
# Theoretical Analysis Of Fiber Separation In A Developed Laboratory Valic Gin

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**ABSTRACT**

This article presents the results of Post-BuildIn this case, the MathematicalOh Modeland Ton the basis of the force analysis, describing the dynamics of separation of the fiber from the seed under the action of the working bodies of the two-knife system. This model will allow you to calculate the trajectory of the flyer, determine the separation time and optimize the system parameters.

**Keywords:** inAlichny, gin, knife, tension, friction, flying, action, equation, resistance, mathematical model.

At the "Research Institute of Fibrous Crops", research work is underway to create a laboratory felt gin for ginning samples of seed cotton of small quantities [1, 2, 3]. A gin scheme has been developed, the scheme of which is shown in Fig.1.

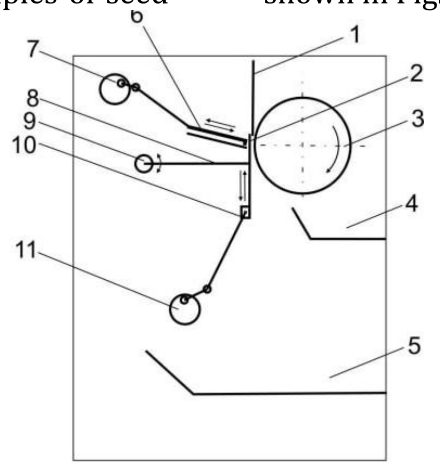

**Figure 1. Diagram of the developed felt laboratory gin with a working roller and a two-knife system in the ginning area**

1-Fixed Knife; 2-Underknife; 3-Work roller; 4-fiber chamber, 5-Seed chamber; 6- Mechanismfor clamping the cotton; 7, 11-camshaft, 8-earforged lattice, 9-pulley, 10-hinge for transmission.

RLet's look at the section of the fiber sandwiched between the fixed knife and the jining roller (Fig. 2).

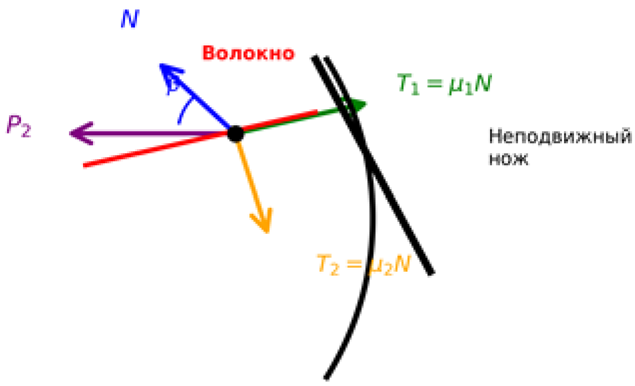


**Figure 2. Diagram of the forces acting on the fiber in the contact area of a fixed knife with a jinning roller**

The following forces act on this section:

The force of pressing the fiber against the roller from the side of the knife is the normal force $N$, directed perpendicular to the surface of the bead causes frictional forces on the jinching roller ($T_1 = \mu_1 N \cos\beta$) and a fixed knife: ($T_2 = \mu_2 N \cos\beta$, where $\beta$ is the angle between the direction of tension of the fiber and the normal to the surface of the roller). We also take into account the component of the pressure force acting along the direction of tension of the fiber:

$$P_2 = N \sin\beta.$$

The resultant force that tends to tear the fiber from the seed is determined by the formula obtained in the work [4]:

$$P_0 = N(\mu_1 - \mu_2)\cos\beta + N \sin\beta.$$

At small angles $\beta(\beta \approx 0)$ This formula is simplified:

$$P_0 \approx N(\mu_1 - \mu_2). \qquad (1)$$

Coefficient of Friction of Fiber on Ginating Roller $\mu_1$ depends on the coating material of the bead and the condition of the fiber surface. For a leather roller working with fine-fiber cotton, it has been experimentally established [5] $\mu_1 = 0{,}463$, and the coefficient of friction on the surface of the knife $\mu_2$ is determined by the material of the knife and its processing is equal to $\mu_2 = 0{,}32$. Substituting these values into formula (20), we get:

$$P_0 = 0{,}143N. \qquad (2)$$

This ratio shows that the tearing force is approximately 14.3% of the normal pressing force.

Normal Pressure Force $N$ depends on the elastic properties of the fiber and the geometric parameters of the system. According to research [52], the ratio can be used to estimate this strength:

$$N = \frac{qbL}{\delta_0}, \qquad (3)$$

Where: $q$ – specific pressure per unit contact area; $b$ – the width of the contact zone (the length of the knife); $L$ is the length of the fiber section in contact; $\delta_0$ – the gap between the knife and the roller.

Specific pressure is related to the depth of indentation of the fiber into the surface of the roller. According to the Hertz formula modified for textile materials [6]:

$$q = \left[\frac{h}{\alpha}\right]^{1/0,75} = \frac{h^{4/3}}{\alpha^{4/3}}, \qquad (4)$$

Where: $h$ - depth of the dent; $\alpha$ is a coefficient depending on the elastic properties of materials ($\alpha =$ 415 for leather roller and cotton fiber).

The depth of the dent, in turn, is related to the gap:

$$h \leq (r_к)/2$$

where: $r_к$ is the radius of the rounding of the edge of the knife.

At typical values $r_к = 0{,}5$ммWe have $h \leq$ *0,25* mm. Substituting in Formula (4) we get:

$$q = \frac{(0{,}25)^{4/3}}{415^{4/3}} \approx 3{,}5 \cdot 10^{-6} \text{ МПа}.$$

This is a very low pressure, which is explained by the elastic properties of the fiber. To obtain sufficient breakout force, a long contact length must be provided $L$ or small clearance $\delta_0$.

The introduction of a movable knife creates an additional dynamic component of the tearing force. The mechanism of action of a movable knife is based on two effects. When the movable knife moves away from the roller (in the phase of increasing the gap), the bats move away, which increases the arm of the friction force of the roller relative to the point of attachment of the fiber to the seed. This effect can be described through an additional point:

$$\Delta M = F_{тр.в} \cdot \Delta L, \qquad (5)$$

Where: $\Delta L = A \sin(\omega_н t)$ – an additional shoulder created by moving the bat.

Periodic changes in the force of impact on the fiber lead to alternating stresses in the area of attachment of the fiber to the seed. This causes fatigue loosening of the bond, which can be accounted for through the effective attenuation factor $\eta_{ус}$:

$$F_{связи,эфф} = \eta_{ус} F_{связи},$$

where $\eta_{ус} < 1$ It depends on the number of loading cycles and the amplitude of pulsations.

Total tearing force in a movable knife system:

$$P_{общ}(t) = P_0 + P_{доп}(t) = N(\mu_1 - \mu_2) + k_{доп} A \omega_н^2 \sin(\omega_н t), \qquad (6)$$

where$k_{доп}$is a coefficient that takes into account the effect of knife oscillations on the tearing force.

From the formula (6) it can be seen that the movable knife creates a periodic additive to the static force, and the amplitude of this additive is proportional to the square of the vibration frequency and the amplitude of displacement.

For effective fibre separation, it is necessary that the maximum breaking force exceeds the bonding force, taking into account the attenuation:

$$P_{общ,max} = P_0 + k_{доп} A \omega_н^2 \geq \frac{F_{связи}}{\eta_{ус}}. \qquad (7)$$

At the same time, the condition of non-damage to the fiber must be met:

$$P_{общ,max} < \frac{F_{разр}}{k_{без}}, \qquad (8)$$

Combining the conditions (7) and (8), we get the range of permissible values of tearing force:

$$\frac{F_{связи}}{\eta_{ус}} \geq P_{общ,max} < \frac{F_{разр}}{k_{без}}. \qquad (9)$$

This inequality determines the valid combinations of parameters$N, A, \omega_н$, providing high-quality ginning.

The obtained force ratios make it possible to proceed to the compilation of equations of motion of the system and the development of a method for calculating the optimal parameters of two knife system.

On the basis of the force analysis, we will build a mathematical model describing the dynamics of the separation of the fiber from the seed under the action of the working bodies of the two knife system. This model will allow you to calculate the trajectory of the flyer, determine the separation time and optimize the system parameters.

Let us consider a flying machine as a material point with a mass of$m_л$, moving under the influence of forces from the ginting roller, knives and resistance forces. Let's choose a coordinate system with a start in the center of the roller, the axis $x$ Point tangentially to the surface of the roller at the point of contact with the fixed knife.

Differential Equation of Motion of a Flyer in Projection on an Axis $x$:

$$m_л \frac{d^2x}{dt^2} = F_{тр.в} - F_{тр.н} - F_{аэр} - c\frac{dx}{dt}, \quad (10)$$

$c$ is a damping coefficient that takes into account internal friction in the fiber and energy dissipation during deformation.

Taking into account the previously obtained ratios:

$$F_{тр.в} = μ_1 N(t),$$

$$F_{тр.н} = μ_2 N(t),$$

$$F_{аэр} = \frac{1}{2} c_x ρ S_{миделя} v^2,$$

Where: $N(t)$ – normal pressure force, depending on the position of the movable knife; $c_x$ – coefficient of aerodynamic drag;ρ– air density; $S_{миделя}$ is the area of the mid-section of the flyer;$v = dx/dt$ is the speed of the flyer.

The normal pressure force varies due to the oscillations of the movable knife:

$$N(t) = N_0 + ΔN \sin(ω_н t + φ_0),$$

where$N_0$– average normal strength;$ΔN$ is the amplitude of pulsations of normal strength.

By substituting these expressions into the equation (10), we get:

$$m_л \frac{d^2x}{dt^2} + c\frac{dx}{dt} + \frac{1}{2} c_x ρ S_{миделя} \left(\frac{dx}{dt}\right)^2 = (μ_1 - μ_2)[N_0 + ΔN \sin(ω_н t + φ_0)]. \quad (11)$$

This second-order nonlinear differential equation with variable coefficients describes the motion of a flyer taking into account the pulsating load from a movable knife.

At low speeds ($v$ < $2$ m/s), the quadratic term of aerodynamic drag is small compared to the other forces and can be neglected. Let's introduce the effective damping factor:

$$c_{эфф} = c + c_{аэр},$$

where $c_{аэр}$ takes into account linearized aerodynamic drag.

Linearized equation:

$$m_л \frac{d^2x}{dt^2} + c_{эфф}\frac{dx}{dt} = (μ_1 - μ_2)[N_0 + ΔN \sin(ω_н t + φ_0)]. \quad (12)$$

Let's divide both parts into $m_л$ and enter the notations:

$$2γ = \frac{c_{эфф}}{m_л}, \quad F_0 = \frac{(μ_1 - μ_2)N_0}{m_л}, \quad F_1 = \frac{(μ_1 - μ_2)ΔN}{m_л}.$$

Let's substitute the receipt in (13):

$$n = \frac{f_н}{f_в} = \frac{ω_н}{ω_в}, \quad (13)$$

Then the equation (13) will take the form:

$$\frac{d^2x}{dt^2} + 2γ\frac{dx}{dt} = F_0 + F_1 \sin(ω_н t + φ_0). \quad (14)$$

It is an inhomogeneous linear differential equation with constant coefficients.

The general solution of the equation (14) consists of the solution of a homogeneous equation (free oscillations) and a partial solution of an inhomogeneous equation (forced oscillations).

$$\frac{d^2x_{одн}}{dt^2} + 2γ\frac{dx_{одн}}{dt} = 0.$$

Characteristic equation: $λ^2 + 2γλ = 0$,Roots: $λ_1 = 0, λ_2 = -2γ$. General solution of a homogeneous equation:

$$x_{одн} = C_1 + C_2 e^{-2γt}. \quad (15)$$

We will look for a partial solution of an inhomogeneous equation in the form of:

$$x_{\text{част}} = A_0 t + B_1 \sin(\omega_н t + \varphi_0) + B_2 \cos(\omega_н t + \varphi_0).$$

PEqualizing the coefficients for the same functions, we get:

$$A_0 = F_0,$$

$$B_1 = \frac{F_1 \cdot 2\gamma\omega_н}{4\gamma^2\omega_н^2 + \omega_н^4}, \quad B_2 = -\frac{F_1\omega_н^2}{4\gamma^2\omega_н^2 + \omega_н^4}.$$

With low damping ($\gamma \ll \omega_н$) These coefficients are simplified:

$$B_1 \approx \frac{2\gamma F_1}{\omega_н^3}, \quad B_2 \approx -\frac{F_1}{\omega_н^2}.$$

Amplitude of forced oscillations:

$$B = \sqrt{B_1^2 + B_2^2} \approx \frac{F_1}{\omega_н^2}\sqrt{1 + \frac{4\gamma^2}{\omega_н^2}} \approx \frac{F_1}{\omega_н^2}. \quad (16)$$

Then the general solution is presented as follows:

$$x(t) = C_1 + C_2 e^{-2\gamma t} + F_0 t + B \sin(\omega_н t + \varphi_0 + \psi), \quad (17)$$

where $\psi$ is a phase shift determined from the ratio of $\tan\psi = B_1/B_2$.

Constant $C_1$ and $C_2$ are determined from the initial conditions:

$$x(0) = 0, \quad \left.\frac{dx}{dt}\right|_{t=0} = 0.$$

From the first condition: $C_1 + C_2 + B\sin(\varphi_0 + \psi) = 0$.

From the second condition: $-2\gamma C_2 + F_0 + B\omega_н \cos(\varphi_0 + \psi) = 0$.

Solving this system, we find $C_1$ and $C_2$.

From the solution (17) it can be seen that the movement of the bat consists of three components: Transitional component $C_2 e^{-2\gamma t}$ fades quickly with a characteristic time $\tau = 1/(2\gamma)$. For typical system parameters $\tau \approx 0{,}01 \ldots 0{,}05$ с, which is much less than the time the bat stays in the ginning zone. $F_0 t$ at a constant speed $v_{ср} = F_0 = (\mu_1 - \mu_2)N_0/m_л$ Oscillatory component $B\sin(\omega_н t + \varphi_0 + \psi)$ with the amplitude determined by the formula (16).

Fig. 3 A graph of the movement of the fly at typical system parameters is presented.

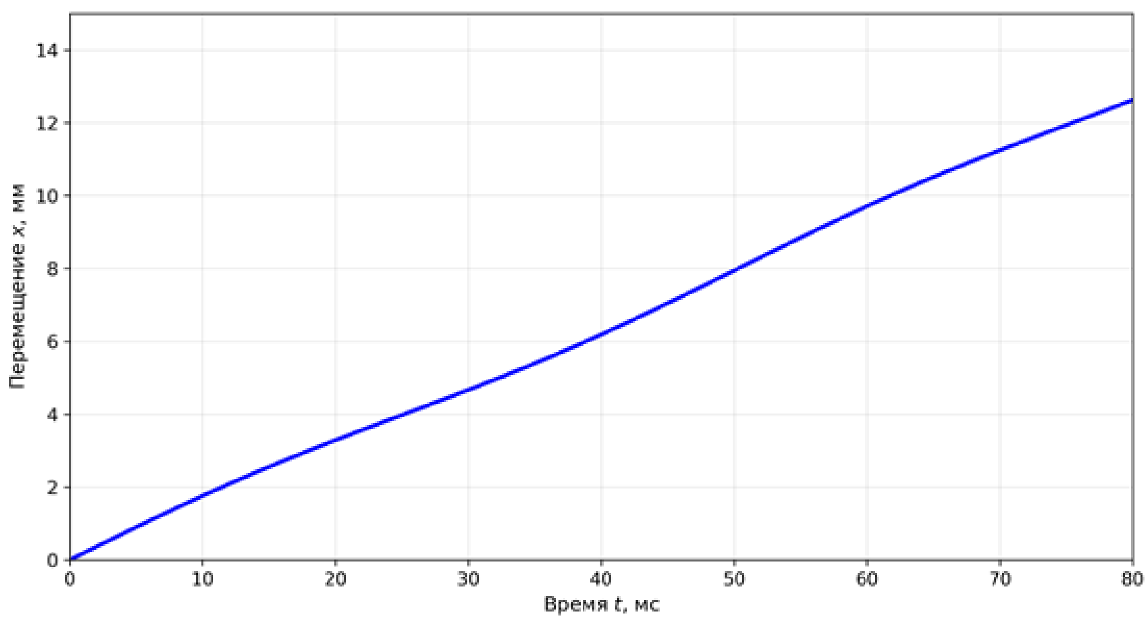

**Figure 3. Dependence of the movement of the fly on time with the following parameters:** $N_0 = 5Н, \Delta N = 2Н, \omega_н = 125рад/с, m_л = 4{,}5г$

Schedule Fig. 3 shows that after a short transient process, the bat moves with an increasing average speed, which is superimposed by high-frequency oscillations caused by the pulsation of the force from the moving knife. These oscillations contribute to the fatigue weakening of the fiber-seed bond.

The fiber is separated from the seed at the moment when the movement of the bat reaches a critical value $x_{кр}$, at which the tension in the area of attachment of the fibre to the seed exceeds the binding force:

$$T(x_{кр}) = F_{связи}/\eta_{ус},$$

where $\eta_{ус}$is the coefficient of bond attenuation due to cyclic loading.

The tension of the fiber is related to the movement through Hooke's law:

$$T = E_в S_в \frac{x}{L_в},$$

where$E_в$– modulus of fiber elasticity;$S_в$– cross-sectional area of the fiber;$L_в$is the length of the fiber.

Critical Displacement:

$$x_{кр} = \frac{F_{связи} L_в}{\eta_{ус} E_в S_в}. \quad (18)$$

Separation time $t_{отд}$ is from the condition $x(t_{отд}) = x_{кр}$. With the predominance of uniform movement ($F_0 t \gg B$):

$$t_{отд} \approx \frac{x_{кр}}{F_0} = \frac{m_л F_{связи} L_в}{(\mu_1 - \mu_2) N_0 \eta_{ус} E_в S_в}.$$
(19)

The expression (18) shows that the separation time is inversely proportional to the normal pressure force and the difference in friction coefficients, and is directly proportional to the mass of the fly and the strength of the fiber-seed bond. The developed mathematical model makes it possible to proceed to the solution of the problem of optimization, i.e., the determination of such values of design and mode parameters at which the maximum productivity of gin is achieved while ensuring the required quality of cotton processing.

The efficiency of the work of valic gin is determined by a set of technological and technical-economic indicators. As the main criteria for optimality, let's take fiber performance $П$(кг/ч), Cleansing Effect $E_{оч}$(%) , fiber damage coefficient, energy intensity of the process.
The complex criterion of optimality can be formulated as:

$$\Phi = \frac{П \cdot E_{оч} \cdot (1 - K_{повр})}{E_{уд}} \to max,$$
(20)

The productivity of a val gin is determined by the number of bats that can be processed per unit of time and the mass of fiber separated from one bat. According to the works of [5, 6, 7], productivity can be represented as the sum of two components:

$$П = П_1 + П_2,$$
(21)

where: $П_1$– productivity due to the separation of the fiber by the breaker roller and the work of friction forces of the ginting roller:

$$П_1 = к_1 \frac{0{,}06 n_0 P}{f_1 N_1 [l + (Ml_1 + s_1)]},$$
(22)

$П_2$– productivity due to the work of breakout forces under the action of a movable knife:

$$П_2 = к_2 \frac{3{,}6 q b L (\mu_1 - \mu_2) v_{эн}}{(Ml_1 + s_1) f_1 N_1}.$$
(23)

Here: $n_0$– number of revolutions of the knife stroke; $P$ – striking force; $N_1$– the number of fibers in 1 g of fiber; $l$ – length of the jinting roller; $Ml_1$ – mathematical expectation of the length of the fiber on the fly; $s_1$is the empirical mean of the square deviation of the length of the fiber at the fly; $f_1$– strength of fiber attachment to seeds; $\kappa_1, \kappa_2$ – coefficients of unevenness; $q$ – specific pressure per unit contact area; $b$ – the width of the contact zone; $L$ is the length of the fiber section in contact; $v_{эн}$ is the speed of fiber tightening.

In the classic single-knife system, the component $\Pi_2$ It is determined only by the static tear force. In the proposed two-knife system, due to the oscillations of the movable knife, this component increases. Let's introduce the intensification coefficient λ, taking into account the contribution of dynamic action:

$$\Pi_{2двухн} = \lambda \Pi_{2одн}, \quad (24)$$

where $\Pi_{2одн}$ – the performance of the single-blade system, $\Pi_{2двухн}$ – the performance of the two-knife system.

The intensification coefficient depends on the oscillation parameters of the movable knife and the mode of operation of the gin. On the basis of theoretical studies and experimental verification, a dependence was obtained:

$$\lambda = 1 + \alpha_{инт} \left(\frac{A}{\delta_0}\right) \sqrt{\frac{\omega_н}{\omega_в}}, \quad (25)$$

where $\alpha_{инт} = 0{,}15 \dots 0{,}25$ – coefficient depending on the properties of cotton; $A/\delta_0$ – relative amplitude of oscillations; $\omega_н/\omega_в$ – frequency ratio.

At optimal parameters $(A/\delta_0 \approx 2, \omega_н/\omega_в \approx 3)$ The intensification coefficient is:

$$\lambda \approx 1 + 0{,}20 \times 2 \times \sqrt{3} \approx 1{,}69.$$

This means that the second component increases productivity by around 69% compared to a classic single-blade system.
Overall performance of the two-knife system:

$$\Pi_{двухн} = \Pi_1 + \lambda \Pi_2. \quad (26)$$

Fig. 4 The dependence of the relative increase in productivity on the parameters of the moving knife is presented.

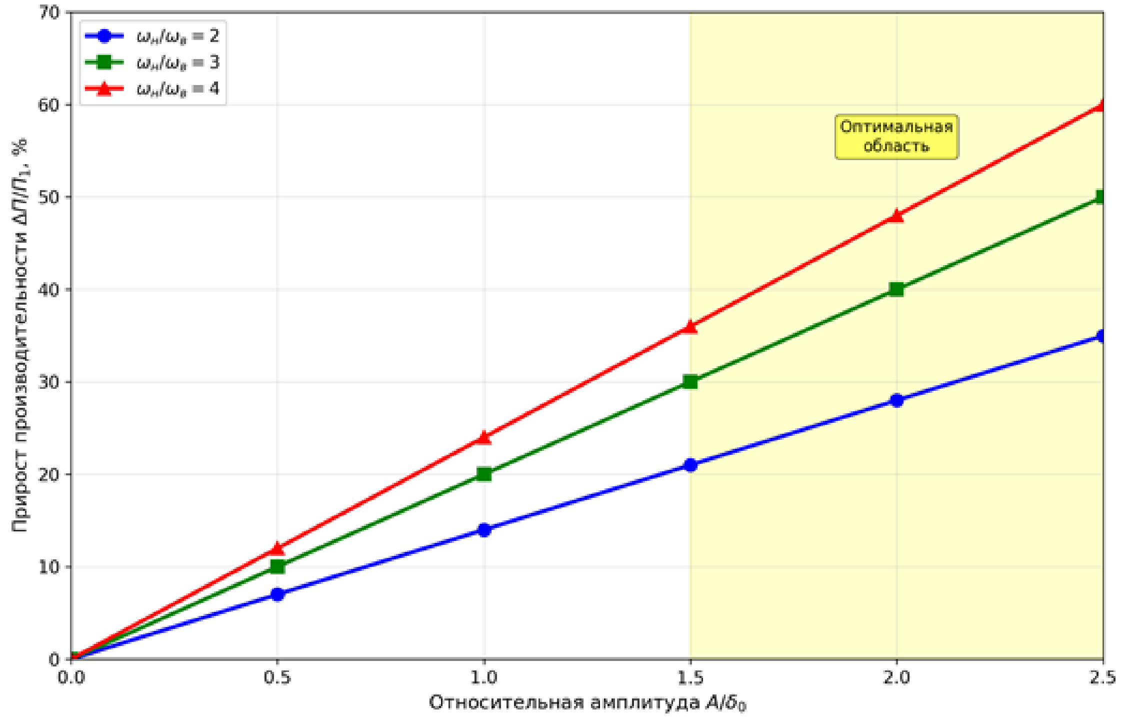


**Figure 4. Dependence of Relative Productivity Gain on Relative Amplitude of Oscillations of a Moving Knife at Different Frequency Ratios**

From the chart Fig. 4 It can be seen that the maximum effect is achieved with $A/\delta_0 =$

$2{,}0 \dots 2{,}5$ and $\omega_{н}/\omega_{в} = 3 \dots 4$. Further increases in these parameters are not feasible because of the increased risk of fiber damage.

**Conclusion.** On the basis of the force analysis of the construction ofEna MathematicalAya a model describing the dynamics of separation of fiber from seed under the action of the working bodies of two knife system. This model will allow you to calculate the trajectory of the flyer, determine the separation time and optimize the system parameters.

In the classic single-knife system, the component Performance It is determined only by the static tear force. In the proposed two-knife system, due to the oscillations of the movable knife, this component increases.

On the basis of theoretical studies and experimental verification, the dependence ofand intensifying the process of ginning cotton in felt gin. It has been revealed thatThe intensification factor depends on the oscillation parameters of the moving knife and the operating mode Valichny gin.

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