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Вплив строку збирання на якості бавовни-сирцю, а також на фізико-механічні властивості волокна, має величезне значення, так як від зрілості і засміченості бавовни залежить ефект очищення бавовни від сміття. Експериментальні дослідження проводилися в реальних польових умовах. Результати досліджень підтвердили, що час збирання істотно впливає на зрілість і якість бавовни-сирцю. Встановлено, що понад 60 % бавовни-сирцю зібраного при розкритті від 50 % до 60 % коробочок відповідає вимогам першого промислового сорту, тобто розривне навантаження волокна вище 4,5 гр. с. З огляду на той факт, що зрілий бавовна-сирець добре деформується, це призводить до підвищення очисного ефекту.

В результаті теоретичних досліджень визначені розпірні зусилля при деформації шару бавовни лопатями очищувача і проаналізовані форми деформованого шару бавовни-сирцю. Проведено оцінку пружних характеристик бавовни-сирцю і розрахунок розпірних зусиль. Для визначення чисельних значень сил тиску лопаті на потік бавовни-сирцю в коефіцієнті узагальнених властивостей матеріалу К величина V для бавовни-сирцю була прийнята в діапазоні 0,25–0,3.

Експерименти показали, що шар бавовни-сирцю товщиною від 170 до 380 мм і шириною 700 мм навантажувався зосередженої по лінії силою 3–10 кгс. Згідно з наведеними розрахунками встановлено, що 38,89 % часу в очищенні бавовни-сирцю бере участь одна лопать валика.

В результаті експериментальних і теоретичних досліджень отримані дані, які дозволяють організувати ефективну роботу очисних машин в бавовноочисній промисловості

Ключові слова: бавовна-сирець, розривне навантаження, очищувач великого сміття, бавовнозавод, зрілість бавовни сирцю, потік бавовни-сирцю, летучка бавовни-сирцю

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INFLUENCE OF ELASTIC CHARACTERISTICS OF RAW COTTON ON THE MECHANICS OF FEED ROLLERS IN THE CLEANERS FROM LARGE IMPURITIES

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1. Introduction

Development of a system for estimating the uniformity of feeding the cleaners, as well as requirements to the characteristics of feeding devices, is of practical importance in order to prepare raw cotton for the principal technological process. Studying the mechanics of interaction process between the working elements of feeding devices and a layer of transported material, as well as searching for feed systems with a targeted change in the technological properties of raw cotton, requires particular attention. It is a relevant task to investigate the interrelation between the physical-mechanical properties of raw cotton, the elastic characteristics of raw cotton, and efforts in the feed rollers. Addressing these issues would make it possible to find the optimal variant of raw cotton harvesting, which could lead to the improvement of harvested cotton, as well as strengthen the effect of cleaning the raw cotton from weedy impurities.

2. Literature review and problem statement

Paper [1] explored issues on cleaning the thin-fiber raw cotton, with focus on the strength of keeping the «fly» particles by the drum's combs. The authors proposed a theoretical formula for calculating the efforts of detachment of «fly» particles from blades; its results somewhat differ from the results from experimental study. The paper has apparently did not take into consideration the influence of elastic characteristics of raw cotton; the scheme did not account for the friction forces and failed to take into consideration the interaction between «fly» particles and multiple blades.

Article [2] reported a research aimed to improve the mechanism of the feeder of collet rollers. The authors studied the interaction between a collet and a piece of raw cotton, with a fibrous connection to cloth formed by feed rollers. However, the study did not achieve the required effect for large impurities.

Raw cotton that contains structural particles of spherical shape with multiple «fly» particles, was suggested for consideration in processes that take place in the cleaners from large and small impurities [3]. Indeed, the conditions for the formation of such lumps of cotton emerge at a pretreatment section. Based on this model, the author attempted to describe the conditions when a material gets on the blade and is fixed by the brush drum, taking into consideration the deformation of portions of raw cotton. When solving the specified problems, the author rightly focuses on the need for the uniform feed to cleaners, which is an issue that remains largely unsolved to date.

Paper [4] examined the interaction between impurities and cotton, but failed to address the influence of elastic characteristics of raw cotton on adhesion between impurities and cotton.

Article [5] explored ways of enhancing the effectiveness of cleaning raw cotton from small impurities by improving the slatted collet drums. However, changing the profile of a meshed surface does not improve the effect of cotton cleaning from large impurities. Practical tests have shown that when a collet hits cotton at a speed of 12 m/s the seeds are damaged, which leads to an increase in the number of defects in fiber.

Studies [6, 7] described basics of the mechanics of interaction process between the «fly» particles of raw cotton and working bodies of the unit that removes large impurities. The authors, however, did not address the influence of density on the elastic characteristics of cotton.

Paper [8], while addressing the choice of feed roller blade geometry parameters, used a model of the process that could reveal both the interaction between «fly» particles and the collet drum of the feeder, and a number of causes of the process of defect formation. However, the author did not study the influence of elastic characteristics of raw cotton on the qualitative indicators. Article [9] investigated the impact of harvesting time on the maturity of raw cotton. This work is continuation of the earlier study.

In [10], a given issue was examined only for the raw cotton harvested by machines. The authors did not consider the friction forces and the influence of elastic characteristics of raw cotton. The desired cleaning effect was not achieved. Therefore, it should be recognized that the impact of elastic characteristics of raw cotton on spreading force, as well as ensuring the uniform feed to cleaners of feed rollers, remains to be studied.

3. The aim and objectives of the study

The aim of this work is to study the process of influence of the raw cotton maturity on physical-mechanical properties of fibers, elastic characteristics of raw cotton in the cleaning process, and to determine the magnitudes of spreading forces that act on feed rollers.

To accomplish the aim, the following tasks have been set:

– to determine experimentally the effect of the raw cotton ripening degree on physical-mechanical properties of the fiber;

– to reveal the mechanics of the process of action of spreading forces at feed rollers and to analyze the shape of the deformed layer of raw cotton;

– to choose an estimate for the evenness of feeding the cleaners, taking into consideration the elastic characteristics of raw cotton;

– to select a procedure for the estimation of the moment when blades contact the transported layer of raw cotton.

4. Influence of maturity on the physical-mechanical properties of raw cotton

Harvesting time substantially affects the quality of raw cotton and changes the weight of crop varieties that is reflected by the physical-mechanical properties of the fiber and by the quality of products manufactured by cotton mills and the textile industry in general. To examine these issues, we performed experiments under actual field conditions.

The study lasted over several years at a cotton-growing farms. Harvesting under field conditions was carried out in three variants, at the cotton bolls opening of 60 %, 70 %, 80 % of the total number of cotton bolls in the cotton. Experiments were repeated 5 times under different field conditions.

The study has confirmed that the lower the cotton bolls to the sympodial branches and the closer to the brain stem, the higher the maturity of the fiber.

It was determined that raw cotton of the first group in all variants of experiments complies in terms of quality with industrial grade, while that from the second group does not (Table 1). It was established that more than 60 % of the raw cotton harvested at the cotton boll opening from 50 % to 60 % meet the requirements of the first industrial grade, at the cotton boll opening from 35 % to 40 %, 80 % meet the requirements to the first industrial grade.

We harvested more raw cotton at later harvesting, but the increase (from 5 % to 8 %) is due mainly to the raw material that does not comply with the quality of an industrial grade.

Under field conditions, we also studied the influence of machine harvesting time on the quantity and quality of raw cotton. It was established that the machine harvesting leads to an increase in yield with the increasing degree of cotton boll opening, especially notable for first harvests.

For example, at the cotton boll opening from 50 % to 60 % a single run of the cotton harvesting machine yielded 25 c/ha; at 70 % – 27 c/ha, at 80 % and larger – 29 c/ha. An increase in yield was observed in general for all types of harvesting: at the cotton boll opening from 50 % to 60 % the yield was 37 c/ha; at 70 % – 38 c/ha; and at 80 % – up to 40 c/ha.

The difference in yield is explained by the fact that during machine harvesting at the cotton boll opening from 50 % to 60 %, the unopened cotton bolls are damaged, they are often torn from the bush, and fall, resulting in a loss of raw cotton. During machine harvesting, at the cotton boll opening from 70 % to 80 %, the losses decrease.

Table 1

Effect of machine harvesting time on the amount of raw cotton

	C-3038					C-2747				
	Yield per type of harvesting, c/ha	Fiber maturity coefficient	Fiber tensile load, cN	Raw cotton moisture content, %	Content of impurities, %	Yield per type	Fiber maturity coefficient	Fiber tensile load, cN	Raw cotton moisture content, %	Content of impurities, %
variant I										
At opening of 50–60 %		2	5	9	11	21	2	5	12	8
At additional opening of 20–30 %		2.0	4.0	10.0	16	10	2	4	11	9
Additional harvesting of harvest I	3	2	5	12	16	3	2	4	14	13
Additional harvesting of harvest II	1	2	4	15	18	2	2	4	14	16
variant II										
At opening of 70 %	12	25		10	10	27	2	4	11	8
At additional opening of 20–25 %	7	2	4	10	14	6	2	4	11	7
Additional harvesting of harvest I	3	2	4	12	15	3	2	4	12	12
Additional harvesting of harvest II	1	2	4	15	20	2	1	3	12	13
variant III										
At opening of 80 % and larger	12	2	5	10	8	30	2	4	11	7
At additional opening of 10–15 %	7	2	4	10	13	5	1	3	10	7

It should be noted that the difference in time between the degree of maturity and the opening of cotton bolls of 50 % and 80 % is from 10 to 15 days. During this time, the structure of the fiber and seed undergoes biological changes. From day 10 to day 15, which is required for the cotton boll opening, the fiber and seeds ripen, their weight changes, which increases the total weight of raw cotton harvesting.

The results of the study show that during machine harvesting with the increased degree of cotton boll opening, the average maturity coefficient and tensile load of the fiber reduce from 0.1 to 0.2 cN. During second harvesting, the tensile load decreases from 0.1 to 0.4 cN. These results allow us to argue about the experimental acquisition of data that testify to the impact of raw cotton maturity on physical-mechanical properties of the fiber.

4. 1. Spreading force and analysis of shape of the deformed layer of raw cotton

Consider the problem in a general form. Let the semi-infinite medium, linearly elastic, isotropic, be exposed to the action of several blades, of length $2l$ and width $2b$ (Fig. 1). Denote the deformation of the layer under the blades as W_1, W_2,..., W_j,..., and the corresponding reactions of elastic medium as P_1, P_2,..., P_j.

In the presence of n forces and the same number of displacements, corresponding to them, we derive the following system of equations based on the principle of independence of displacements on the order of force application:

$$\begin{aligned} W_1 &= W_{11}(P_1)+W_{12}(P_2)+\cdots+W_{1i}(P_i)+\cdots+W_{1n}(P_n),\\ W_2 &= W_{21}(P_1)+W_{22}(P_2)+\cdots+W_{2i}(P_i)+\cdots+W_{2n}(P_n),\\ &\text{-------------------------}\\ W_j &= W_{j1}(P_1)+W_{j2}(P_2)+\cdots+W_{ji}(P_i)+\cdots+W_{jn}(P_n),\\ &\text{-------------------------}\\ W_n &= W_{n1}(P_1)+W_{n2}(P_2)+\cdots+W_{ni}(P_i)+\cdots+W_{nn}(P_n), \end{aligned} \quad (1)$$

where W_{ji} is the displacement of point j under the action of force P_i, applied at the i-th point.

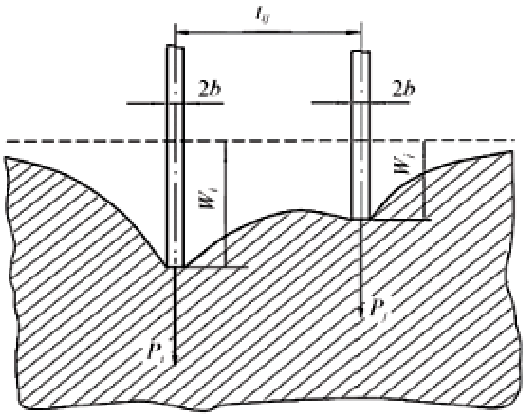

Fig. 1. Schematic of determining the spreading efforts at a layer deformation

Considering, in accordance with [10], that displacements depend linearly on forces, and denoting the matrices-columns of displacements and forces through:

$$\left\|W_j\right\| = \begin{Vmatrix} W_1 \\ W_2 \\ \cdots \\ W_i \\ W_n \end{Vmatrix} \left\|P_i\right\| = \begin{Vmatrix} P_1 \\ P_2 \\ \cdots \\ P_i \\ \cdots \\ P_n \end{Vmatrix}, \quad (2)$$

and the square matrix of rank n of coefficients of influence δ_{ij} through:

$$\left\|\delta_{ij}\right\| = \begin{Vmatrix} \delta_{11}\delta_{12}\ldots\delta_{1i}\ldots\delta_{1n} \\ \delta_{21}\delta_{22}\ldots\delta_{2i}\ldots\delta_{2n} \\ \ldots\ \ldots\ \ldots \\ \delta_{j1}\delta_{j2}\ldots\delta_{ji}\ldots\delta_{jn} \\ \ldots\ \ldots\ \ldots \\ \delta_{n1}\delta_{n2}\ldots\delta_{ni}\ldots\delta_{nn} \end{Vmatrix}; \quad (3)$$

linear equations (1) can be represented in a matrix form:

$$\|W_j\| = \|\delta_{ij}\| \cdot \|nP_i\|. \quad (4)$$

Hence:

$$\|P_i\| = \|\delta_{ij}\|^{-1} \cdot \|W\|_j. \quad (5)$$

Here δ_{ij} is the displacement at point j under the action of a single force applied at point i; coefficient of influence; $\|\delta_{ij}\|^{-1}$ is the matrix inverse to $\|\delta_{ij}\|$.

The principle of independence of displacements means that:

$$\delta_{11} = \delta_{22};......;\delta_{ij} = \delta_{ji}.... \quad (6)$$

Coefficients of influence of the matrix diagonal can take the form:

$$\delta_{11} = \delta_{22} = \ldots \delta_{ii} = \frac{W_{cp}}{P} = \frac{W_{cp}}{4qbl}. \quad (7)$$

Denoting the magnitude t through t_{ij}, that is, by giving it the value corresponding to the distance between the i-th and j-th blades, we shall similarly obtain the rest of the coefficients' values at $i \neq j$ with respect to (Fig. 2).

$$\delta_{ij} = \delta ji \frac{Wt}{P} = \frac{Wt}{4qbl}. \quad (8)$$

The shape of the surface of the deformed layer of raw cotton can be determined by summing the displacements of the point, the distance between which and the i-th blade t_i.

$$W = \sum_{i=1}^{i=n} Wt_i. \quad (9)$$

For a small total number of blades that simultaneously deform a cotton layer ($n \leq 3$), matrix inversion (3) is not difficult and the calculation of forces based on the assigned displacements can be performed using determinants from the Cramer formula.

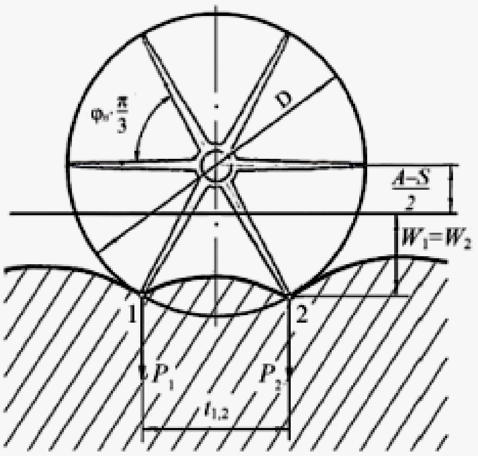

Fig. 2. Estimation scheme for determining the spreading efforts at deformation of a layer of cotton by two blades of a roller

Denoting the determinant:

$$\det\|\delta_{ij}\| = \Delta_0 = \begin{vmatrix} \delta_{11}\delta_{12}\cdots\delta_{1i}\cdots\delta_{1n} \\ \delta_{21}\delta_{22}\cdots\delta_{2i}\cdots\delta_{2n} \\ \cdots\cdots\cdots\cdots\cdots \\ \delta_{j1}\delta_{j2}\cdots\delta_{ji}\cdots\delta_{jn} \\ \cdots\cdots\cdots\cdots\cdots \\ \delta_{n1}\delta_{n2}\cdots\delta_{ni}\cdots\delta_{nn} \end{vmatrix}, \quad (10)$$

that has a non-zero value, since the rank of matrix (3) is equal to n, and the attached determinants through:

$$\Delta_i = \begin{vmatrix} \delta_{11};\delta_1(i-1);...W_{1i};...\delta_{1n} \\ \delta_{21};\delta_2(i-1);...W_{2i};...\delta_{2n} \\ ------------ \\ \delta_{j1};\delta_j(i-1);...W_{ji};...\delta_{jn} \\ ------------ \\ \delta_{n1};\delta_n(i-1);...W_{ni};...\delta_{nn} \end{vmatrix}, \quad (11)$$

where elements of the i-th column are replaced with elements of the matrix-column of displacements (2), we derive the expressions for calculating efforts P_i:

$$P_1 = \frac{\Delta_1}{\Delta_2} \geq 0; P_2 = \frac{\Delta_2}{\Delta_0} \geq 0;.....P_i = \frac{\Delta_i}{\Delta_0} \geq 0. \quad (12)$$

The non-negativity of magnitude P_i implies the condition that the blade touches the surface of a layer of raw cotton, and if this condition is not met, it is required to recalculate the system from which a blade with $P_i < 0$ should be deleted.

4. 2. Evaluation of elastic characteristics of raw cotton and calculation of spreading efforts

In order to determine numerical values for the pressure forces at which a blade acts on the flow of raw cotton, it is required to know magnitudes E and ν in the coefficient of the generalized properties of material k.

It is possible to derive them from [10], where in the system coefficients of the power function $y_x = m \cdot p^n$ acquire a value (for the medium-staple cotton grades at a moisture content of 7...9 %) $m = 11.4–11.54$; $n = 0.3$ in the interval of pressure $q = 1÷30$ kN/m^2.

For most actual materials, $\nu = 0.25–0.3$, which could be accepted for raw cotton.

If one takes, at $q_{0x} = 0$, the initial height of the prismatic volume of raw cotton to be h_0 at original density y_{x0}, and the final height at q to be h, it becomes possible to introduce a conditional magnitude of the relative deformation of cotton:

$$\varepsilon = \frac{h - h_0}{h_0}. \quad (13)$$

An increase in the transverse size of the prism should equal $b - b_0 = v\varepsilon b_0$, which yields an equation of the following form:

$$b = b_0(1 + v\varepsilon). \quad (14)$$

Because the weight of the deformed volume is constant, it is possible to determine density of the mass of raw cotton in the deformed state:

$$y_x = y_{x0} \frac{1}{(1-\varepsilon)(1+\nu\varepsilon)^2}. \quad (15)$$

Substituting (15) in $y_x = m \cdot p^n$ from [10], we obtain dependence $q(\varepsilon)$:

$$q(\varepsilon) = \left[\frac{y_{x0}}{m(1-\varepsilon)(1+\tau\varepsilon)^2} \right]^{\frac{1}{n}}. \qquad (16)$$

The resulting ratio indicates that $q(\varepsilon)$ is a hereditary function, depending on the initial state of the raw cotton that is associated with previous technological operations of its processing and storage. The drawback of (16) is that the area with the existence of pressure is limited. It is known that the modulus of elasticity is the coefficient depending on the deformation due to the stresses applied, and, in the simplest case, this dependence is linear, while the modulus of elasticity is the constant number (the Hooke's law). In the mechanics of nonlinear elastic bodies, they accept to be the modulus of elasticity in the vicinity of a given point the magnitude of derivative:

$$E(\varepsilon) = \frac{dq}{d\varepsilon}, \qquad (17)$$

which, as a variable over the entire region of changes in the values ε, can be considered to be constant over a small section in the vicinity of the assigned point.

By differentiating (16) for E, we shall obtain:

$$E(\varepsilon) = \frac{1}{n}\left[\frac{1}{(1-\varepsilon)} - \frac{2\tau}{(1+\tau\varepsilon)} \right] \left[\frac{y_{x0}}{m(1-\varepsilon)(1+\tau\varepsilon)^2} \right]^{\frac{1}{n}}. \qquad (18)$$

Paper [10] gives the estimation values for q and E for $E(\varepsilon)$ $\gamma_{x0} = 92$ kq/m^3; $m = 11.54$; $n' = 0.3$, $\nu = 0.25$ and $\nu = 0$ (for the conditions of cotton deformation in a squeezed volume).

For the feed device with characteristics shown in Table 2 [10], at $n = 6$, and when $2l = 1.840$ mm and $2b = 4$ mm, we obtain $\delta_{11} = \delta_{12} = 0.0096$ for the accepted designs of feed rollers. For two blades, $t_{12} = t_{21} = 70$ mm, and, accordingly, $\delta_{11} = \delta_{ii} = 0.00515k$.

With three blades (r_{max}), we obtain:

$$\delta_{12} = \delta_{21} = \delta_{23} = \delta_{32} = 0{,}00552k,$$

$$\delta_{13} = \delta_{31} = 0{,}00412k.$$

According to (14), for $r_{min} = 2$ and $W_1 = W_2 = 45.6$:

$$P_1 = P_2 = 3091{,}5\frac{1}{k}(H). \qquad (19)$$

The total force is the magnitude:

$$P_\Sigma = 6183\frac{1}{k}(n).$$

In the case $r_{max} = 3$ and $W_1 = W_3 = 20$ mm, $W_2 = 45$ mm (Fig. 3):

$$P_1 = P_3 = -\frac{13.88}{0.3368n10^{-2}k} < 0.$$

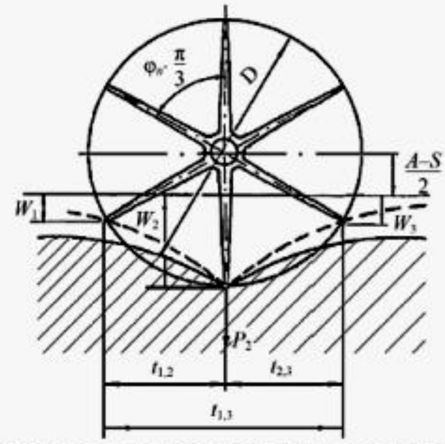

Fig. 3. Estimation scheme for determining spreading efforts when a layer is deformed by three blades

This indicates that blades 1 and 3 layers of raw cotton are not in contact and the scheme is reduced to the single-blade one. In this case,

$$P_2 = P_{\Sigma^3} = \frac{W_2}{\delta_{22}} = 5729.2\frac{1}{k}. \qquad (20)$$

Table 2 gives values for k, P_{Σ_2} and P_{Σ_3} at the different relative deformation of a layer at $\gamma_0 = 92$ kg/m^3. The values derived for $\nu = 0.25$ at $\varepsilon = 0.2$–0.7 are in good agreement with the experimental results obtained in studies [10–13].

Table 2 shows that experimental data are in good agreement with the results of theoretical studies.

Table 2

Estimation values for spreading efforts at different relative deformation of a layer

Magnitudes	ε							
	0.2		0.3		0.5		0.7	
	$\vartheta = 0$	$\vartheta = 0.25$	$\vartheta = 0$	$\vartheta = 0.25$	$\vartheta = 0$	$\vartheta = 0.25$	$\vartheta = 0$	$\vartheta = 0.25$
K, cm/H	0.359	0.752	0.201	0.453	0.0468	0.124	0.0051	0.0161
P_{Σ_2}, H	172.4	82.2	307.4	136.6	1,321.1	499.8	12,087	3,838.0
P_{Σ_3}, H	159.7	76.2	284.9	126.5	1,224.2	463.2	11,200	3,556.3
Experimental data								
K, cm/H	0.340	0.762	0.215	0.457	0.0453	0.128	0.0059	0.0158
P_{Σ_2}, H	172.4	83.2	302.4	136.6	1,312.1	496.8	12,086	3,826.0
P_{Σ_3}, H	156.7	74.2	288.9	125.5	1,212.2	467.2	11,212	3,514.3

4. 3. Determining the moment when blades contact the transported layer

Ratio (9) with respect to (1) and (2) in the examined case has made it possible to determine the shape of the deformed layer of raw cotton; in this case, the calculation of spreading forces showed that in the case of r_{max}, the surface of the layer of constant thickness will be contacted only by the middle blade.

Fig. 4 shows the estimated shapes of the surface layer for the specified cases: for points separated by 17.5 mm along the flow of a product; as well as the deviations of the surface from its non-deformed state 0–0. In the case from Fig. 5, as shown by the diagram, blades 1 and 3 do not contact a layer of cotton because they deviate from the 0–0 line by 20 mm, while the deformation of the layer under the blades is ≈33,6 mm.

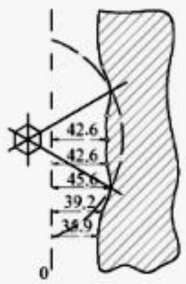

Fig. 4. Border shape of the deformed layer of raw cotton at $n_{min}=2$

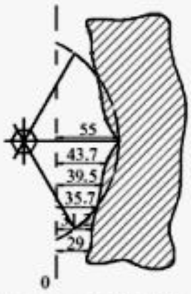

Fig. 5. Border shape of the deformed layer of raw cotton at $n_{max}=3$

To verify the relevance of the examined process pattern, we conducted a special experiment aimed to determine to what extent the bulk weight of cotton complies with the Boussinesq formula [14].

A raw cotton layer with a thickness of 170 to 380 mm and a width of 700 mm was loaded by the force of 3–10 kgf concentrated along the line, in the region located by 10 mm and more away from the point of load application we determined the deformation of the surface.

Research results are shown in Fig. 6. The criterion of conformity between the experimental law of deformation and the theoretical one is the straightness of the experimental dependence in the $W-t^{-1}$ coordinate axes. The charts demonstrate that the experimental dependence is linear, which testifies to the relevance of considering the problem on the interaction between blade rollers and raw cotton from the standpoint of contact problems from the theory of elasticity.

Because almost all the variants of loading a layer by the feed rollers' blades match the two variants of values for the number of blades that interact with a layer of raw cotton, and each variant has its maximum, it is advisable to consider problems on determining the moment of transition from r_{min} to r_{max} and vice versa.

To solve the problem, we shall apply matrix (5), subject to condition P_1–0 or P_{max}–0, which, based on the symmetry of the system, indicates that the extreme blade contacts the surface of the processed layer, respectively, at the moments when it enters the contact and exits the contact.

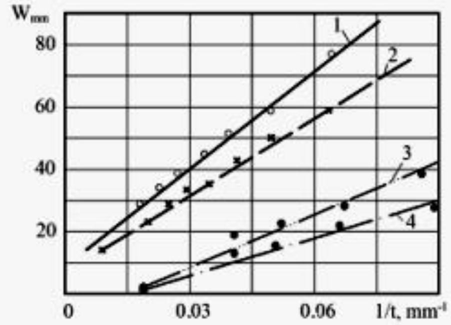

Fig. 6. Dependences of displacements W of the boundary layer of raw cotton on distance to the point of load application P: 1–2 – a layer thickness of 380 mm at P_1 and P_2, respectively ($P_1>P_2$); 3–4 – a layer thickness of 170 mm at P_3 and P_4 ($P_3>P_4$)

To satisfy the specified conditions, it is required that:

$$\begin{vmatrix} W_1;\delta_{12};...\delta_{1r} \\ W_2;\delta_{22};...\delta_{2r} \\ .... \\ W_r;\delta_{r2};...\delta_{rr} \end{vmatrix} = \begin{vmatrix} \delta_{11};\delta_{12};...W_1 \\ \delta_{21};\delta_{22};...W_2 \\ .... \\ \delta_{r1};\delta_{2r};...W_r \end{vmatrix} = 0. \quad (21)$$

That necessitates expressing the values for W_i and δ_{ij} through a shared variable. The easiest way is to express them through α, by having preliminary established the link between a variable pitch t_{ij} and a given angle (Fig. 7):

$$t_{ij} = D\sin\frac{\pi}{n}(j-1)\sin\left[\varphi_0+\alpha+\frac{\pi}{n}(i+j-2)\right]. \quad (22)$$

In the examined case, $r_{min}=2$, because at $r_{max}=3$ only one blade contacts raw cotton.

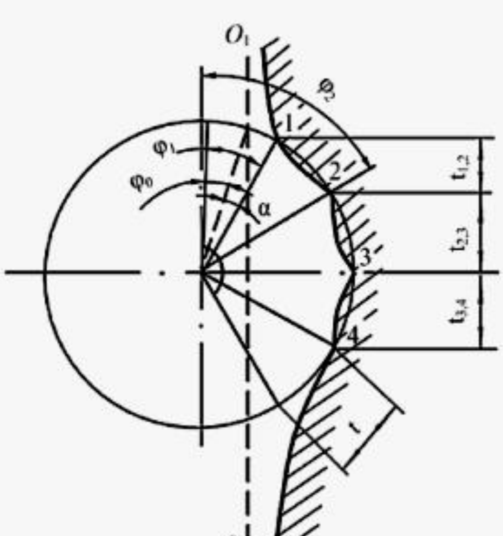

Fig. 7. Scheme for determining a distance between the points of load application

At $\varphi_0 = 0.216$ rad and $D = 140$ mm, we obtain from Fig. 5:

$$W_1 = 140\sin\frac{\alpha}{2}\cos\left(0.216+\frac{\alpha}{2}\right),$$

$$W_2 = 140\sin\left(\frac{\pi}{6}+\frac{\alpha}{2}\right)\cos\left(0.216+\frac{\pi}{6}+\frac{\alpha}{2}\right), \qquad (23)$$

and conditions (21) are reduced to the form of $W_1\delta_{22} = W_2\delta_{12}$.

By denoting for brevity records $\delta_{12} = \delta_{12}(t_{12}) = \delta_{12}(\alpha)$, which could be represented in the analytical form using (8), (2), and (22), we obtain a transcendental equation. A given equation could be solved by a numerical method employing two or three approximations (at $\delta_{11} = 0.0096k$):

$$\frac{\sin\frac{\alpha}{2}\left(0.216+\frac{\alpha}{2}\right)}{\sin\left(\frac{\pi}{6}+\frac{\alpha}{2}\right)\cos\left(0.216+\frac{\pi}{6}+\frac{\alpha}{2}\right)} = \frac{0.0096k}{\delta_{12}(\alpha)}. \qquad (24)$$

Second approximation produces a value of $\alpha = 1.172$ (67°10), which can be accepted as the ultimate result of calculation because the raw cotton does not contact the blade. This angle is matched by the angle at which blade 2 exits the contact with raw cotton $\varphi_1 = 2.435$ (139°32′).

It is not required to construct an equation for deriving the angle of blade contact because it follows from the symmetry of the system that $\varphi_1 = (\pi - \varphi_2) = 0.706(40°28)$, hence $a_{bk} = 0,490(28°6')$.

Fig. 8 shows a sequence diagram of operation of a feed roller blades as a function of the blade 1 rotation angle according to the calculations presented, which suggests that 38.89 % of the time accounts for the operation of a single blade of the roller, and 65.11 % – two blades.

Each blade that comes in the contact with a fibrous material deforms over 39°4′ the layer with the preceding blade, then, over 20°5′, a single blade operates, and, at the end of the process, over 39°4′, it deforms the layer together with the next blade.

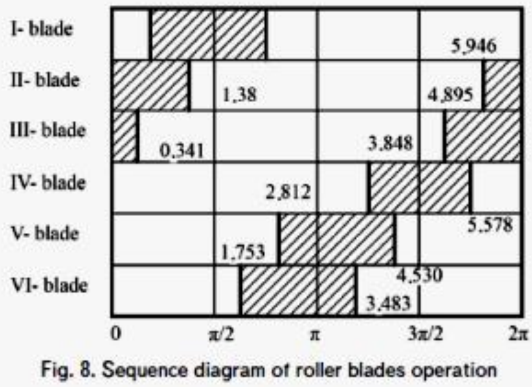

Fig. 8. Sequence diagram of roller blades operation

5. Discussion of results of studying the influence of elastic characteristics of raw cotton at feed rollers in the cleaners from large impurities

The result of our study is the established interaction between a feed roller blades and the transported layer of raw cotton. That has made it possible to determine the shape of the deformed layer of cotton; in this case, the calculation of spreading forces has revealed that in the case of r_{max} the surface of the layer of constant thickness would be in contact only with the middle blade. The result reported here is continuation of the earlier studies [10].

We have derived dependences (23) of displacements W of the boundary layer of raw cotton on distance to the point of load application on thickness of the layer of raw cotton. We have constructed a sequence diagram of the roller blades operation (Fig. 7) indicating that 38.89 % of time account for the work of a single blade of the roller, and 65,11 % – two blades.

The proposed systems are ensured through the deformation of the structural particles of cotton, as well as by the optimal *parameters for the technological system* determined in the course of calculation and experimentally as well. We have determined parameters for spreading, inclination angles of collets at loosening rollers in the processes of capturing, deforming and self-release of raw cotton.

The benefits of this research, compared with analogs, are in that the theoretical calculations take into consideration the most important technological characteristics of raw cotton. Modulus of elasticity is a coefficient in the dependence of deformation on the applied stresses; in the simplest case, this dependence is linear. Modulus of elasticity is a constant number. The degree of mass looseness correlates with the capability of raw cotton to separate weed impurities. In order to improve existing designs and to enhance the cleaning effect, we have developed a number of highly efficient feed roller blades designs that make it possible to maximally retain the natural qualities of cotton and seeds. This study makes it possible to determine theoretically and experimentally the values for spreading efforts at different relative deformation of a layer (Table 1); this would allow choosing the cleaner's engine power depending on the physical-mechanical properties of raw cotton.

The merits of this research, compared with analogs, are in that the theoretical calculations account for the most important technological characteristics of raw cotton as a material for cleaning. Specifically, we took into consideration the magnitudes of effective open surface of the structural particles of cotton per unit of its weight, associated with the coefficients of structure and the generalized material properties and the degree of mass looseness, which correlates with the capability of cotton to separate weed impurities.

The results obtained could be applied in the cotton cleaning industry.

6. Conclusions

1. We have established the effect of maturity of raw cotton on physical-mechanical properties of the fiber. In case the harvesting is delayed for 10 days, the fiber breaking load reduces by 0.1 fiber breaking load 0.2 cN.

2. The mechanism of interaction between a feed roller blades and the transported layer of raw cotton has been revealed. It was theoretically proven that the non-negativity of the magnitude P indicates the condition when a blade comes into contact the surface layer of raw cotton.

3. We have solved a geometrical problem on the deformation of a layer by blade rollers, and determined analytically

the extrema of total deformation. The total deformation of the layer is 39 degrees.

4. Application of the matrix method for calculating the spreading efforts and the shape of a deformed layer, based on a system of elastic characteristics of raw cotton, makes it possible to develop new designs of a roller blade, which reduce spreading efforts and deformation along the length of the rollers' blade. That could reduce consumption of energy by the cleaner's mechanism engine by 30 %. Based on a given model, we made an attempt at revealing the conditions for throwing a material on the blade and fixing it by a brush drum taking into consideration the deformations of portions of raw cotton. Our calculation has established that the deformation of the layer under the blades is 33.6 mm.

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