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PRUJINA BILAN MAHKAMLANGAN QOZIQCHALI BARABANLARDA PAXTA OQIMINING DINAMIK HARAKATINI MATEMATIK MODELLASHTIRISH

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Abstract. The article mathematically models the dynamic effect of spring-loaded drum spools used in cotton gins on the cotton flow. The radial vibrational motion resulting from the interaction of a cotton boll with a spring-loaded drum spool is expressed based on differential equations. Homogeneous and particular solutions of the equations of motion are determined, and the effect of system parameters on the cotton flow motion is analyzed. The results obtained are explained by the fact that they allow for stable cotton flow transfer, reduced mechanical damage, and increased efficiency of the cleaning process.
Keywords: cotton flow, drum with pegs, spring, mathematical model, differential equation, dynamic motion.

Annotatsiya. Maqolada paxta tozalash mashinalarida qo'llaniladigan prujina bilan mahkamlangan qoziqchali barabanlarning paxta oqimiga dinamik ta'siri matematik modellashtirilgan. Paxta bo'lakchasining prujinali qoziqcha bilan o'zaro ta'siri natijasida yuzaga keluvchi radial tebranish harakati differensial tenglamalar asosida ifodalangan. Harakat tenglamalarining bir jinsli va xususiy yechimlari aniqlanib, tizim parametrlarining paxta oqimi harakatiga ta'siri tahlil qilingan. Olingan natijalar paxta oqimini barqaror uzatish, mexanik shikastlanishni kamaytirish va tozalash jarayonining samaradorligini oshirish imkonini berishi bilan izohlanadi.
Kalit so'zlar: paxta oqimi, qoziqchali baraban, prujina, matematik model, differensial tenglama, dinamik harakat

Аннотация. В статье разработана математическая модель динамического воздействия барабанов с подпружиненными колками, применяемых в хлопкоочистительных машинах, на поток хлопка. Радиальное колебательное движение хлопкового клочка, возникающее в результате взаимодействия с подпружиненным колком, описано с использованием дифференциальных уравнений. Определены общее решение однородного уравнения и частное решение уравнения движения, а также выполнен анализ влияния параметров системы на характер движения потока хлопка. Полученные результаты позволяют обеспечить более стабильную транспортировку потока хлопка, снизить механические повреждения волокна и повысить эффективность процесса очистки.
Ключевые слова: поток хлопка, барабан с колками, пружина, математическая модель, дифференциальное уравнение, динамическое движение.

Introduction

In the primary processing of cotton raw materials, the cleaning operation is one of the most important stages that determine the quality of the product. The efficiency of the cleaning process directly affects not only the amount of impurities removed, but also the ability of cotton fiber and seeds to be transported to subsequent technological stages without damage. Therefore, cleaning efficiency and reducing mechanical impact on the fiber are considered two main criteria in improving modern cotton ginning machines.

Although the widely used drum with piles is effective in separating impurities by moving and shaking the cotton stream, there are a number of technological shortcomings in their operation. In particular, the quality of cleaning can be reduced due to the clogging of the cotton stream between the piles, mechanical damage to the fibers due to the impact (hard) impact of the piles on the cotton piece, and the instability of the transfer process between the drums. In such conditions, taking into account the elastic properties of the system elements, “smoothing” the impact on the cotton stream and stabilizing the transfer appear as an urgent scientific and technical problem.

One way to solve this problem is to fix the pegs to the drum with a spring. The theoretical essence of the idea of u200b\u200bspring fastening is that instead of a rigid kinematic connection (rigid impact) in the interaction between the peg and the cotton ball, an elastic-dynamic connection occurs. That is, the cotton flow is transmitted not by a single impact under the influence of the pegs, but by creating an oscillatory (vibrating) motion. In this case, the spring deformation “absorbs” and “returns” energy in a short time, as a result of which the trajectory and acceleration of the cotton ball are free from sharp jumps, and the dynamic regime of the system is stabilized. Also, the elasticity of the spring can optimize the “compression-relaxation” states of the cotton flow between the pegs, reducing the likelihood of jamming.

The effect of a spring-loaded drum on the cotton flow can be interpreted from a mechanical point of view as a dynamic system of the mass-spring type. The cotton ball is an inertial element with a certain mass, and the spring is an elastic element, and the ratio between centrifugal forces and elastic forces during the rotation of the drum determines the radial displacement of the cotton ball. The following main factors are important for a correct assessment of the dynamic state in such systems:

- Inertia factor (m): As the mass of the cotton ball increases, the “response” behavior of the system changes; the amplitude of the oscillations and the time-dependent transients can be distinguished.
- Elasticity factor (k): The stiffness of a spring is the main parameter that determines the natural frequency of a dynamic system, the amplitude of vibration, and the conditions under which a piece of cotton will separate from the pile.
- Rotation factor (ω): As the drum angular velocity increases, the proportion of centrifugal forces increases; this can increase the radial displacement of the cotton sliver or accelerate separation under certain conditions.
- Geometric factor (R and pile position): The pile radius and the initial position of the cotton ball form the initial conditions of the dynamic equations, which are important in determining the realistic process trajectory.

In this context, mathematical modeling for spring-loaded drum assemblies serves two main purposes:

1. create a theoretical basis for the system by formulating dynamic equations of motion for cotton flow;
2. to provide a scientific basis for choosing rational values of spring stiffness and drum angular velocity.

Research objective

To express the dynamic motion of a cotton stream in the radial direction under the influence of a spring-loaded drum with a peg based on a mathematical model, obtain analytical solutions, and determine the laws of influence of the main parameters (k, ω, etc.) on the motion of the cotton stream.

Research tasks

- mechanically justify the main forces acting on a piece of cotton (elasticity and centrifugal forces);
- formulate a differential equation of motion based on Newton's laws;
- determine homogeneous and particular solutions and find integral constants through initial conditions;

- analysis of the displacement trajectories of the cotton flow at different values of spring stiffness and drum angular velocity;
- drawing scientific conclusions on the factors affecting process stability, reduction of mechanical damage, and transmission quality based on the theoretical results obtained.

Object: The process of screening and transferring a stream of cotton using drums with pegs.

Subject: Dynamic (oscillating) motion of a piece of cotton in the radial direction under the influence of spring-loaded pegs and the mathematical relationships that describe it.

Scientific novelty and practical significance

The scientific aspect of the work is explained by the expression of the dynamic behavior of cotton flow in spring-loaded drums using differential equations and the theoretical assessment of the influence of system parameters. In practical terms, the obtained relationships are useful in choosing drum designs and operating modes, and in substantiating engineering solutions aimed at increasing the stability of cotton flow transmission and reducing mechanical stress on the fiber.

Research methods

The research uses classical theoretical mechanics and solutions of differential equations, as well as parametric analysis and graphical modeling approaches (computational and trajectory analysis).

Literature analysis

The working process of the drum with pegs used in cotton ginning machines and their impact on the cotton flow have been considered in many scientific studies. In these studies, the processes of picking, conveying and separating impurities from the cotton flow using the working bodies with pegs were analyzed mainly from a mechanical and technological point of view. It was noted that as a result of the hard (inelastic) mechanical impact on the cotton flow in traditional drum with pegs, the cleaning efficiency increased, as well as the degree of fiber damage.

In classical sources in theoretical mechanics, vibrating systems involving elastic elements are analyzed based on the mass-spring model. In such systems, the equations of motion are expressed in the form of differential equations, and the balance between elastic and inertial forces plays a key role. Although this approach has been widely used in the analysis of some components of production machines, it has been applied to a limited extent for the pile drums of cotton ginning machines.

In some studies, the rotation speed of the pick drums, the length of the pick, and the location of the pick were considered as the main factors affecting the movement of the cotton stream. However, these studies did not sufficiently explain the dynamic processes that occur as a result of the elastic fastening of the pick, i.e., its attachment to the drum by a spring. Also, most studies analyzed the movement of the cotton stream within the framework of a kinematic or simplified static model, and the real vibration processes were not fully explained theoretically.

Studies on improving the efficiency of impurity separation in the cotton ginning process have focused mainly on technological parameters, namely cleaning efficiency and productivity. In this case, the dynamic interaction between the working bodies and the cotton flow is considered a secondary factor. However, the dynamic behavior of the cotton flow is one of the important factors determining the mechanism of impurity separation.

Therefore, an analysis of the existing literature shows that the issue of mathematical modeling of the dynamic movement of cotton flow in spring-loaded drums has not been sufficiently studied, and research in this area is scientifically and practically relevant.

Research methodology

In this study, theoretical-analytical methods were used to study the dynamic behavior of cotton flow in spring-loaded drums with pegs. The research methodology is based on classical theoretical mechanics and the theory of differential equations.

In the study, the cotton flow was considered as a set of individual cotton pieces, and their motion was represented by a simplified mechanical model. The cotton piece was taken as an inertial element (mass), and the spring was taken as an elastic element, and the interaction with the pile was modeled as a mass-spring type dynamic system. Centrifugal forces arising from the rotation of the drum were taken into account as one of the main external forces acting on the cotton piece.

The main stages of the research methodology are as follows:

- determine the forces acting on a piece of cotton (elastic force and centrifugal force);
- construct a differential equation for the motion of a piece of cotton in the radial direction based on Newton's second law;
- simplify the constructed differential equation and divide it into homogeneous and inhomogeneous parts;
- find analytical solutions to the equation of motion and determine integral constants through initial conditions;
- to analyze the effect of system parameters (spring stiffness and drum angular velocity) on cotton flow behavior.

Based on the obtained analytical expressions, a graphical analysis method was used to study the trajectories of the cotton flow movement over time. The calculation results were compared at different values of the parameters and the oscillatory nature of the cotton flow was assessed. This approach made it possible to determine the stability conditions of the process and select rational values of the design and technological parameters.

The chosen methodology provides sufficient accuracy to theoretically substantiate the dynamic behavior of spring-loaded drum drums used in cotton gins and determine their effective operating conditions.

Results

1. Results of dynamic behavior of cotton flow in spring-loaded pile drums

The movement of a cotton stream under the influence of a spring-loaded drum with a peg is determined by the balance between elastic force and centrifugal force. Elastic force

$$F_k = kx$$

and centrifugal force

$$F_m = m\omega^2(R + x)$$

The radial motion of a piece of cotton under the influence of Newton's second law

$$m\ddot{x} = m\omega^2(R + x) - kx$$

This equation is simplified to

$$\ddot{x} + \left(\frac{k}{m} - \omega^2\right)x = \omega^2 R$$

a second-order inhomogeneous differential equation is formed. Analytical solution of the equation

$$x(t) = C_1\cos(\lambda t) + C_2\sin(\lambda t) + \frac{\omega^2 R}{\lambda^2}$$

determined in the form of, taking into account the initial conditions

$$x(t) = \frac{\omega^2 R}{\lambda^2}\left(1 - \cos(\lambda t)\right)$$

This result indicates that the cotton flow is transmitted from the piles through elastic vibrational rather than impacting motion. As a result, mechanical damage is reduced and the transmission process is stabilized.

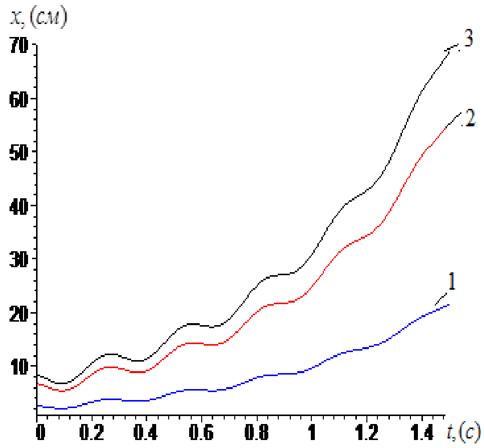


Fig. 1. The behavior of a cotton stream under the influence of spring-loaded pegs for different spring elastic coefficients. $k_1 = 5418\, H/мм$ $k_2 = 10617\, H/мм$ $k_3 = 19178\, H/мм$ time-dependent graph of values

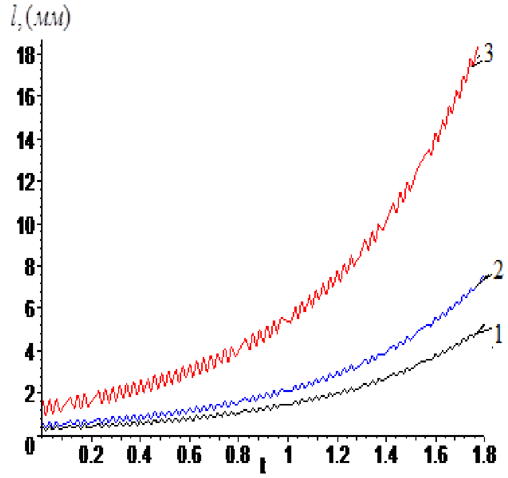


Fig. 2.The behavior of a cotton stream on the surface of piles fastened by a spring at different elastic coefficients of the spring. $k_1 = 5418\, H/мм$ $k_2 = 10617\, H/мм$ $k_3 = 19178\, H/мм$ time-dependent graph of values

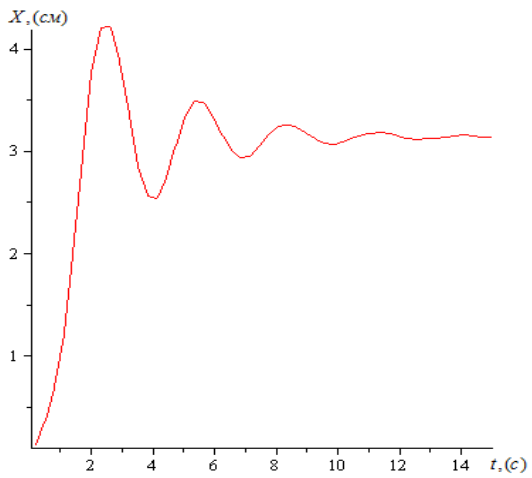
Results of two-stage cotton flow behavior on spring-loaded piles and mesh surface Elastic, centrifugal, and friction forces are taken into account for the movement of the cotton stream between the piles and the mesh. In this case, the equation of motion is

$$m\ddot{x} + c\dot{x} + kx = m\omega^2(R + x)$$

written and simplified as 07.07.2026

$$\ddot{x} + \frac{c}{m}\dot{x} + \left(\frac{k}{m} - \omega^2\right)x = \omega^2 R$$

The graphs constructed based on these equations (Figures 5–7) showed that the amplitude of the oscillation of the cotton stream depends on the elastic coefficient of the spring.



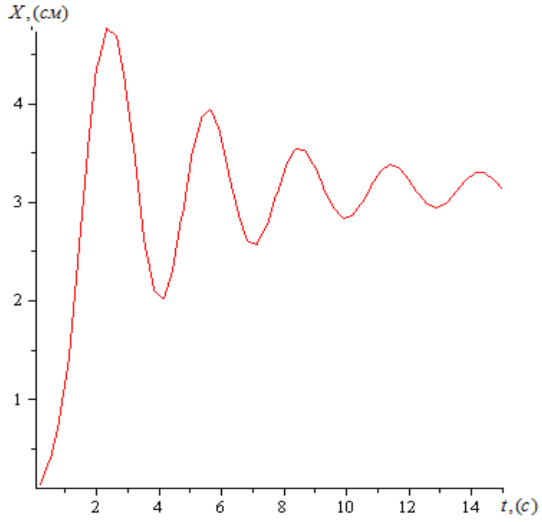


Fig. 3.The behavior of a cotton stream under the influence of spring-loaded pegs is determined by the elastic coefficient of the spring. $k_1 = 5418\, H/мм$ time-dependent graph of value

Fig. 4.The behavior of a cotton stream under the influence of spring-loaded pegs is determined by the elastic coefficient of the spring. $k_3 = 19178\, H/мм$ time-dependent graph of value

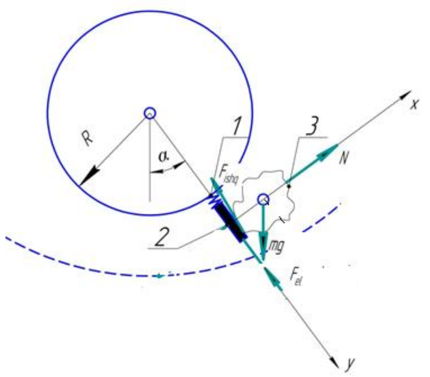
The movement of the cotton stream along the mesh along the UM axis is

$$m\ddot{y} + c\dot{y} + ky = 0$$

is described by the equation. Its analytical solution is

$$y(t) = e^{-\beta t}\left(C_1 \cos\omega t + C_2 \sin\omega t\right)$$

This result shows that the cotton stream moves in a damped oscillatory motion on the surface of the screen. As a result, the cotton stream becomes less clogged between the piles and the transfer process becomes less continuous.



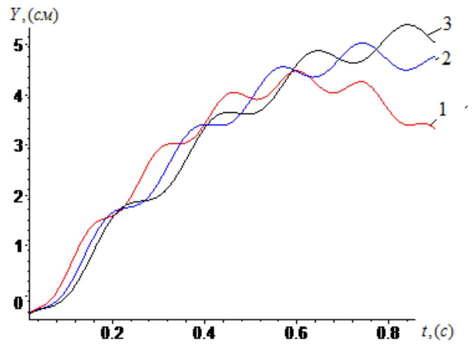


Fig. 5. Diagram of external forces acting on the cotton flow due to the improved spring-loaded pegs.

Fig. 6. The motion of a cotton stream along the OY axis under the action of pegs fixed by a spring is controlled by varying the elastic coefficient of the spring. $k_1 = 5418\, H/мм$; $k_2 = 10617\, H/мм$; $k_3 = 19178\, H/мм$ depends on time in its values.

Results of the efficiency of separation of impurities under the influence of spring-loaded piles

The decrease in mass of a cotton ball over time during the cleaning process

$$\frac{dm}{dt} = -\alpha m$$

is expressed by the equation. The solution to this equation is

$$m(t) = m_0 e^{-\alpha t}$$

The change in the mass of impurities in cotton is

$$\frac{dm_i}{dt} = \beta m - \gamma m_i$$

described by a differential equation and, as a result of integration,

$$m_i(t) = m_{i0} e^{-\gamma t} + \frac{\beta m_0}{\gamma - \alpha}\left(e^{-\alpha t} - e^{-\gamma t}\right)$$

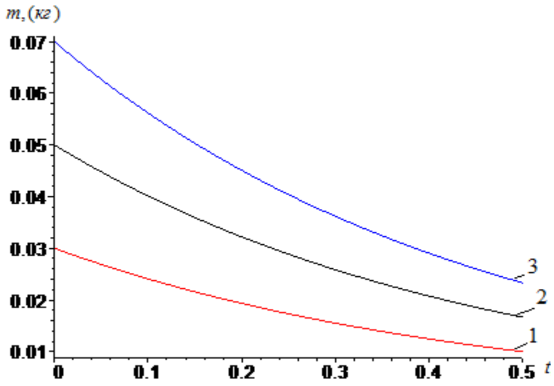


Fig. 7. The change in mass of the cotton ball at different values of the shrinkage coefficient of the cotton ball $k_{1I} = 0{,}08$ $k_{1II} = 0{,}1\, k_{1III} = 0{,}12$ graphs of change over time.

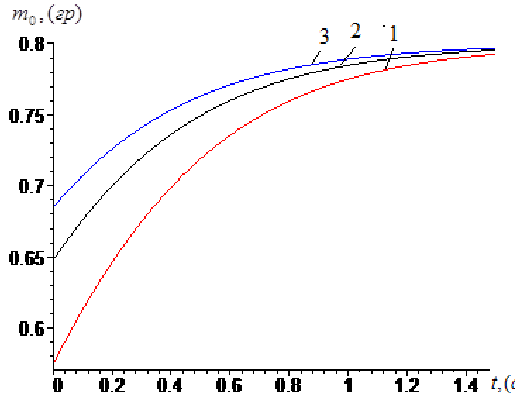


Fig. 8. The change in mass of the cotton ball at different values of the shrinkage coefficient of the cotton ball $k_{1I} = 0{,}08$ $k_{1II} = 0{,}1\, k_{1III} = 0{,}12$ graphs of change over time.

These results confirm that the separation of impurities from the cotton pad is intensified and the cleaning efficiency is high under the influence of spring-loaded pegs.

Conclusion

As a result of theoretical studies, the dynamic behavior of cotton flow in drums with spring-loaded pegs was mathematically substantiated and its impact on the technological process was comprehensively evaluated. It was shown that the interaction of a cotton piece with a spring-loaded peg creates an elastic oscillatory motion, which provides a significant reduction in mechanical shock effects compared to traditional rigid pegs.

The results obtained on the first topic showed that the elastic coefficient of the spring and the angular velocity of the drum are the main factors determining the amplitude of the displacement of the cotton stream in the radial direction and the vibration frequency. At rational values of these parameters, the cotton stream is elastically and stably transmitted from drum to drum, which reduces the possibility of fiber damage and increases the reliability of the technological process.

In the second topic, the two-stage motion of the cotton stream on the surface of spring-loaded pegs and a mesh screen was theoretically analyzed. The results confirmed that the oscillatory motion of the cotton stream reduces the occurrence of jams between the pegs and ensures the continuity of the conveying process along the mesh screen. In particular, the balance between elasticity and friction forces ensures the smooth movement of the cotton stream and increases the stability of the conveying.

The third topic, based on the analysis of mass changes, showed that the separation of impurities from cotton pieces is intensified under the influence of spring-loaded piles. The relationship between the decrease in the mass of the cotton piece and the change in the mass of impurities over time quantitatively confirmed the high cleaning efficiency. This indicates that the transmission of the cotton stream in an oscillatory motion creates favorable conditions for the effective separation of impurities.

In general, the use of spring-loaded peg drums allows optimizing the dynamic movement of the cotton stream, reducing mechanical damage, and increasing cleaning efficiency. The obtained scientific results can serve as a theoretical basis for selecting the structural and technological parameters of cotton ginning machines, as well as for designing new generation cotton ginning equipment.

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