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THEORETICAL STUDY RESULTS OF THE MOTION OF A COTTON LUMP AFTER IMPACT COLLISION WITH DRUM PEGS

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Abstract. The article presents a theoretical analysis of the motion patterns of cotton swabs under the influence of impact interaction with the long-pegged drums of a loosening feeder. A system of equations describing the motion trajectories has been developed.
Keywords: drum, motion, cotton lump, impact, velocity, formula, graph, trajectory.

After an impact collision of a cotton lump with a peg on the drum surface, the direction of its motion changes. The cotton lump moves between the teeth of the rotating drum. As the rotational speed increases, the cotton separates from the drum surface and transitions into free motion (flight). This phenomenon occurs when the balance between centrifugal force and gravitational force is disturbed. While moving along a circular trajectory relative to the drum surface, the cotton lump is subjected to centrifugal and gravitational forces:

$$F_m = mRw^2, \quad F_g = mg\sin\theta \qquad (1)$$

For the cotton lump to remain in motion on the drum surface, the drum must exert a sufficient normal force on it. The cotton separates from the drum if:

$$F_m > F_g, \quad mRw^2 > mg\sin\theta \quad w > \sqrt{\frac{g}{R}\sin\theta} \qquad (2)$$

This is the formula for the critical angular velocity (or critical rotational speed) required for the cotton to separate from the drum.

If the rotational speed is known, it is possible to determine the angle at which the cotton detaches from the drum. Let us rewrite the above expression in inverse form:

$$\theta_{krit} = \arcsin \frac{Rw^2}{g} \qquad (3)$$

When this condition is satisfied, the cotton leaves the drum surface and the free-flight phase begins.

The cotton lump separates from the long-pegged drum at a certain angle and with an initial velocity. This motion corresponds to the projectile motion model at an inclined angle. At this stage, if aerodynamic resistance is neglected, the motion of the cotton lump is described according to the laws of classical mechanics. The thrown cotton lump follows a parabolic trajectory. When the cotton leaves the drum, the following initial conditions are satisfied:
initial velocity and the angle of release (relative to the trajectory).

This is referred to in physics as projectile motion (throwing over a horizontal distance). The motion components [1, 2, 3]:

$$\vartheta_{x,0} = \vartheta \cos\theta,$$
$$\vartheta_{y,0} = -\vartheta \sin\theta. \quad (4)$$
$$\vartheta_x = \vartheta_{x,0} = \vartheta \cos\theta$$
$$\vartheta_y = \vartheta_{y,0} - gt = \vartheta \sin\theta - gt$$

By integrating this equation, the following expressions are obtained for the detached cotton lump in the horizontal and vertical directions, respectively:

$$x(t) = x_0 + \vartheta t \cos\theta,\ \ y(t) = y_0 + \vartheta t \cos\theta - \frac{1}{2} g t^2 \quad (5)$$

When the cotton reaches the ground $y(t) = 0$ and $y_0 = 0$ From this condition, the flight time is determined as follows:

$$t = \frac{2\vartheta_y}{g} = \frac{2\vartheta_0 \sin\theta}{g} \quad (6)$$

In horizontal motion, the velocity remains constant:

$$S = \vartheta_x t = \vartheta_0 \cos\theta \frac{2\vartheta_0 \sin\theta}{g} = \frac{\vartheta_0^2 \sin 2\theta}{g} \quad (7)$$

Substituting the initial velocity into equation (4), we obtain the following expression:

$$S = \frac{w^2 R^2 \sin 2\theta}{g} \quad (8)$$

Here: **R** – drum radius, *w* – angular velocity (rad/s).

These equations fully describe the motion of the cotton lump during its flight after separating under the influence of the drum. If the drum parameters are known under any industrial conditions, the flight distance of the cotton lump can be determined analytically or numerically using these formulas.

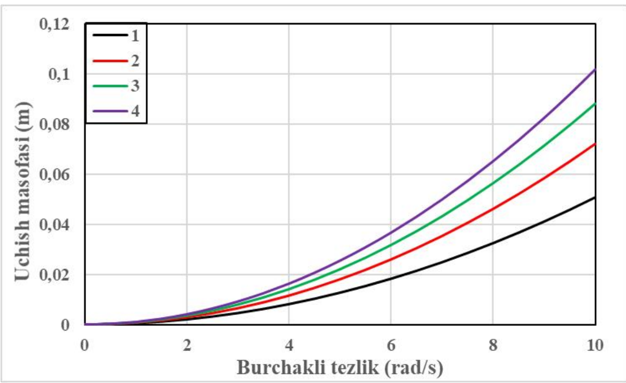

Figure 1. Graph showing the relationship between the flight distance of the cotton lump and the rotational speed of the long-pegged drum at different release angles:1 – 15°, 2 – 22.5°, 3 – 30°, and 4 – 45°.

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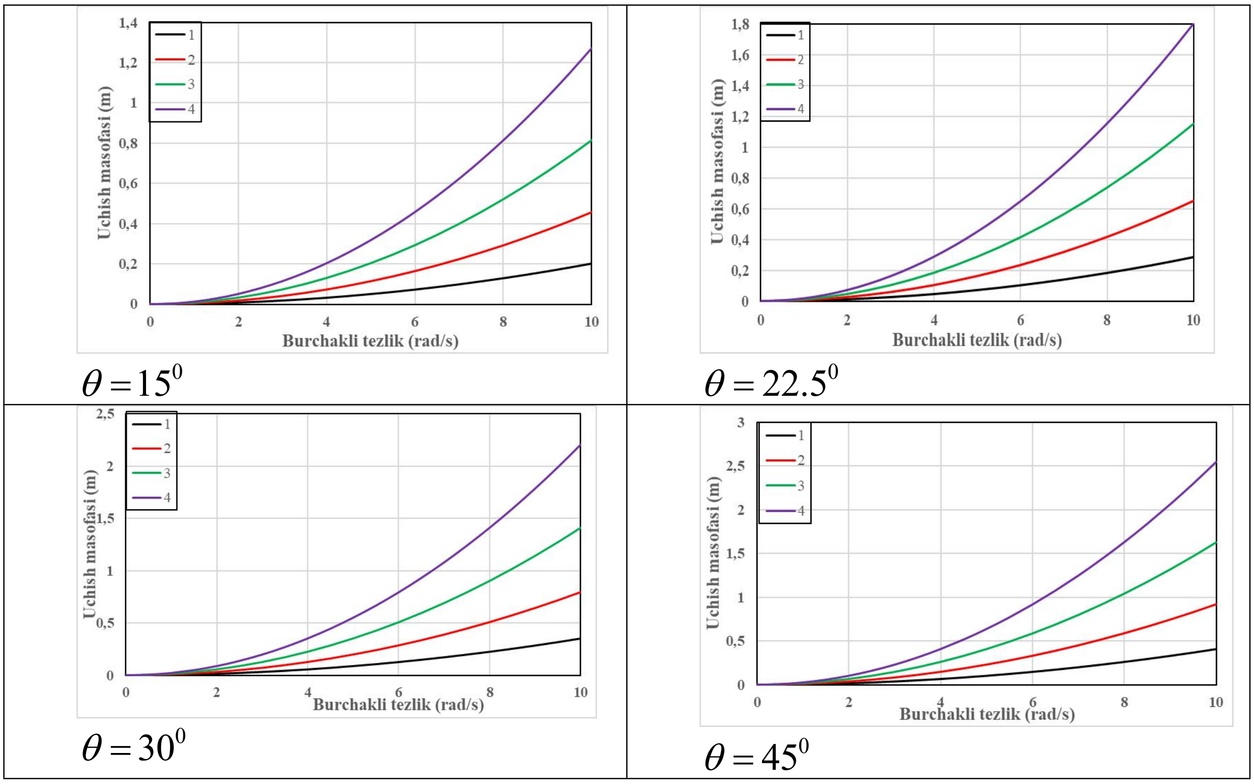


Figure 2. Graph showing the relationship between the flight distance of the cotton lump and the rotational speed of the long-pegged drum for different drum radii:1 – 0.2 m, 2 – 0.3 m, 3 – 0.4 m, and 4 – 0.5 m.

From the analysis of Figures 1 and 2, the following conclusions can be drawn:

As the rotational speed increases, the flight distance increases. For all release angles, as the initial velocity increases, the flight distance grows approximately quadratic ally.

1. The 45° release angle provides the greatest distance. This is a classical physics result—when air resistance is neglected, the maximum range is observed at 45°.
2. At 15° and 22.5°, the flight distance is significantly shorter. This indicates that objects launched at very low angles do not travel far, even if the speed is high.
3. The graph for 30° is considerably higher than that for 22.5°, showing that a small increase in the release angle can significantly increase the flight distance.

Equation of change of path of cotton fibre after impact on drum surface with spikes.

On cotton cleaning lines or separation machines, cotton parts move over the surface of a high-speed drum (cylindrical rotor). Special geometric elements located on the surface of the drum - nails and angular teeth - have a constant effect on these moving parts. As a result of the impact on each rod or corner element, the direction of movement of the cotton crumb, the velocity modulus and the moment of rotation in the possible position change significantly. Based on this model, part of the cotton moves along a path divided into segments, rather than continuous movement, and new initial conditions are created in each segment. In this system, the movement of the cotton part moves along the rotation of the drum, then collides with the nail, receives momentum and continues along the parabolic free flight path. This process is repeated after each blow and turns the general movement into an unconventional, complex one. Therefore, mathematical modeling of this system is important in the development of optimal cotton flow parameters, the calculation of structural elements of equipment and the design of movement control mechanisms.

The direction of movement changes after a shock collision of a piece of cotton with a fly on the drum surface. This causes it to move along a trajectory that splits into sections (segments).Each segment is a phase of movement that begins after a single collision and continues until the next. Trajectory segments are classified as follows:

Segment 1: free movement of a piece of cotton detached from the drum surface (parabolic trajectory);

Segment 2: movement with a new starting speed in the position after hitting the fly;

Segment3and beyond: a new trajectory that is redefined after each subsequent shot.

To determine such a segmented motion, the initial conditions – i.e. the initial speed, direction angle, and coordinates-are updated after each shot. Through this segmented trajectory, it will be possible to fully characterize the path of movement of a cotton lump.

The process of interaction between a piece of cotton and a fly is modeled on the impulse–momentum law. A piece of fly cotton is given a certain amount of Momentum (time of force) as a result of the force acting on it in a short time. This impulse has a direct effect on the full speed of the particle and on the trajectory direction. The conflict is mathematically expressedas [4, 5, 6]:

$$\vec{\vartheta}' = \vec{\vartheta} + \frac{\vec{J}}{m} \tag{9}$$

Where, is the pre-collision velocity vector, is the post-collision velocityvector – is the pulse (N·s),

In percussive motion, typically the direction of the shot is separated in to tangentialand normal components. Then each component has a separate physical mechanism, and the final speed changes depending on them.

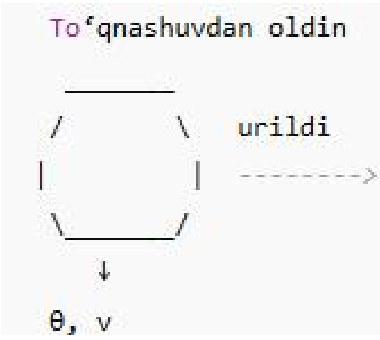
The preservation of elasticity and energy in a shock collision. The collision between the cotton lump and the fly is considered on the basis of an inelastic shock model. In this case, it is possible to determine how the velocity changes after the impact through the shock efficiency coefficient :

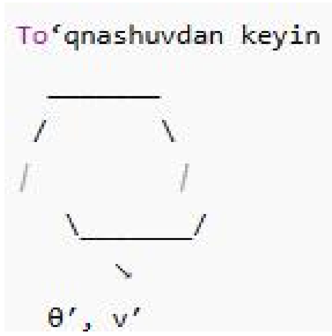
$$e = -\frac{\vartheta_n'}{\vartheta_n} \tag{10}$$

Where, ϑ_n is the normal component in the shock direction(up to collision), ϑ_n' is the normal component after impact. By the rules0<e<1, the collision is inelastic, meaning that some of the energy goes to heat or deformation.

The velocity component in the tangential direction is usually determined by the following equation: $\vartheta_t' = \mu_t \ \ \vartheta_t \ \mu_t -$ the tangential is the conservation coefficient, and may have a value in the range 0.85–0.95.

In each trajectory segment, a piece of cotton performs a parabola-shaped movement. Its coordinates are represented by the following equations:





In this scheme, each stroke turns the direction of the cotton lump and reduces its speed. This makes the entire trajectory of motion complex and multi-segmented.

Trajectory calculation based on mathematical formulas. In each trajectory segment, a piece of cotton performs a parabola-shaped movement .Its coordinates are represented by the following equations [7, 8, 9, 10]:

$$x_i(t) = x_{i,0} + \vartheta_{x,i} \; t,$$
$$y_i(t) = y_{i,0} + \vartheta_{y,i} \; t - \frac{1}{2} g t^2. \qquad (11)$$

Where, are the $x_{i,0}, y_{i,0}$ – segment start points, are the velocity components in the segment. The direction of movement after the blow is found through the $\theta' = \arctan \frac{\vartheta_y'}{\vartheta_x'}$ following angle.

Based on the above analyzes, the movement of the cotton swab is part of the category of shock dynamic systems. Each blow triggers a new phase of the system state. Therefore, in addition to continuous differential equations, discrete impulse changes (jumps) are also taken into account when modeling such an action. By numerical modeling, the trajectory graph, the direction of the velocity vectors, and the intersegment discontinuities are clearly shown.

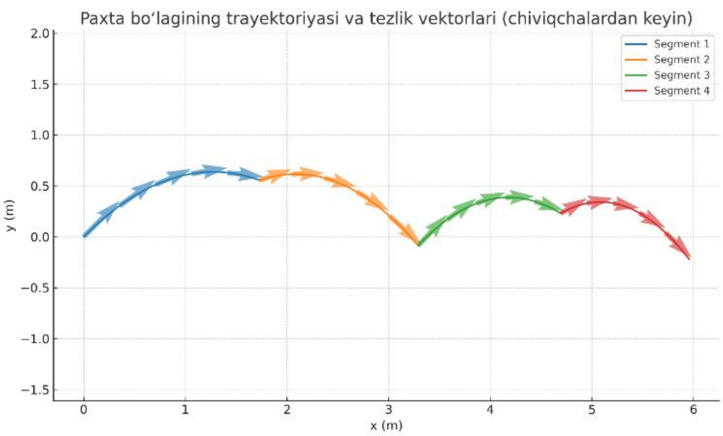


Figure 3. The trajectory and velocity vectors of a piece of cotton after hitting corners and flies are shown.

Each color in Figure 3 denotes a separate trajectory segment (a new movement stage after a stroke).Arrows drawn at every10 pointsindicate velocity vectors.

1.The trajectory after hitting the fly depends on the angle: the larger the initial angle, the steeper the trajectory, but the lower the horizontal distance.

2.Optimalangle-45°: the greatest flight distance was observed at this angle. This ensures that the cotton swab moves to the maximum distance.

3.Angularvelocityand acceleration also affect the trajectory: and θ in the pre-and post-hit position determine the direction of velocity, which directly affects the direction and flight distance.

4.Over time, the vibration fades, which reduces the intensity of hitting the fly.

Conclusion. In this study, the vibrational motion of a cotton swab before hitting a fly and the trajectory motion after hitting were mathematically modeled based on angular velocities, accelerations, and trajectory lines. Using a vibration model based on Newton's laws, the motion dynamics of the cotton swab were determined, and the trajectory lines and velocity vectors were presented graphically. The results of the study showed that:

-The trajectory and flight distance of the cotton lump is significantly dependent on the initial angle, and the longest horizontal distance is observed at an angle of 45°.

-At smaller angles (15°, 22.5°), the cotton lump will approach the ground faster and the trajectory will be lower; at larger angles (60°), it will move higher, but the flight distance will decrease.

-During movement, the direction of the velocity vector changes in accordance with the trajectory, depending on the air resistance and momentum distribution.

-The damping factor (damping) causes a decrease in the amplitude of the vibration over time, and as a result, the frequency of hitting the fly is reduced.

Thus, by modeling the motion of a cotton lump inside a fly drum, it will be possible to predict its most effective motion trajectory, the number of hits on flies, and the duration of motion. This, in turn, is important in improving the mechanical efficiency and optimization of technological parameters of cotton-cleaning equipment.

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