

Розроблено схему живильника, де поряд з традиційними лопатевими валами використовуються розпушувальні валики колкові або колково-планчаті. В живильнику даної конструкції досягається як плавне і рівномірне живлення машини бавовною, так і зміна технологічних характеристик бавовни-сирцю. Додаткові валики призводять до зміни технологічних характеристик бавовни сирцю, тим самим створюють процес інтенсивного виділення бур'янистих домішок. Досліджено механіку процесу взаємодії робочих елементів живильних пристроїв з шаром матеріалу, що транспортується, а також пошук систем харчування з спрямованою зміною технологічних властивостей бавовни-сирцю.

Доведено, що високий очисний ефект може бути досягнутий не тільки за рахунок інтенсифікації процесу очищення, а й спрямованою зміною технологічних властивостей бавовни-сирцю при одночасному збереженні або поліпшенні якості кінцевого продукту. Очевидно, деформація, що отримується частково в розглянутій схемі, буде максимально можливою, граничною, так як конструкція виключає прослизання продукту в зонах між лопатевими і розпушувальними валиками, що не виключається в реальній конструкції.

Досліджено технологічні властивості бавовни-сирцю як матеріалу очищення, вивчені структурні характеристики бавовни і зв'язку їх кінетики з очисними процесами. Встановлено залежності коефіцієнта структури з величиною відкритих поверхонь структурних одиниць бавовни-сирцю. Вивчено просторові характеристики засміченості бавовни-сирцю і умов взаємодії волокна і сміття в обсязі засміченої бавовняної маси. Дано варіанти поєднання живлячих валиків з різними конструкціями колкових валиків, які дозволяють сформулювати основні шляхи інтенсифікації існуючих і створення нових технологічних процесів очищення бавовни-сирцю.

На основі виявлених функціональних зв'язків відкривається можливість створення нових або вдосконалення існуючих конструкцій колкових секцій очисних машин ЧХ-ЗМ1. Отриманий досвід показує, що застосування розробленої схеми живильника в очисниках великого сміття дає значне збільшення очисного ефекту машини

Ключові слова: волокнистий матеріал, велике сміття, колкові валики, елемент бавовни, розпушувальні валики

CONSTRUCTION OF A THEORETICAL METHOD FOR EVALUATING THE KINEMATIC AND GEOMETRIC PARAMETERS OF LOOSENING ROLLERS IN THE CLEANERS OF RAW COTTON FROM LARGE IMPURITIES

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1. Introduction

An important reserve for improving the process that cleans raw cotton from large impurities is a new direction in raw cotton processing technology – preparing raw cotton for cleaning processes by the targeted change of its technological properties. Technological properties of the processed material are understood to be those properties that directly affect the efficiency of a given process. The experiment demonstrates that the use of systems that control technological properties in cleaners from large impurities produces a significant increase in the cleaning effect of the machine.

The regulated technological process of primary processing of cotton provides for a complex of cleaning equipment, which ensures that the product is released at cotton mills in the predefined amounts. However, increasing prices for

equipment, energy, and components, make, at present, cleaning lines almost inaccessible to the consumer. In addition, a significant fleet of inefficient equipment involved in the technological process eventually leads to the increased mechanical influence of working bodies on cotton and, as a result, degrades its physical and mechanical characteristics and leads to defects in the fiber and damage to the seeds.

The cotton growing regions of the CIS cultivate hard-to-clean varieties of cotton, which typically yield a high class of fiber. In this regard, in order to meet the requirements to products, additional cleaning equipment is included in the technological chain, which leads to an unjustified increase in capacity and an increase in the cost of manufactured goods. Under these conditions, the best solution to the problem is the development of high-performance technology and equipment, the price of which could be compensated by the

achieved effect. Given this, it is advisable to design cleaning tools that, at equal labor cost, would provide such an effect compared to existing cleaners from large impurities.

2. Literature review and problem statement

Paper [1] reports results from studying the parameters of basic working bodies in a cleaner, namely: the diameter and peripheral speed of a pinned drum, the angle of inclination of pins and their number, the gap between a pin and a drum, the profile of a tooth. The cited paper derived a formula, by using Koenig and Lagrange equations of the second kind, to determine the emerging shock pulses when a cotton «fly» particle hits the pins, taking into consideration the deviation of the «fly» particle, captured by the pins. The diameter of a pinned drum is chosen based on that the force of impact of cotton «fly» particles against pins at different diameters of the pinned drum is different, which led to an increase in seed damage.

A comprehensive study of the technological capabilities of raw cotton cleaning lines and combined units for removing large and small impurities was conducted in [2], in particular, to investigate the impact of multiplicity and sequence of cleaning on raw cotton indicators. The need to improve the productivity of mills led to an attempt to clean the medium-fiber raw cotton at the rate of drums increased to 500 rpm. The result of the work, however, did not achieve the required cleaning effect in terms of large impurities.

Of interest here are the results from a study that demonstrated the impact of raw cotton structure on the stability and efficiency of the process. The cause of the emergence of soft defects, as indicated in [3, 4], is the presence of structural units in cotton that contain up to 8–10 «fly» particles, elongated in the form of a garland, which twist and overlap each other, thereby acquiring axial torsion, and lead to the emergence of harnesses in the cleaned fiber. All this suggests that it is appropriate to conduct a study on estimating the kinematic and geometric parameters of loosening rollers in the cleaners of raw cotton from large impurities.

Paper [5] established that when a cotton «fly» particle hits the working face, the «fly» particle and impurities are reflected differently from a pin. The direction and speed of reflection are determined by the angle at which the pins are set along the radius of a pinned drum. It was experimentally found that the best results are obtained when installing the pins at an angle of 155–157° to the radius of the pinned drum. However, the calculations did not take into consideration the deviation of a «fly» particle from the tooth at the pinned drum rotation and the speed of the tooth surface.

The most up-to-date studies of processes taking place in the zone «pinned drum – pins» zone are reported in work [6, 7]. The result of theoretical research by the author, who considered the phenomenon of interaction between cotton «fly» particles and a pin, included the sliding of a cotton «fly» particle on its surface. He also investigated transitional processes of reflecting a «fly» particle as a result of the impact and its returning to original position. A scientifically sound choice of structural and technological parameters for a pinned cleaning section was given. A variant to overcome related difficulties might be the need for theoretical preconditions to justify the parameters.

Significant contribution to the scientific foundations of raw cotton cleaning technology was made in studies [8, 9]. They examined the dynamics of the process based on basic

elements of interaction between working bodies and raw cotton. It was shown that the process and its effectiveness are determined by two counter factors – the quality of raw cotton and the effectiveness of impurity removal. This approach has remained the general direction in studying the existing, and creating new, cleaning processes. The duality of the process is characteristic – increasing the intensity and multiplicity of impact of the pinned roller increases at the same time the cleaning effect. The damage to fiber and seeds with the formation of collateral defects in the fiber always presents a difficult task for process researchers on increasing the intensity of cleaning while preserving the natural properties of the material.

Papers [10, 11] suggest a more advanced design of a cleaner from large impurities. In this structure, under the sawed drums, there are many fixed pins with a flat working face set at a certain angle to the radius of the pinned drum. That was the basis for constructing the first Azerbaijani cleaner from large impurities, brand ChKh-3, consisting of two sections, which surpasses its predecessors in terms of performance and cleaning effect.

The removal of weeds in the cleaners of these types is carried out through the impact of cotton «fly» particles, captured by the teeth of the pinned drum.

Work [12] found that the construction of cleaners for medium-fiber raw cotton did not take into consideration the possibility of cleaning the thin-fiber raw cotton, which has a lower strength of attaching the fiber to the seeds. Cleaning the thin-fiber raw cotton requires determining the high-speed cleaner modes, which would preserve the natural physical and mechanical properties of fiber and seeds.

However, the calculations do not take into consideration the friction of a «fly» particle against the surface of a pin, and the time of impact is taken to be conditional.

The practice of processing thin-fiber raw cotton has shown that cleaning raw cotton in cleaning machines is accompanied by significant damage to seeds, which increases the amount of defects in fiber due to a fiber skin and broken seeds [13, 14]. Therefore, the rotation rate of drums was reduced at many mills in order to improve the quality of fiber and seeds [15].

Most of the cited studies are of an applied character and focus on examining particular designs of cleaners from large impurities. The scientific literature has almost no generalizations of main attributes of the feasibility of loosening rollers and a mathematical description of the effect on the characteristics of the cleaning process.

3. The aim and objectives of the study

The aim of this study is to determine the effect of kinematic and geometric parameters of loosening rollers on the quality of raw cotton in cleaners from large impurities. That would make it possible to find the optimal combination of feed rollers with different structures of pinned rollers, which could improve the effect of cleaning raw cotton from weed impurities.

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

- to determine the conditions for capturing raw cotton particles by a pin of loosening rollers when cleaning raw cotton from large impurities;
- to determine the conditions for the self-discharge of raw cotton particles by a pin of loosening rollers when cleaning raw cotton from large impurities;

- to determine the dependence of the technological characteristics of raw cotton on loosening process;
- to investigate experimentally the effect of kinematic and geometric parameters of loosening rollers on the characteristics of cleaning process and the quality of raw cotton.

4. Determining the condition for capturing raw cotton particles by a pin of loosening rollers when cleaning raw cotton from large impurities

The pins introduced to the fibrous mass have a significant speed of 1.8–2.3 m/s at the end of the pin, which makes it possible to deform particles of raw cotton. Let us consider this process in detail.

Fig. 1 shows a diagram of forces acting on an element of cotton weighing m captured by the pin; in this case, in the first diagram, the friction force prevents the particle from being removed from the pin, and in the second – to the particle of mass m being shifted to its base. This phase of the process directly follows the above-considered introduction of pin to the fibrous mass, while the external force acting on a particle (N) represents resistance of the pin’s end to the deformation and stretching of structural particles. Obviously, the stretching forces here are already absent or negligible, and therefore the force N is directed either strictly vertically or with a slight deviation at angle ξ .

The element is exposed to the reaction Q and friction force $F_{TP} \leq \mu Q$ from the side of the pin.

The inner force is the centrifugal force of inertia $P_c = m\omega_2^2 r^2$ while weight mg can be neglected.

For Fig. 1, at $\xi=0$, we have equilibrium conditions:

$$\left. \begin{aligned} \mu Q &\geq P_c \cos \alpha_1 + N \cos \lambda_c, \\ Q &\geq -P_c \sin \alpha_1 + N \sin \lambda_c. \end{aligned} \right\} \quad (1)$$

For case in Fig. 2, at $\xi=0$, we have equilibrium conditions:

$$\left. \begin{aligned} \mu Q &\geq -P_c \cos \alpha_1 + N \cos(\pi - \lambda_c), \\ Q &\geq -P_c \sin \alpha_1 + N \sin(\pi - \lambda_c). \end{aligned} \right\} \quad (2)$$

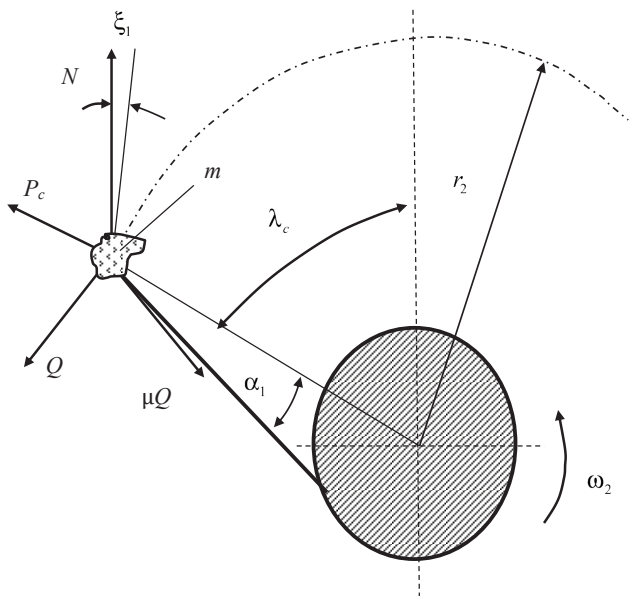


Fig. 1. Schematic of forces acting on a cotton element captured by the pin at friction against the base of the pin

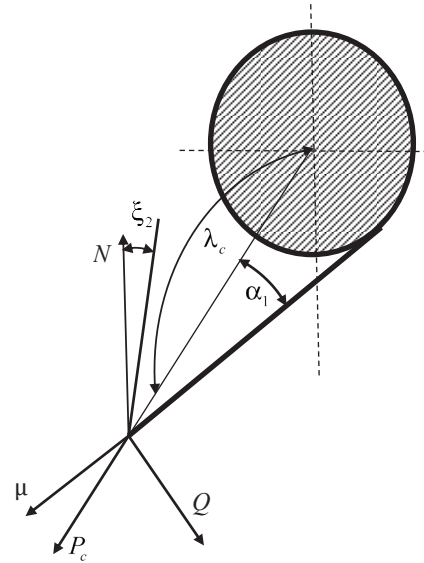


Fig. 2. Schematic of forces acting on a cotton element captured by the pin at friction against the base of the pin

The first system could produce a balance condition in the form:

$$\operatorname{tg} \lambda'_c \geq \frac{Q + m\omega_2^2 r_2 \sin \alpha_1}{\mu Q - m\omega_2^2 r_2 \cos \alpha_1}, \quad (3)$$

and the second:

$$\operatorname{tg}(\pi - \lambda''_c) \geq \frac{Q + m\omega_2^2 r_2 \sin \alpha_1}{\mu Q + m\omega_2^2 r_2 \cos \alpha_1}. \quad (4)$$

Since:

$$\frac{\partial \lambda'_c}{\partial \mu} < 0, \quad \frac{\partial \lambda''_c}{\partial \mu} > 0, \quad (5)$$

an increase in μ increases the range of change in angle $\lambda_0 = \gamma_0 + \varphi$, during which the strand is on the pin in the equilibrium state and whose extreme values are determined from conditions (2) and (3).

If the magnitude P_c can be neglected, these conditions are simplified: λ' and λ'' become a function of the friction coefficient:

$$\operatorname{tg} \lambda'_c \geq \frac{1}{\mu}; \quad \operatorname{tg}(\pi - \lambda''_c) \geq \frac{1}{\mu}; \quad (6)$$

$$\lambda'_c \geq \frac{\pi}{2} - \rho; \quad \lambda''_c \leq \frac{\pi}{2} + \rho. \quad (7)$$

Extreme values for angles in (7) determine the range of change in λ_c and its corresponding value of φ :

$$\frac{\pi}{2} - \rho \leq \lambda_c = \gamma_0 + \varphi \leq \frac{\pi}{2} + \rho, \quad (8)$$

whose magnitude is the doubled angle of friction:

$$\lambda_c \geq 2\rho, \quad (9)$$

as indicated above.

If one accepts the deviation of force N from the vertical to the right at angle ξ , it will correspond to change in conditions (8) reduced to the form:

$$\frac{\pi}{2} - \rho - \xi_1 \leq \lambda_c \leq \frac{\pi}{2} + \rho - \xi_2. \tag{10}$$

Obviously, the magnitude of range of change in λ_c will remain the same, and its lower and upper boundaries will shift to the beginning of the process at $\xi_1 \approx \xi_2$.

5. Determining a condition for the self-discharge of raw cotton particles by a pin of loosening rollers when cleaning raw cotton from large impurities

The result of introduction of pins to the tuft of raw cotton, the capture of structural particles by pins of the loosening roller and their deformation is the enlargement of structural units of significant size. Another result is the removal from the entire mass of cotton of smaller particles, slightly deformed due to the presence of a field of friction forces in loosened cotton.

This process is ordinary, implied by the technology of preparing raw cotton for cleaning. At the end of these processes, the particles still held by rollers' pins must lose contact with the cotton beard and proceed to the next section unhindered as a result of self-discharge.

The conditions for self-discharge are reduced to similar for the self-discharge of a fibrous material by the teeth of sawed tools, established for the fiber-cleaning machine.

In this case, angles α_1 and α of a given scheme correspond to the negative value of the frontal angle at the end and at the base of a pin.

One accepts with sufficient accuracy, in the saw, given the large difference between the height of a tooth and the radius of the saw, the permanence of the frontal angle, although it is shown that the distortion of the value of this angle at the top of a tooth can reach a significant magnitude. Here (Fig. 3) the magnitude of the angle is:

$$\psi_1 = \alpha - \alpha_1 = \alpha - \arcsin\left(\frac{r}{r_2} \sin \alpha\right). \tag{11}$$

One can find from (11) and (8) the values for the specified angle for any intermediate position of a particle on the pin.

By projecting the forces acting on a raw cotton element, we obtain, along the orthogonal coordinate axis (Fig. 4), the conditions for the self-discharge (a particle rests at the end of a pin):

$$\left. \begin{aligned} Q &= \omega_2^2 r_2 (cr_2 \cos \alpha_1 - m \sin \alpha_1) - mg \cos \varphi < 0; \\ \mu Q &= \omega_2^2 r_2 (cr_2 \cos \alpha_1 + m \sin \alpha_1) + mg \sin \varphi, \end{aligned} \right\} \tag{12}$$

where the air resistance factor is denoted via c .

The first of conditions (12) means the disruption of a contact between a cotton particle and the pin's surface, the second – the descent of a particle along the pin's surface as a result of sliding from the base to the end, under condition the first condition is not met in this case.

If mg is neglected, the first condition is recorded in the form:

$$\text{tg} \alpha_1 > \frac{cr_2}{m}, \tag{13}$$

which corresponds to roller rotation at a considerable speed. At low speed, this condition will take the form:

$$0 < \alpha_1 < \frac{\pi}{2}. \tag{14}$$

The second condition is more convenient to convert:

$$\mu < \frac{cr_2 \sin \alpha_1 + m \cos \alpha_1 + \frac{mg}{\omega_2^2 r_2} \sin \varphi}{cr_2 \cos \alpha_1 - m \sin \alpha_1 + \frac{mg}{\omega_2^2 r_2} \cos \varphi}, \tag{15}$$

which is also simplified at low weight:

$$\mu < \frac{cr_2 \text{tg} \alpha_1 + m}{cr_2 - m \text{tg} \alpha_1} \tag{16}$$

and is solved relative α_1 :

$$\text{tg} \alpha_1 > \frac{\mu cr_2 - m}{cr_2 - \mu m}. \tag{17}$$

These conditions hold when one changes the sign of α_1 . In this case, since (17) and (14), respectively:

$$\frac{\partial(\text{tg} \alpha_1)}{\partial r_2} = \frac{cm(\mu^2 + 1)}{(r_2 c + \mu m)^2} > 0, \tag{18}$$

$$\frac{\partial(\text{tg} \alpha_1)}{\partial r_2} = \frac{c}{m}, \tag{19}$$

at the same time as r_2 decreases and α increases, the right-hand sides of expressions (13) and (17) decrease.

From (17), at low air resistance ($c=0$), there is an obvious possibility of negativity of angle α_1 , but in general, it follows both from (14) and from (18) that at $\mu cr_2 > m$ the tilt of the pins is justified to the side inverse to rotation.

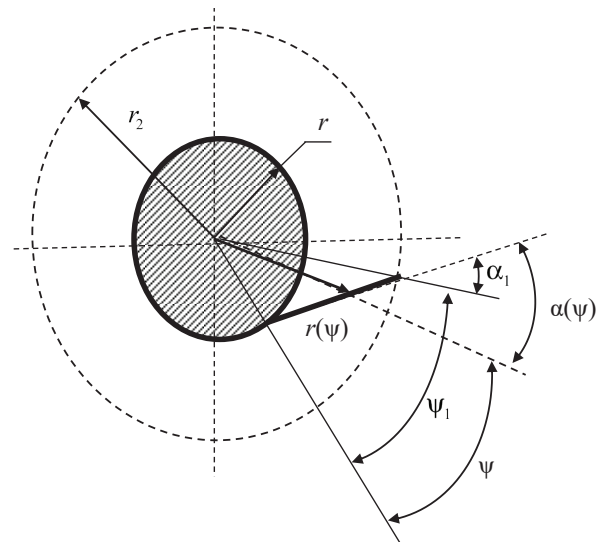


Fig. 3. Analyzing the conditions for self-discharge – dependence between angles α_1 and ψ

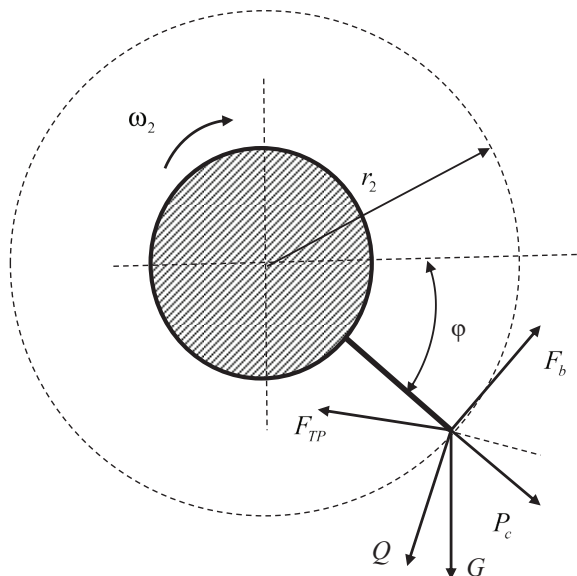


Fig. 4. Schematic of forces at particle self-discharge

The formation of windings on pinned rollers occurs in cases when the raw cotton particles, captured by a pin, in the zone of stable equilibrium at the pin's surface $\lambda_c > 0$ do not have time to lose contact with the cotton tuft due to destruction or exit from the field of friction forces. In this case, the balance of a cotton particle on the cylindrical surface of the pin is disturbed and, if condition (4) or a second condition (6) is not met, it shifts, having overcome the threshold value of friction force, to the base of the pin. Subsequently, at the turn of a pinned roller, the tail part of the specified structural particle can be captured by the following pin, resulting in a fairly stable system.

A statically indefinable system may form, where one end of the structural particle is captured by the frontal pin and shifted towards its base, the second – by the following one that holds the particle by a rear end, while the structural particle itself is pulled by the force, caused by its initial deformation. Obviously, the strength of such a system can be significant and, therefore, the particle self-discharge will not occur.

The main condition for the exclusion of windings on pinned rollers remains ensuring the destruction of bonds between the captured structural units of cotton and a layer of raw cotton.

6. Determining a dependence of the raw cotton technological characteristics on a loosening process

It was previously noted that the raw cotton structure indicator m_c and its density γ_{x0} define in a combination one of the main technological characteristics of cotton as a cleaned material through the value of effective open surface. The requirements to this characteristic appear to be variable for all stages of raw cotton processing. For example, it is problematic to excessively loosen cotton at ginning the medium-fiber cotton, and, at the same time, at roller ginning, it is better, as shown in [8], to have loosened raw cotton, with a low structure indicator.

To determine the extent of impact exerted by various variants of the structures of loosening rollers and existing feeders, as well as by their kinematic parameters, on a change in m_c and γ_{x0} , a series of experiments were performed involving raw cotton of T1, 1D grades, machine-collected, with technological humidity $W=7.9\%$.

The speed of feed rollers was adopted based on the most typical performance, $n=8$ rpm. At the same time, the rotation rate of loosening rollers varied: $n=200-600$ rpm. The cleaning section was fed at the starting density of raw cotton $\gamma_{x0}=72$ kg/m³ characteristic of the storing mines. The density of cotton that passed through the feed device was also measured – γ_{x1} . Ratio:

$$k_p = \frac{\gamma_{x0}}{\gamma_{x1}} \tag{20}$$

was accepted as a criterion for the effectiveness of the raw cotton loosening process in a given feed scheme.

Fig. 5 shows schematics of variants combining feed rollers and loosening rollers of different design.

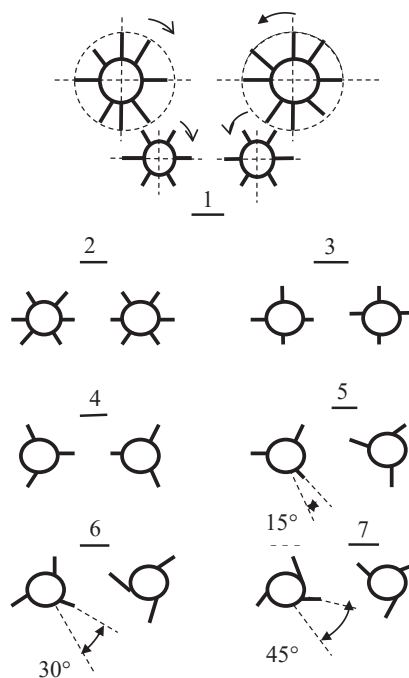


Fig. 5. Variants of combining feed rollers and pinned rollers of different designs

Our analysis of experimental results, shown in Fig. 6 in the form of charts, has revealed an overall decrease in the density of raw cotton. In this case, k_p increases with an increase in n_2 and in the number of pins on a roller. This is due to an increase in the number of impacts of pins on the same mass of raw cotton, and the increase in the number of pins by 2 times for all variants of angular speed n_2 leads to an average increase in density by 5%.

Comparison of diagrams 4–7 shows that with the increase in angle α the degree of raw cotton loosening decreases, progressively at that, which confirms the conclusions from a theoretical analysis.

The growth of k_p with the increase in n_2 is also consistent with the conclusions from a boundary problem, in which the limiting deformation of structural particles of raw cotton is observed in the zone of pinching the feed rollers, which is transported at the rate $\omega_1 r_2$ to the loosening rollers [15]. From the moment when its lower end is in the pinching zone, the deformation process begins, as the lower end of a particle leaves the zone at speed $\omega_2 r_2 > \omega_1 r_1$. The process is completed when the top end of the particle leaves the zone of feed

rollers or the particle collapses. Obviously, the deformation experienced by a particle in the considered scheme would be maximally possible, limiting, because the model excludes the slippage of a product within zones of feed and loosening rollers, which is not excluded in an actual structure.

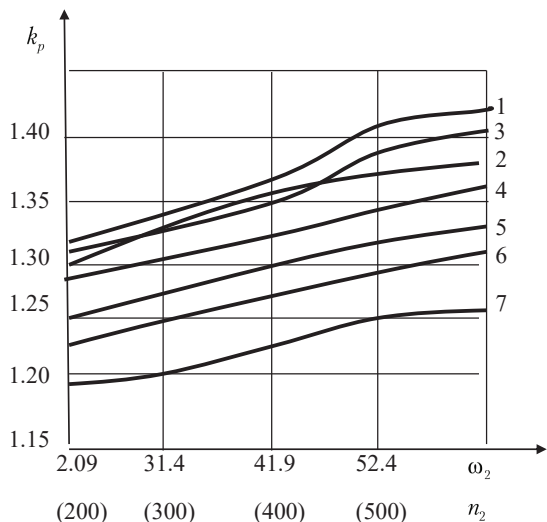


Fig. 6. Change in k_p for variants of pinned rollers designs (for schemes 1–7, Fig. 5) as a function of frequency n_2

Approximately the same dynamic was observed in the study of the kinetics of structural coefficient m_c . This is a dimensionless coefficient of change in the average size of structural particles or the degree of breaking up raw cotton particles into smaller units, measured in the laboratory. For some cleaning sections of machines, the structure of cotton changes is more complex. For example, the pinned and sawed sections of ChKh-3M1 break up the structural particles of cotton more intensely in comparison with OKh-E. The introduction of characteristic m_c and the study into its kinetics in cleaners have made it possible to re-examine the effectiveness of cleaning processes, because there is a close relationship between them. The higher the degree of breaking up raw cotton into smaller units, the easier it is to remove large and small impurities from the fibrous mass. In addition, the more intense the value of m_c decreases in a given cleaning process, the more the bonds between fiber and weed particles are loosened.

Fig. 7 shows the kinetics of structural coefficient m_c as a function of n_2 for schemes 1–6, depicted in Fig. 6. It demonstrates that the intensity of the deformation process and breaking up the structural particles of raw cotton into smaller units is proportional to the extent to which the pins act on fibrous material. Here, one notes the influence of the number of pins on the intensity of decrease in m_c , though less significant. And if one takes into consideration that with an increase in the number of rows of pins on a loosening roller with a slight increase in the effect of loosening the product there is a significant increase in the effects on cotton, accompanied by a deterioration in the quality of the material, the optimal number of rows of pins should be 3.

The introduction of blades (scheme 2) leads to a more intensive process of change in k_p than in the structure (scheme 4) where the blades are absent.

In parallel with a study into the effect of parameters of the feed unit on the efficiency of change in the technological characteristics of raw cotton, a series of experiments were

performed on the technological reliability of loosening rollers at values $\alpha=0; 15^\circ; 30^\circ$ and 45° . It turned out that at frequency $n_2=200-600$ rpm and $\alpha=0$ and 15° raw cotton, having favorable characteristics k_p , often forms windings that grow progressively and are difficult to eliminate. At $\alpha=30^\circ$, even more so at 45° , there was no formation of windings over the entire range of possible values γ_{x0} and k_p . Therefore, the value of α was accepted to be 30° .

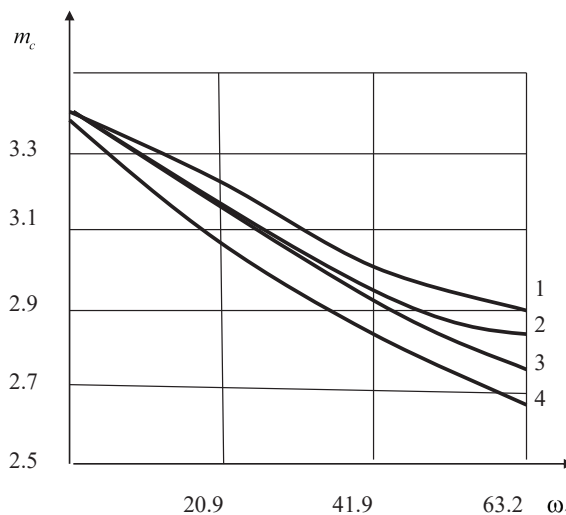


Fig. 7. Kinetics of structural coefficient m_c as a function of n_2 (for schemes 1–6, Fig. 6)

Taking into consideration the variation in the magnitude of filling the accumulators of cleaners from large impurities and, therefore, the density of raw cotton γ_{x0} , we have experimentally examined the effect of this magnitude on the technological reliability of a feed system and values γ_{x1} and m at $\gamma_{x0}=60-105$ kg/m³.

Over the entire range of change in γ_{x0} , the structure of the feed unit demonstrated reliable performance. With an increase in starting density, there was a significant increase in loosening coefficient k_p (Fig. 8) of raw cotton, while the coefficient of structure m_c (Fig. 9) slightly decreased. This has a simple explanation, because an increase in the starting density of a material leads to an increase in the intensification of loosening and deformation processes. The processes become more intense with a random factor excluded to a large degree.

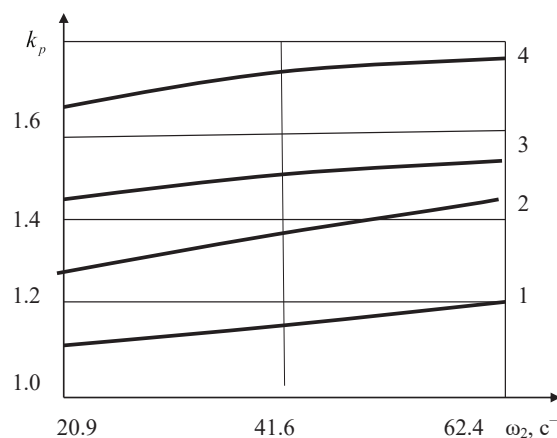


Fig. 8. Change in k_p as a function of n_2 for scheme 6 (Fig. 5): 1–4 – at $\gamma_{x0}=60, 72.90$ and 105 kg/m³, respectively

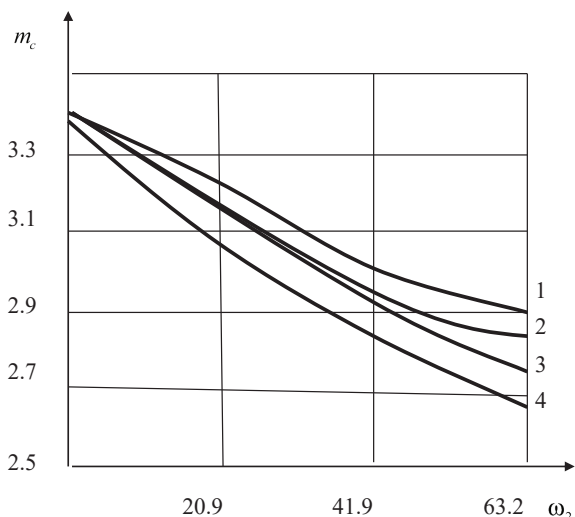


Fig. 9. Kinetics of m_c as a function of n_2 for scheme 6 (Fig. 5): 1–4 – at $\gamma_{x0}=60, 72.90$ and 105 kg/m^3 , respectively

7. Experimental study of the effect of loosening elements on the characteristics of the cleaning process and the quality of raw cotton

Experiments were conducted at an experimental bench, using T-1 cotton of grades 1, 2, machine-collected, clogged by 5.3 % (including large impurities, 3.4 %), with seed damage of 1.59 % and at the initial amount of free fiber 0.1 %. The feed was carried out at rate $n_1=8 \text{ rpm}$ at $\gamma_{x0}=72 \text{ kg/m}^3$. Experiments were carried out at the installation (Fig. 10); the diameter of the loosening roller was selected at 90 mm based on the condition for minimizing the interaxial distance between the pinned and lobed rollers; the minimum spread between the ends of the pins was 15 mm, which ensures the unhindered exit of structural particles, captured by pins, from the loosening zone.

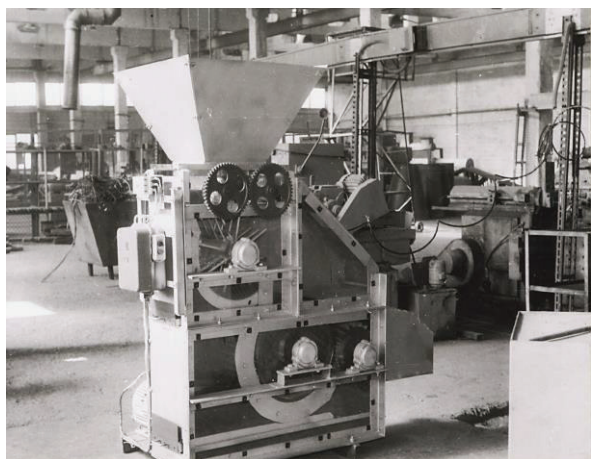


Fig. 10. A general view of the experimental bench to study the feed process and the process of cleaning raw cotton from large impurities

In order to eliminate the accidental effect of the working bodies of the preliminary and main cleaning sections on the results of comparative tests, at the first stage of experiments, analysis of the quality of raw cotton was carried out for a ma-

terial that passed only a feed device with different variants of the rotation frequency of pinned roller n_2 . The main variants of the schemes of feed rollers, shown in Fig. 5, were studied, except for scheme 2. The experimental results from testing different feed schemes are summarized in Table 1.

Table 1

Results from studying the effect of various variants of the pinned roller rotation frequency on the damage to seeds and the release of free fibers

n , rpm	Feed scheme	Impurities, not associated with cotton, % to overall amount		Damage to seeds, %	Free fiber, %
		large	total		
200	1	9.7	10.3	1.65	0.120
	2	9.6	9.7	1.65	0.120
	3	8.7	9.2	1.64	0.113
	4	8.5	8.7	1.61	0.100
	5	7.4	8.1	1.61	0.100
	6	6.0	6.5	1.59	0.099
400	1	14.0	13.3	1.72	0.143
	2	13.2	12.5	1.70	0.136
	3	13.0	12.2	1.66	0.127
	4	11.8	11.8	1.58	0.123
	5	11.1	11.0	1.54	0.11
	6	8.6	9.4	1.52	0.10
600	1	17.3	16.3	1.79	0.200
	2	15.9	15.3	1.78	0.183
	3	15.3	15.1	1.7r	0.180
	4	14.3	14.9	1.72	0.180
	5	13.3	14.0	1.69	0.140

Here there is an obvious dependence of the number of impurities, which have lost contact with the fiber and are ready for discharge, on the effectiveness of the impact of pins of the loosening roller, depending on n_2 and the number of rows of pins on the roller. Similar to the previously investigated technological characteristics k_p and m , here the efficiency of the process falls with an increase in angle α . This, together with the previously stated, confirms the close relationship between the examined technological characteristics of raw cotton and the possibilities for impurity removal.

However, the possibilities to intensify preparation are not limitless – the criterion for optimizing the geometric and kinematic parameters of the device is the quality of a processed product. With an increase in n_2 , almost all variants of schemes demonstrate an increase in seed damage and the amount of free fiber in raw cotton, so this work adopted an acceptable rate $n_2=400-450 \text{ rpm}$.

With an increase in α in variants 4–7, these characteristics change at first quite progressively, but already at 30° and 45° they are almost identical. Therefore, the conclusion about the optimality of $\alpha \approx 30-35^\circ$, drawn earlier based on theoretical assumptions and experiments, has been fully confirmed here.

One significant observation should be made: a slight increase in the amount of free fiber in cotton-raw as a result of

breaking up its structure into smaller units is, to a significant degree, if not decisive, the consequence of the separation of units into «fly» particles, and inevitably must accompany any process in which the coefficient m is reduced.

At the second stage, analysis of the operation of standard feed rollers and the optimized structure of the system (with loosening rollers paired with lobed feed rollers) was carried out in combination with two designs of pre-cleaning section drums – pinned (ChKh-3M2) and pinned-planked (ChKh-3M). The results of comparative tests of different feed systems are summarized in Table 2.

Table 2

Results of studying the effects of different study variants on damage to seed and the release of free fibers

Characteristic of the study variant	Impurities, not associated with cotton, % to overall amount		Seed damage, %	Free fiber, % to total mass
	large	total		
Feed rollers – pinned drum	12.3	10.2	1.82	0.177
Feed rollers – pinned rollers – pinned drum	16.4	13.5	1.69	0.193
Feed rollers – pinned-planked drum	16.4	16.8	1.92	0.213
Feed rollers – pinned rollers – pinned-planked drum	20.1	19.2	1.97	0.238

Analysis of data from Table 2 showed that the system with pinned drums demonstrates a softer mode of operation than that with the pinned-planked drums and less intensively removes impurities while providing a gentle mode of cotton processing. The introduction of an additional pinned loosening pair for both drum structures increases the amount of impurities extracted from a fiber material by 2.5–3.7 %, and large impurities by 3.8–4.1 % (in absolute values). In this case, the preparation reduces seed damage, which ultimately reduces the number of defects in the fiber. With the introduction of a loosening system, for natural reasons, the amount of free fiber in raw cotton becomes somewhat larger.

This is the essence of significant effect from preparing raw cotton to a cleaning process. A high cleaning effect could be achieved not only by intensifying the cleaning process, but also by the directed change in the technological properties of raw cotton while maintaining or improving the quality of the resulting product.

8. Discussion of results of studying the method for estimating the kinematic and geometric parameters of loosening rollers on the quality of raw cotton

Already at the stage of testing a feeder for the cleaner from large impurities, equipped with an element of pre-loosening and breaking up structural particles of raw cotton into smaller units, the issue arose about ways to improve it. The main drawback of this system is the inability to break up particles with a small number of «fly» particles due to the distance between the zone of exposure to the loosening pair and the region of pinching raw cotton by lobed blades.

In order to eliminate the specified drawback, a new feed system was tested in the laboratory, with the trajectories of feed and loosening rollers executed as intersecting, where the blades of a feeding roller have slits through which the pins of a loosening roller move freely.

The study has shown that such a feed system quite intensively loosens raw cotton (values of k_p for $n_2 = 300, 400,$ and 500 rpm are, respectively, 1.33, 1.37, and 1.40) and reduces the size of structural particles (at starting $m=3.45$ the values for a structure coefficient were 2.75, 2.65, and 2.45, respectively, to the enumerated values for n_2) at a slight increase in free fiber.

The lobed feed rollers paired with pinned ones showed, for the specified range of frequencies, the values of S_{yg} : 0.725; 0.769; 0.828, and the pinned feeders at n_2 equal to 300 and 500 rpm, respectively, 0.642 and 0.713.

Another reserve of the process – ensuring a more even uniformity of feed to the machine – is that the improvement of the accepted scheme of removal of large impurities is impossible without formulating theoretical foundations for the condition of self-discharge of raw cotton particles by a pin of loosening rollers considering the synthesis of an equilibrium condition and the analysis of particles on a pin. Here one needs to find rational combinations of feed rollers and different designs of pinned rollers in terms of compliance of technology with the laws of impact on a processed product.

The feed system, which is a combination of lobed rollers and loosening rollers, even though the lobed rollers themselves have a low coefficient S_{yg} , ensures a higher uniformity of product feed [10, 11].

The pinned feed rollers also showed instability in feeding a material and sensitivity to the characteristics of raw cotton in an accumulator. While demonstrating a better characteristic of feed uniformity, they cannot provide for a reliable retention of a product layer, which, as a result, reduces the evenness of feeding a product to the machine.

There is also an overall increase in the uniformity of feed with an increase in the frequency of n_2 , which is natural. The overall increase in the uniformity of raw cotton feed to the machine is 42–53 % for S_{yg} relative to the conventional feed system at $n_2=400–500$ rpm. And this is another reserve for improving the efficiency of cleaning processes.

An important reserve for improving the process is a new direction in the technology of processing raw cotton – preparation of raw cotton for cleaning processes by the directed change in its technological properties. Technological properties of the processed material are understood to be those properties that directly affect the efficiency of a given process. The results obtained from experiments on testing different feed schemes in terms of seed damage and the release of free fibers (Table 1) show that the use of systems that control technological properties in the cleaners from large impurities produces a significant increase in the cleaning effect of the machine. Analysis of the experimental results (Fig. 6) has revealed an overall decrease in raw cotton density. In this case, k_p increases with an increase in n_2 and the number of pins on a roller. The main thing is that the use of systems that combine feed rollers with different structures of pinned rollers (Fig. 5) makes it possible to reduce the degree of impact of the machine on raw cotton, thereby eliminating an excessive damage to a processed material.

The proposed feed system has solved the boundary problem on deforming the structural particles of cotton; the optimal magnitudes have been determined by estimations, as well

as experimentally, for setting, angles of inclination of pins for loosening rollers in the processes of introduction, capture, deformation, and self-discharge.

9. Conclusions

1. The equations have been derived for the forces that act on a cotton element captured by the pin at friction, both to the base and from the base of the pin, taking into consideration the conditions of equilibrium. It has been proven that an increase in the friction coefficient between the pin and a cotton element increases the range of change in the angle of inclination to a layer's surface, where the pin additionally deforms raw cotton by its side surface.

2. To study the variants of the cleaner's feed system with a loosening structure, the effects of the kinematic and geometric parameters of the system on the technological properties of raw cotton have been determined – its structure and volume mass. The study has shown that such a feed system quite intensely loosens raw cotton at values k_p for $n_2=300, 400$ and 500 rpm, respectively, 1.33, 1.37, and 1.40, respectively. This reduces the size of structural particles at a certain growth of free fiber. The introduction of the loosening system

results, for natural reasons, in that the amount of free fiber in raw cotton becomes somewhat larger.

3. Schemes have been proposed of the variants of combination of feed rollers with different designs of pinned rollers. The systems have been developed to assess the uniformity of feed plants in terms of preparing raw cotton for the basic technological process. The mechanics has been investigated of the process of interaction between working elements of feed devices and a layer of the transported material, which makes it possible to search for feed systems with a directed change in the technological properties of raw cotton.

4. Several variants have been examined of rollers with a different number of pins, in a combination of pins with planks, with a different inclination of pins ($\alpha=15^\circ, 30^\circ, 45^\circ$); loosening rollers have been explored in a combination with lobed and pinned feed rollers. With an increase in n_2 almost all variants of schemes demonstrate an increase in seed damage and the amount of free fiber in raw cotton. Therefore, this work has adopted acceptable speed $n_2=400+450$ rpm. Analysis of results from the study has revealed that the system with pinned drums has a softer mode of operation than that with the pinned-planked drums, it removes impurities less intensively, but provides a gentle mode of cotton processing.

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