{N}\,. \tag{1}$$

Since $\overline{W}=\overline{W_{rn}}+\overline{W_{r\tau}}+\overline{W_{en}}+\overline{W_{e\tau}}+\overline{W_{kor}}$, then for the relative motion we obtain

$$m\cdot\overline{W_{r\tau}}=-m\cdot\overline{W_{rn}}-m\cdot\overline{W_{en}}-m\cdot\overline{W_{kor}}+\overline{F_{fr}}+\overline{P}+\overline{F_c}+\overline{F_{resist}}+\overline{N} \tag{2}$$

where $\overline{W_{kor}}=2\cdot\omega\cdot\dot{s};\dot{s}=ds/dt$ is the velocity of relative movement of raw cotton, m/s; $\overline{W_{rn}}=\dot{s}^2/R$; $\overline{W_{e\tau}}$ is the tangential acceleration in translational motion, equal to zero, since $\dot{\omega}$=const.

Projecting equation (2) onto the $O_1\tau$-axis (see Figure 1), we obtain

$$N+m\cdot\omega^2\cdot R\cdot\sin\gamma-K^*\cdot(\omega\cdot R)^2-2\cdot m\cdot\omega\cdot\dot{s}-m\cdot g\cdot\sin(\omega\cdot t+\varphi_o-\alpha)=0\,. \tag{3}$$

Hence, we find the normal reaction

$$N=K^*\cdot(\omega\cdot R)^2+2\cdot m\cdot\omega\cdot\dot{s}+m\cdot g\cdot\sin(\omega\cdot t+\varphi_o-\alpha)-m\cdot\omega^2\cdot R\cdot\sin\gamma\,. \tag{4}$$

Projecting (2) onto the O_1n -axis (see Figure 1) and reducing the weight of cotton, we obtain the equation for the relative motion of cotton over the surface of the spike drum

$$\ddot{s}=\frac{d^2s}{dt^2}=K_{fr}\cdot\left[\frac{K^*\cdot(\omega\cdot R)^2}{m}+2\cdot\omega\cdot\dot{s}+g\cdot sin(\omega\cdot t+\phi_o-\alpha)-\omega^2\cdot R\cdot sin\gamma\right]-\frac{\dot{s}^2}{R}-g\cdot cos(\omega\cdot t+\phi_o-\alpha)+\omega^2\cdot R\cdot cos\gamma. \tag{5}$$

The absolute value of the trajectory of cotton movement was determined by equation $L'=L'+s$ at different angles $(\omega\cdot t+\varphi_o-\alpha)$, and in coordinates – by equations $x=R_1\cdot cos(\omega\cdot t+\varphi_o)+L\cdot cos(\omega\cdot t+\varphi_o-\alpha)$ and $y=R_1\cdot sin(\omega\cdot t+\varphi_o)+L\cdot sin(\omega\cdot t+\varphi_o-\alpha)$. In this case, the value of $R\neq const$ for equation (5) is determined from expression $R=\sqrt{x^2+y^2}$, and the angle from $\gamma=arctg\ y/x$ (see Figure 1).

When solving equation (5) for the first part (section) of the movement of raw cotton on the spike of the drum, for $L<L'$, the solution to equation (5) ceased; this corresponded to the separation of raw cotton from the surface of the drum spike.

Here Δ_a=0.018 m is the distance between the spike drum and the rib grate; Δ_x=0.2365 m is the distance between the axes of the drum and the saw cylinder along the *X*-axis; Δ_y=0.08969 m is the distance between the axes of the drum and the saw cylinder along the *Y*-axis; L' is the equation of motion of cotton, which takes place on the surface of the drum spike as a function of the angle of rotation; R_1 is the radius of the throwing drum without spike tops; R_2 is the radius of the throwing drum with the tops of the spike.

The calculated scheme for the movement of cotton with separation from the drum spike (see Figure 2) consists of mass m thrown from the surface of the drum spike at velocity V_{ro} at a fall angle of $\varphi_1(\omega \cdot t+\varphi_o)$ to the horizontal axis, and displacement S in time t.

We choose a fixed coordinate system with the origin at fixed point O and denote it by *XOY*. There are two forces acting on the raw cotton: the force of gravity $\overline{P}$, directed vertically downwards, and the airflow resistance force $\overline{F_{resist}}$, the direction of which is opposite to the direction of velocity V_{ro}. The resultant force is

$$m \cdot \overline{W} = \overline{P} + \overline{F_{resist}} \; . \tag{6}$$

Assuming that in the selected position of the point in positive values of $\overline{V}_x$ and $\overline{V}_y$, for the projections of the resultant force $m \cdot \overline{W}$ onto coordinate axes, we have

$$F_x = -(K^* \cdot V_y^2) \cdot \sin(\varphi_1); \quad F_y = -(K^* \cdot V_y^2) \cdot \cos(\varphi_1) - m \cdot g \; . \tag{7}$$

Differential equations for the relative motion of cotton are:

$$m \cdot \frac{d^2 x}{dt^2} = -(K^* \cdot V_x^2) \cdot \sin(\varphi_1); \quad m \cdot \frac{d^2 y}{dt^2} = -(K^* \cdot V_y^2) \cdot \cos(\varphi_1) - m \cdot g; \tag{8}$$

or

$$\frac{d^2 x}{dt^2} = -\frac{(K^* \cdot V_x^2) \cdot \sin(\varphi_1)}{m}; \quad \frac{d^2 y}{dt^2} = -\frac{(K^* \cdot V_y^2) \cdot \cos(\varphi_1)}{m} - g \; . \tag{9}$$

The absolute value of the cotton trajectory in coordinates is determined by equations $x=x+s$ and $y=y+s$, the angle of hit of the cotton on the blade of the saw cylinder is $\varphi_0 = arctg\left[\frac{y+\Delta_y}{x+\Delta_x}\right]$, and the length of the straight line is $L_d = \sqrt{(x+\Delta_x)^2 + (y+\Delta_y)^2}$.

When solving the system of equations (9) for the second section of the cotton movement with separation from the drum spike, for $L_d<=R$, the solution to equation (9) ceased, this corresponded to the fall of the cotton on the surface of the saw cylinder.

When solving equation (5) and system (9), the Runge–Kutta numerical method was used for a second-order differential equation of the form $\ddot{s} = d^2 s / dt^2 = F(t, s, \dot{s})$ [9-10]. Before starting the calculations, step Δt and initial values t_o, $s(t_o)=s_o$ and $\dot{s}(t_o) = \dot{s}_o$ were set.

The authors used the following initial data for a 137-saw gin, installed at the Uzbekistan cotton plant in the Tashkent region:

- constructive characteristics – l_{work}=0.55m; L=0.015m; $R_в$=0.07m; R=0.0725m; R_1=0.058m; Δ_x=0.2365m; Δ_y=0.08969m; Δ_a=0.018m; $\varphi_o=60^o$; $\alpha=60^o$;
- kinematic characteristics - – $\omega_в$=1.277 s^{-1}; ω=36.65 s^{-1}; $V_{ro}=\omega_в \cdot R_в$=0.089 m/s;
- aerodynamic characteristics – $K^*=\Delta_{av} \cdot l_{work} \cdot \omega \cdot R$=0.01216 kg/m;
- technological characteristics – ρ_v=30 kg/m^3; $s_{giv}=l_{work}\times$0.015=0.0079m^2; Π=1200 kg/h; q=0.499 kg/m^2; $m=q \cdot s_{giv}$=0.0021 kg; Δ_{ave}=0.0166m.

3 Results and discussion

Based on the computer implementation of a mathematical model of a saw gin with a throwing drum, graphs of the change in the movement of raw cotton on the surface of the drum spike were plotted depending on the angle of fall and the velocity of fall V_{ro} on the surface of the drum spike (frequency of rotation of the feed rollers and feeder productivity); on the diameter (Figure 3) and the rotational velocity of the throwing drum (Figure 4).

It was stated, that with an increase in φ_0, the path and time of the cotton passage along the surface of the spike of the throwing drum increased. Determined that with an increase in the frequency of rotation of the feed rollers, the productivity of the feeder and the path of cotton passing along the surface of the spike of the throwing drum, increase accordingly.

According to Figure 3, with an increase in the diameters of the throwing drums, the angle and height of the cotton hitting the saw cylinder increase.

It was determined (Figure 4) that with an increase in ω, the path and time of the passage of cotton along the surface of the spike of the throwing drum decreased and the angle and height of the cotton hit on the surface of the saw cylinder increased.

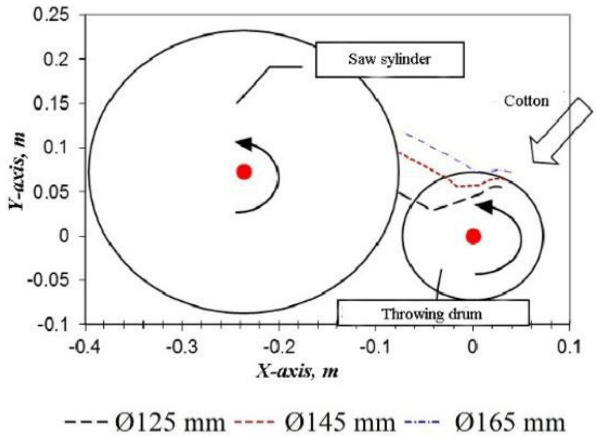

Fig. 3. Change in the trajectory of cotton depending on the diameter of the throwing drum.

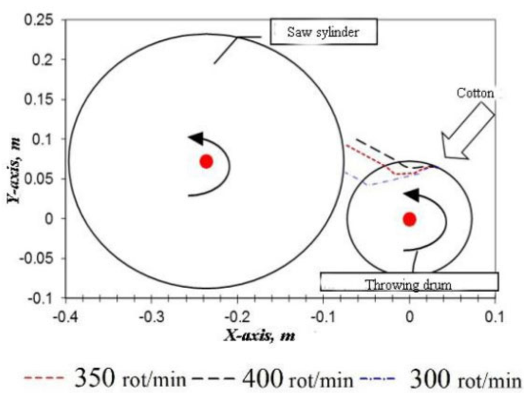

Fig. 4. Change in the trajectory of cotton depending on the rotational frequency of the throwing drum.

It was revealed that with an increase in α due to the smallness of the height of the spike (L=0.015 m), the angle and height of the cotton hit on the surface of the saw cylinder increased insignificantly.

The following parameters were taken in the study: φ_o=45–75º; Π=1000–1400 kg/h; ω=36.65–47.12s^{-1}; R=0.0625–0.0825 m; R_1=0.048–0.068 m. Determination of the rational parameters of the throwing drum was performed by the Gauss-Seidel method [11] according to the criterion of the path of reducing the shock pulse of cotton to the saw cylinder.

Analysis of Figures. 3 - 4 showed the following:

- a decrease in the angle of fall of the cotton on the surface of the throwing drum from 90° to 45° leads to an increase in the size and weight of the working chamber of the gin, in the angle of cotton hit from -11° to 7° on the surface of the saw cylinder and a decrease in the cotton velocity from 2.93 to 2.07 m/s;
- an increase in cotton productivity from 1000 to 1400 kg/h leads to a decrease in the angle of cotton hit on the surface of the saw cylinder from 5° to -4°;
- an increase in the diameter of the throwing drum from 125 to 165 mm leads to an increase in the size and weight of the working chamber of the gin and the angle of cotton hit on the surface of the saw cylinder from -15° to 12°;
- an increase in the frequency of rotation of the throwing drum from 300 to 400 rpm leads to a proportional increase in the cotton velocity up to 30% and a decrease in the angle of cotton hit from – 10° до 6°, and at a frequency below 300 rpm there is no fall of cotton from the drum spike;
- change in the angle of spike inclination insignificantly affects the pattern of raw cotton movement.

To check the reliability of theoretical studies of the law of cotton motion, we conducted experimental studies (Figure 5).

Fig. 5. Cotton movement trajectory (diameter - 145mm, rotation frequency - 350 rpm, productivity - 1200 kg/h, angle of fall of cotton on the surface of the spike of the throwing drum φ_o=60º).

4 Conclusions

As a result of studying the kinematics and size of the throwing drum of a 137-saw gin using the movement of raw cotton, the relative velocity of cotton in the falling zone was 0.2667 m/s at an angle of 114º relative to the drum. The velocity before hitting the surface of the saw cylinder was 2.562 m/s at an angle of 1º02' relative to the saw cylinder. These parameters were obtained at axis distances Δ_x=0.2365 m; Δ_y=0.08969 m, and the distances between the throwing drum (∅145) and the saw cylinder (∅320) were a_w=0.25294 m

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