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THEORETICAL SUBSTANTIATION OF THE CONDITIONS FOR CAPTURE OF FIBER BY THE WORKING DRUM BY THE KNIFE IN ROLLER GINS

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Roller ginning provides 2–3 times less mechanical damage to cotton fiber than saw ginning. In recent years, these positive moments have predetermined attempts to gin medium-fiber cotton on roller gins. However, the low productivity of roller gins compared to saw gins does not yet allow for a complete transition to this process.

To design high-efficiency roller gins, it is necessary to deeply study the mechanics of the basic processes of interaction of raw cotton with the working organs of the gin. It is necessary to determine the reserves for improving the efficiency of the process of capturing and tightening the fiber behind the knife, to investigate the mechanics of the process of rebounding seeds, and to find new solutions to reduce their damage.

As a result of the research reported here, a mathematical model of the roller ginning process has been built, which makes it possible to determine the impact of technological and structural parameters of the roller gin on the efficiency of the process. This allows for the reasonable application of a variable periodic friction field between the knife and working drum.

When studying the kinematics of the interaction of the surface of the working drum with the knife, dependences were established to accelerate the points of the surface of the working drum before it enters behind the knife, making it possible to determine the forces acting on the fiber when it is captured by the micro-irregularities of the drum.

In the study of the process of tightening the fiber with a pair of working drum-fixed knife, the conditions for ginning the flyer fibers and the dependence of productivity on the average pressure in the contact of the knife with the drum were determined. The study of the influence of the rigid characteristics of the working drum-knife system on the ginning capacity of a roller gin has made it possible to reveal new reserves for improving the efficiency of roller ginning

Keywords: drum surface, tightening force, knife-drum, flyer fiber, wedge gap

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1. Introduction

The most important process in the technology of primary processing of fine-fiber cotton is roller ginning. The first varieties of fine-fiber raw cotton with fiber types I–III are ginned on roller gins. The main advantage of roller gins is the ability to ensure maximum preservation of the valuable natural properties of cotton fiber during ginning with less than with saw ginning formation of various fiber defects.

The processes of research of roller ginning can be divided into the capture and tightening of the fiber by the working drum behind the knife and interaction with the breaking body.

The main disadvantages of the roller gin (RG) are the low productivity of gin on fiber, large damage to seeds, and contamination of fiber with them. Therefore, the search for new designs of the working bodies of the roller gin continues. The developed gin DV-1M has a rigid breaking body of multi-impact action. The new gins made it possible to increase the productivity of the gin but the damage to the seeds [1] still exceeds 5 % while the physical appearance of the fiber deteriorated since the flyers during ginning, due to the presence of axial and longitudinal mixing, are stretched and twisted. In addition, the new gin was very sensitive to the increased humidity of raw cotton and lost its productivity at a cotton humidity of 9–10 %.

Thus, the design of roller gins is constantly being improved but at the present stage, roller ginning still remains one of the weak links in the primary processing of cotton. Therefore, a comprehensive study of the process is needed in order to increase the efficiency of ginning and improve the quality of the fiber.

2. Literature review and problem statement

In works [2, 3], a more correct hypothesis was expressed about the mechanism of capture of fibers by the working drum. It is noted that in the roller gin there is a process similar to the work of the saw gin: the capture process and the separation of the fiber from the seed, and the basis of the capture is the interaction of the fiber with the rough surface of the drum. Obviously, in order to determine the best gripping conditions, more detailed studies into the process of interaction of the drum surface with the fiber are necessary.

It is known [4] that the physical and mechanical properties of the working drum material determine the productivity of the machine and the quality of the fiber. The capturing and ginning ability of a drum depends primarily on the frictional properties of its material. The greater the coefficient of friction of the fiber on the material of the drum, the more efficient the ginning process. The traditional material for the working drums was technical leather (boogie, yak, camel, walrus, etc.).

Study [5] gives a mathematical notation of the process of pressing cotton fibers into bales and establishes the characteristics of such a process. The study of the desired dependences was based on a mathematical description of the mechanical model of Kelvinn-Voitt in relation to textile fibers. However, the paper does not investigate such issues as the acquisition of defects in cotton raw materials after passing through garbage cleaners and other technological machines, the compaction of individual particles along the periphery, fiber deterioration, and stalling with the formation of soft defects.

The practice of processing fine-fiber raw cotton has shown [6] that the cleaning of raw cotton on cleaning machines is accompanied by significant damage to the seeds, which increases the amount of defects in the fiber due to the peel with fiber and broken seed. However, there are no answers to the question on what the properties of cotton in dynamics are, what processes can be implemented in this case.

Among the studies considering the choice of the speed parameters of the working drum and the breaking body, worth noting is the work investigating the effect of the speed of the gin drum and the force of pressing the knife on the performance of the gin [7]. Work [8] found that with an increase in speed from 1.6 to 4.0 m/s and the force of pressing the knife to the drum from 52 to 108 N/cm, the productivity of the gin increased from 236 to 720 kg/h during a short-term experiment. However, due to the great work of the frictional forces, overheating of the drum was quickly achieved and it failed.

The task of increasing the tightening force of the working drum behind the knife by increasing the pressure of pressing the knife and preventing overheating of the drum led to the idea of using periodic pressing of the knife with a load amplitude exceeding the traditional one [9]. That has made it possible to open up a new large reserve for improving the efficiency of roller ginning and to patent a new principle in the UK [10]. However, such areas as modeling the laws of deformation and change of shape, volume of raw cotton under the influence of static and dynamic loads have not been studied.

Studies into the influence of the speed of the working drum on the ginning process, conducted by the authors of [11], showed that an increase in the productivity of the gin was observed only with an increase in speed of 2.5 m/s. Further increase in speed caused a deterioration in the capturing ability of the drum as the centrifugal force increased sharply. The same opinion is shared in [1].

Paper [12] reports the result of studies into the process of roller ginning, processing on roller machines of fibers and seeds of raw cotton that are subjected to repeated dynamic influences. In practice, after the completion of cleaning, the fibers are significantly damaged, subject to deformations of the plasticity limit, and have lost the physical and mechanical properties valuable for obtaining high-quality products. The experiments were not performed correctly by the researcher in the sense of choosing the frequency of the system's natural oscillations, and, at a minimum, the values of the impact force obtained in this work are an order of magnitude higher than the actual ones that take place.

Studies of the effect of the diameter of the gin drum on the operation of the gin have shown that with an increase in diameter from 200 to 400 mm, its performance increases by 1.5 times [13].

But increasing the diameter of the working drum complicates its design and increases the weight. The explanation for increasing productivity by reducing centrifugal forces alone is unconvincing. Apparently, with an increase in the diameter of the working drum, the area of fit of the fixed knife (contact area) also increases, this makes it possible to increase the pressing of the knife to the drum, and, consequently, the tightening force. Here, too, the influence of the stiffness characteristics of the drum-knife system was clearly manifested since the drum of a larger diameter had less rigidity, and the knife had a thickness greater than the traditional one.

When observing the process of tightening and ginning the fiber, the thickness of the fiber bundles passing between the knife and the drum was not taken into account [14]. At the same time, it is obvious that the fiber causes additional deformation of the knife-drum system, increases pressure and tightening force.

To increase the productivity of the roller gin, it is necessary to make fuller use of the working surface of the drum per unit of time, both along the length of the working drum (across the product ginning stream) and along the flow. The coefficient that characterizes the efficiency of ginning is primarily affected by the capturing and tightening ability of the working drum. This depends on the frictional properties of the material, its adhesion to the flyer fibers, as well as the best conditions for adhesion of the fibers to the micro-irregularities of the surface of the working drum.

Analysis of the scientific literature [15, 16] showed that the effect of drum surface stiffness on the ginning process was practically not studied. Some attempts to solve this issue were made in [17]. The uniformity of the compression density of the knife disk package along the forming drum has not been studied at all, and in fact the resulting friction forces against the shaft can significantly distort the picture.

The feeding of rolled gins and the pre-preparation of raw cotton for ginning for fine-fiber varieties are practically not well understood.

Ensuring the necessary uniformity of the cotton supply to the machine and creating the right structural composition for the ginning process is an essential source of improving the quality of the fiber.

3. The aim and objectives of the study

The aim of this study is to theoretically substantiate the conditions for capturing fibers by studying the process of stable penetration of part of the volatile fibers into the wedge gap between the knife and the surface of the drum. This will further solve the problem of optimizing the parameters to increase the productivity of the gin, reduce the damage to the seeds and the contamination of fiber with them.

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

– to determine the stability conditions of the dynamic grip of the flyer in the wedge gap between the knife and the surface of the drum at the edge of the knife;

– to determine the speed of movement of the flyer in the gap between the knife and the surface of the drum under the unstable mode of operation of the ginning machine.

4. The study materials and methods

The object of this study is roller gins, which are installed in the gin shops of cotton factories; their purpose is to mechanically separate cotton fiber from seeds in fine-fiber varieties of cotton. The following technological requirements are imposed on roller gins: the effect of the ginning roller and the breaker mechanism on the raw cotton during fiber separation should not lead to damage to seeds and the formation of fiber defects; damaged ones should not enter the fiber seeds, and fiber contamination should be minimal.

The hypothesis of the study assumed the possibility of determining the conditions for capturing fibers by studying the process of stable penetration of part of the flyer fibers into the wedge gap between the knife and the surface of the drum and clarifying the speed of movement of the flyer in the gap between the knife and the surface of the drum.

Interaction of the working drum with fibers in the contact area with the knife is the main process that determines the tightening capacity of the gin and the efficiency of ginning.

The fibers of the raw cotton flyers entering the ginning zone are captured by the surface of the rotating working drum at the edge of the knife and pulled by the knife. Once in the contact zone with the knife, the fiber is transported according to the scheme of a rotating drum – material – fixed plane.

The material (fiber) will move if the condition is met [9]:

$$\mu_1 N > P_0 + \mu_2 N, \tag{1}$$

where N is the force of pressing the drum to the plane; $F_\delta=\mu_1 N_1$ is the frictional force of the drum applied to the transport material, it is the driving force; P_0 is the material motion resistance force; $F_n=\mu_2 N$ is the resistance force of the material to be moved, due to the frictional forces of the fixed plane; μ_1 is the coefficient of friction of the material against the drum; μ_2 is the coefficient of friction of the material on the fixed plane.

Equation (1) demonstrates that the force of separation of the fiber depends on the force of pressing per unit length of the knife N and the difference in friction coefficients. If the value of P_0 exceeds the strength of fixing the fibers, the raw cotton is ginned. When designing a friction unit composed of a fixed ginning knife-roller, one must strive to ensure that the coefficient of friction μ_1 is the largest while μ_2 is the smallest.

Then the condition of motion of the material follows from equation (1):

$$N(\mu_1 - \mu_2) > P_0, \tag{2}$$

where the left-hand side of the inequality is the driving force of the working drum-material-knife system, which determines the pulling capacity of this system, i.e.

$$P_z = N(\mu_1 - \mu_2). \tag{3}$$

The expression for the pulling force of the fiber by the working drum behind a knife for a roller gin in this form is known from works [3, 9].

The resistance force of the movement of the fiber P_0 in a roller gin should be understood as the forces of fixing the fibers on the seed. Obviously, the separation of the fibers from the seed will occur if the condition is met:

$$P_z > P_0. \tag{4}$$

Expression (4) is a condition for the ginning of a fly of finely fibrous raw cotton. Given the strength of the fixation of the fibers on the seed f, the simultaneity coefficient of the separation of the fibers m and the average number of fibers on the fly z, one can write:

$$P_0 = mfz.$$

Now the ginning condition takes the following form:

$$N(\mu_1 - \mu_2) > mfz. \tag{5}$$

In expression (5), the simultaneity coefficient of the separation of the fibers from the seed is determined by the fact that after the fibers are tightened by the drum behind the knife and the seed is pulled up to the edge of the knife, some fibers begin to stretch, others straighten and occupy a position in the meridian plane relative to the working drum passing through the point of fixation of the fiber on the seed.

In the event that the tension force exceeds the binding force of the fibers, the fibers will break away from the seed. The initially tightened fiber bundle typically contains 20 to 50 percent of the total number of flyer fibers. Breaking off the tighter bonds allows the seed to be reoriented by pulling the undisturbed flyer fibers. All of this happens within hundredths of a second. This separates the fiber from a single fly whose fibers are not bonded or tangled.

The intensity of the fiber separation process largely depends on the tension of the flyer fibers tightened behind the knife. The amount of tension depends on the tightening force developed by the drum-knife system.

It is known [5, 8] that the efficiency of ginning, and the productivity of the roller gin primarily depend on the intensity of the fiber tightening behind the knife. In addition, the effect of the average pressure in the contact between the knife and the drum on the performance of the roller gin was studied. Studies were conducted on a serial DV gin installed at a gin with a working drum from RKM-2.

The dependence of the increase in the productivity of the gin (U) on the pressure of pressing the knife to the surface of the drum is shown in Fig. 1. The plot (Fig. 1) demonstrates that the productivity of the roller gin increases significantly with increasing pressure (q) between the knife and the drum, and its growth is greater for the 5904-I variety, which has a lower strength of attaching fiber to seeds compared to the C-6029 variety.

This nature of the ginning process is fully described by condition (5).

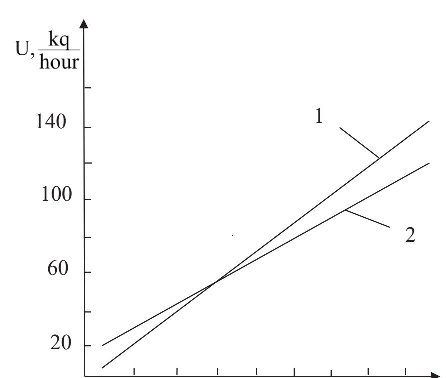

Fig. 1. Dependence of the productivity of the roller gin on the average pressure of the knife pressing: 1 — corresponds to the fine-fiber raw cotton of the variety 5904-I of the 1st grade, manual collection, fiber type III; 2 — corresponds to the variety C-6029 of the I-th grade, manual collection, fiber type I)

It should be noted that the dependence for the tightening effort (3) and the ginning condition (5) do not fully reveal the essence of the process of pulling and ginning. They mainly show that the frictional properties of the working drum material have a significant impact on the tightening force. The clamping force of the knife N is limited by the permissible limit of the criterion for the durability of the drum material $[qV]$ (for PKM-2 $[qV]$=230÷250 Nm/cm^2).

The main disadvantage of the mathematical description of the process (3) and (5) is that these dependences do not take into account the stiffness of the knife and the surface of the working drum, the thickness of the pulled product (fiber). It has been shown that it is the cause of deformation of the knife-working drum system, the law of pressure distribution in the contact zone. These factors significantly affect the ginning capacity of a roller gin.

5. Determining the rational conditions for the capture of fibers by the working drum of the roller gin

5. 1. Stability study of dynamic flyer capture

If a flyer of mass m is moving at an absolute velocity V, then its total energy P consists of kinetic energy $mV^2/2$ and compression energy $kl^2/2$, into which the kinetic energy passes at the moment the flyer is deformed when it hits an obstacle. Thus, the total energy is:

$$\frac{mV^2}{2}+\frac{kl^2}{2}=\Pi, \tag{6}$$

where k is the coefficient of elasticity of the flyer material, and l is the amount of its deformation. In (6), the values V and l are current, a decrease in one of them causes an increase in the other, and vice versa.

The absolute speed of movement of the flyer can be represented in the form:

$$V=V_0+\Delta V, \tag{7}$$

where V_0 is the rate at which and below which the capture of the raw material particles by the contact pair becomes impossible, and ΔV is some excess in excess of V_0 velocity. It is assumed that $V_0<\omega_b$, where ω_b is the circumferential velocity of the working drum of the gin.

The amount of deformation l of the flyer after hitting an obstacle can also be represented as:

$$l=l_0+\Delta l, \tag{8}$$

where l_0 is the deformation of the flyer when it hits an obstacle, and Δl *is* the correction value of the deformation caused by ΔV – the difference in velocities V and V_0.

Substitution (7), (8) in (6) results in the following equation:

$$\left(\frac{mV_0^2}{2}+\frac{kl_0^2}{2}\right)+\left(mV_0\Delta V+kl_0\Delta l\right)+ \\ +\left(\frac{m\Delta V^2}{2}+\frac{k\Delta l^2}{2}\right)=\Pi=\Pi_0+\Delta\Pi. \tag{9}$$

One can now use (9) for further analysis in two cases. In the first of these, the values of ΔV^2 and Δl^2 are assumed to be small compared to the other terms in (9), and then they can be omitted from consideration:

$$\left(\frac{mV_0^2}{2}+\frac{kl_0^2}{2}\right)+\left(mV_0\Delta V+kl_0\Delta l\right)=\Pi=\Pi_0+\Delta\Pi. \tag{10}$$

If the values of ΔV^2 and Δl^2 in (9) cannot be neglected, then (9) in its entirety will be used to analyze the question.

In the ginning node, the size of the gap between the knife and the drum is very small. Initially, at the time of the impact of the flyer on the knife with a small speed of ΔV, a very small part of the flyer can enter the gap, the direction of speed coincides with the direction of the wedge-shaped gap of the contact pair.

The main part of the raw material is outside the entrance to the slot of the gap, hitting a fixed knife. The outcome of further events in the capture of the flyer is determined precisely by the dynamic behavior of that small part of the flyer that turned out at the entrance to the gap in the vicinity of point 0 (Fig. 2).

Based on this, it can be assumed that in (10) the main part of the energy:

$$\frac{mV_0^2}{2}+\frac{kl_0^2}{2}=\Pi_0,$$

changes when struck by the reaction force from the surface of the knife and cannot affect further events at the entrance to the slot of the gap of the ginning pair.

Let's assume that in (10) magnitude:

$$mV_0\Delta V+kl_0\Delta l=\Delta\Pi, \tag{11}$$

is that small part of the energy ΔP that can enter the gap between the knife and the surface of the working drum at the boundary of the knife-drum contact spot, where the pressure force N pressing the knife rises from zero to some maximum value.

This is where the events of capturing (or pushing back out of a slit) fiber take place.

In the depth of the contact spot, the pressing forces of the knife N reach a very large value of 86 N/cm^2. But this is caused by the technological need to hold the fibers when the seeds are detached from them, and not by the need for the initial capture of the fibers at the border of the contact spot. If the capture conditions (even at the smallest) are farther, then the further process of movement of the flyer to the center of contact goes on by increasing under any law of external pressure on the contact.

The total inflow of energy into the gap at the boundary of the contact spot consists (11) of the energy ΔP coming from the side of the flyer, and the work of the frictional force A_t from the side of the drum and knife.

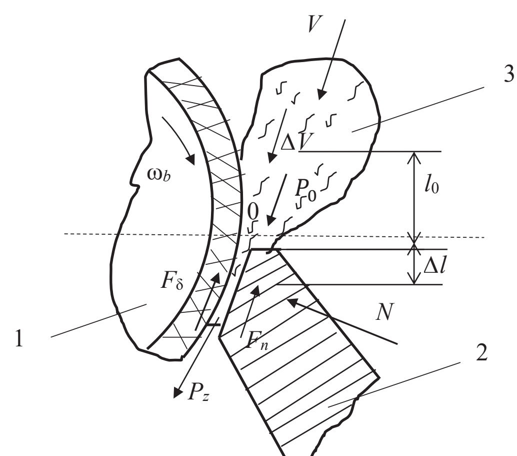

Fig. 2. Scheme of interaction of the knife with the drum: 1 – drum; 2 – knife; 3 – flyer, at $V>\omega_b$; $V<\omega_b$ when $\Delta V=0$, $P=P_O$, $\Delta l=\Delta l_{max}$

It is important to solve the question under which mode – stable or unstable – the ginning machine works in a stationary technological process.

The condition of stability of the system requires that the flow of energy into the ginning gap be less than the flow rate, i.e.:

$$\Delta\Pi + A_t < 0 . \qquad (12)$$

In this case, the system behaves as a dissipative and its oscillations fade. The flyer will always remain in the small vicinity of point 0 (Fig. 2) at the entrance to the gap, without penetrating further inside the contact spot towards the exit from the gap. But this condition is exactly undesirable when ginning. With this course of events, a stationary technological process becomes impossible.

The purpose of the technological machine is to draw the particles of raw materials into the gap and their further movement along the gap. In this case, the flyer, having passed point 0 at the entrance of the gap, must always move away from it to the exit from the gap. This requirement actually means the creation of conditions for the instability of movement at the entrance to the slit of the gap. If the flow of energy into the gap exceeds the flow rate, then:

$$\Delta\Pi + A_t > 0, \qquad (13)$$

in this case, the equilibrium position of the system is unstable. The system comes out of this position without any external influence and fluctuates with increasing amplitude.

It is necessary to consider the arrangement and nature of the forces that arise when the flyer enters the contact gap at the time of the impact of the flyer with a stationary knife. There are two kinds of forces here – the large impact forces of the flyer compression and the frictional forcing forces of the drum and knife, as well as the usual final forces in the stationary ginning process. As is known from the theory of impact, it is possible to neglect the action of finite forces in comparison with the shock forces, which are an order of magnitude higher than the finite ones.

In addition, the positions of the colliding bodies in the process of impact are considered instantly unchanged, only the magnitudes and directions of the velocities of the colliding bodies can change.

As already mentioned, when the flyer moves at a speed of V_0 or less than it, the raw material does not fall into the gap, which means that the frictional force in the gap when the flyer strikes at a speed of V_0 increases by ΔV.

Let the value of ΔV be small, then according to (10) and (11), in inequality (13) the value $\Delta P = mV_0\Delta V + kl_0\Delta l$ is positive.

The work of the frictional forces F_δ and F_n applied to the flyer on the side of the drum and knife on the movement of Δl is always negative since the frictional forces are directed opposite to the movement of Δl (Fig. 2):

$$A_t = -\left(F_\delta + F_n\right)\Delta l.$$

Substituting these values for Δl and A_t in (13), an inequality of the following form is obtained:

$$mV_0\Delta V + kl_0\Delta l - \left(F_\delta + F_n\right)\Delta l > 0 . \qquad (14)$$

Two phases of motion are subject to consideration when pushing ΔV velocity. Let in the first phase of the impact the amount of deformation of the medium Δl be maximum, and $\Delta V=0$. This corresponds to the end of the push of the speed ΔV. At $\Delta V=0$, it follows from (14):

$$kl_0 > F_\delta + F_n. \qquad (15)$$

In the left part of this expression, kl_0 is actually the force P of the maximum elastic compression pressure on the side of the flyer on the gap at the end of the impact, when the $\Delta V=0$, taking this into account, inequality (15) will take the final form:

$$P_0 > F_\delta + F_n. \qquad (16)$$

Expression (16) is the desired initial condition for the capture of raw materials, imposed on an arbitrarily small area Δl of the introduction of raw materials at the boundary of the contact spot. In the first phase of the push, it connects such dynamic characteristics of the system as the compressive force P_o of the flyer and friction F_δ and F_n on the surface of the drum and knife. When this condition is met, the capture of cotton particles between the knife and the drum leads to the further advancement of the raw material to the exit from the gap.

Expressions (14), (16) demonstrate that the greater the excessive rate of $\Delta V=0$, the more active is the capture of the raw material particle and the more reliable the guarantee of capture by the ginning pair since the dynamic force of the introduction P_0 and the depth of the introduction Δl of the cotton particle into the contact gap increase. The greater force of the introduction P_0 makes it possible to overcome the frictional resistance $F_\delta+F_n$ from the first blow at the entrance to contact in a short period of time.

However, if the excess velocity $\Delta V=0$, this does not mean that the capture of the cotton particle at the input to the contact is impossible. Provided $\Delta V=0$, the capture becomes not instantaneous and one-time but stretched indefinitely in time.

At $\Delta V=0$, the oncoming particles of raw materials begin to accumulate at the entrance to the contact gap. At the same time, when the gin is operating, the entire structure of the working roller vibrates due to a number of inevitable conditions of a production, constructive, and technological nature. Because of this, the behavior of frictional resistance $F_\delta+F_n$ at the entrance to the slit is oscillatory in nature and at times can fall to a very small value. In these moments, favorable conditions are created for capturing the accumulated raw materials at the entrance to the gap. Here, the flyers also vibrate along with the roller design and periodically create a very small force of introduction into contact P by the flyer.

5. 2. Determining the flyer speed under the unstable mode of operation of the ginning machine

At moment $P_0>F_\delta+F_n$ the flyer is captured but as mentioned, there are very small quantities on the right and left sides of the latter inequality.

If the value of ΔV in (9) becomes significant, the values ΔV^2 and Δl^2 in (9) can no longer be neglected. Then, from (9), the value of the energy:

$$\Delta\Pi = \left(mV_0\Delta V + kl_0\Delta l\right) + \left(\frac{m\Delta V^2}{2} + \frac{k\Delta l^2}{2}\right), \qquad (17)$$

and the work of frictional forces has already been found earlier in the form:

$$A_t = -\left(F_\delta + F_n\right)\Delta l.$$

Substituting these values for $\Delta\Pi$ and A_t in (13), an inequality of the following form is obtained:

$$\left(mV_0\Delta V + kl_0\Delta l\right) + \left(\frac{m\Delta V^2}{2} + \frac{k\Delta l^2}{2}\right) - \left(F_\delta + F_H\right)\Delta l > 0. \quad (18)$$

Here, the maximum value of deformation Δl is reached at the end of the push velocity $\Delta V=0$. If we substitute $\Delta V=0$ in (18), it follows that:

$$kl_0 + \frac{k\Delta l}{2} > F_\delta + F_n, \quad (19)$$

here $kl_0=P_0$ is the pressure of the flyer after braking at its initial impact velocity V, and $k\Delta l/2=\Delta P$ will be some additional pressure value caused by an increment of velocity by ΔV. With this in mind, (19) will take the final form:

$$P_0 + \Delta P > F_\delta + F_n. \quad (20)$$

Inequality (20) expresses a necessary condition for capturing raw materials in the vicinity of point 0. In appearance, it summarizes the previously obtained capture condition (17), derived in the assumption of smallness V. In (20), the term of the form ΔP strengthens the inequality sign compared to (17). Of course, if the value is very small, then in (20) $\Delta P=0$ and, as you might expect, this is where (17) follows.

Expression (20) suggests that as ΔV increases, the ΔP component increases, and this in turn improves the capture of raw materials by the ginning pair.

Now the case can be considered when the value of ΔV is small. In the second phase of the push, the rebound of the flyer from the knife begins (Fig. 3), and then the force $P_0=0$ disappears, and the speed of the push becomes opposite to the original direction, i.e. $-\Delta V$.

After that, the raw material that falls at the entrance to the gap begins to lag behind the circumferential velocity of the drum and tends to exit the gap back. This leads to the fact that the frictional forces F_δ and F_n on the side of the drum and knife abruptly, with a jump equal in magnitude to $\Delta F=2(F_\delta+F_n)$, change their direction to the opposite (Fig. 3), holding the raw material at the entrance to the gap. Under the influence of such a push of forces, a push of velocity ΔV inside the gap occurs (Fig. 3).

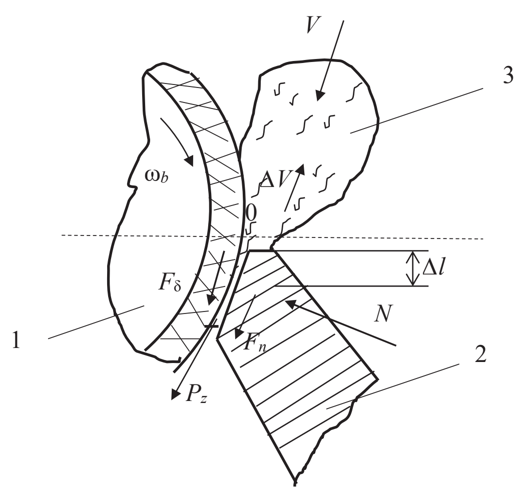

Fig. 3. The balance of power at the end of the push when $P_O=0$, $\Delta l\neq 0$, $l_0=0$

In the real process, as a rule, a set of flyers approaches the knife, the fibers of which are simultaneously pulled behind the knife and lifting the seeds to the edge of the knife is difficult due to reorientation. As a result, an equilibrium is created between the pulling force P_z of the working drum and the resistance force of the fixations of the fibers on the seed.

As a result, the surface of the working drum begins to slip along the fiber, which leads to wear of the drum and damage to the outer layer-cuticle of the fiber. This equilibrium continues until the working drum-fiber-knife-seed system receives an impulse of movement. The additional energy of the system is most often supplied by the breaking body, which significantly contributes to the separation of fiber from the seeds.

After the end of the second phase, the surface of the drum drags the raw material inside the gap with a circumferential velocity ω_b. At this stage, the condition for dragging the raw material into the gap takes the following form (now at the usual finite friction forces):

$$F_\delta > F_n. \quad (21)$$

It is important to consider the case when the movement of the flyer when it lags behind the rotation of the drum is described by the condition $V<\omega_b$. In this case, the alignment of forces in the small vicinity of the point 0 at the time of the impact of the flyer on the knife is depicted in Fig. 2. Since the surface of the drum is taken instantly motionless at the moment of impact, the frictional force F_δ on the side of the drum and the knife F_n are directed against the speed V of the flyer impact.

In addition, since the surface of the drum moves faster than the flyer, there is a finite (non-shock) friction force on the side of the drum, which drags the flyer in the direction of rotation of the drum. But, as mentioned above, this finite frictional force is small compared to the main striking force F_δ, so it can be neglected.

The sum of the work of the friction forces will now be:

$$A_t = -\left(F_\delta + F_n\right)\Delta l.$$

The energy entering the gap at low, as well as ΔV in the previously considered case $V>\omega_b$, is equal to:

$$\Delta\Pi = mV_0\Delta V + kl_0\Delta l.$$

Substituting ΔP and A_{TP} in (18) results in an equation of the form:

$$mV_0\Delta V + kl_0\Delta l - \left(F_\delta + F_n\right)\Delta l > 0, \quad (22)$$

and hence, at the end of the impact, at $\Delta V=0$, it follows:

$$P_0 > F_\delta + F_n. \quad (23)$$

In this form, (23) completely coincides with (17). Hence, in the case under consideration $V<\omega_b$ in the first phase of motion, up to the disappearance of P_0, the conclusions obtained for the case of the movement of the flyer $V>\omega_b$ are quite applicable.

In the second phase of motion, exactly the same events will occur during the rebound of the fly that have already been noted earlier at $V>\omega_b$.

As for the numerical value of the velocity V_0, at which the capture of raw materials becomes dynamically possible, its value is as follows.

From the expression:

$$mV_0^2 = kl_0^2, \qquad (24)$$

where V_0 is the speed of the flyer at the beginning of the impact and l_0 *is* the deformation of the flyer at the end of the impact, it is possible to determine the compressive force P_0 at the end of the impact:

$$P_0 = kl_0 = mV_0 \frac{V_0}{l} = mV_0\omega. \qquad (25)$$

In expression (25) $V_0/l_0=\omega$ is the magnitude of the frequency of the flyer's natural oscillations, which depends on the density of the raw material ρ.

Substituting (25) to (17) produces:

$$V_0 = \frac{F_\delta + F_n}{m\omega}. \qquad (26)$$

A numerical approximate calculation of (26) may be given. It is believed that the sum of the frictional forces at the entrance to the ginning contact pad is commensurate with the weight of the flyer, i.e., $F_\delta+F_n=G=mg$. The frequency ω depends on the density of the raw material ρ. If we assume that at the end of the blow of the fly on the knife its density reaches $\rho=90$ kg/m^2, then $\omega=10$ s^{-1}. Substituting these data in (26), it turns out that $V_0=mg/m\omega=G/\omega=1$ m/s.

Thus, the approximate speed of the flyer V_0, at which its dynamic capture and ginning becomes possible, is $V_0=1$ m/s.

The efficiency of the use of the friction area along the flow is significantly affected by the slippage of the working drum along the pulled fiber, as a result of violation of the ginning condition:

$$P_z > F_n, \qquad (27)$$

where P_z is the pulling force of the fiber on the side of the drum-knife system; F_n – the force holding the fiber (the reinforcement force of the seed fiber, the friction force against the seed and the knife, the force determined by the strength of the fibers when the uluke and debris are captured, etc.).

The loading of the working drum along the contact with the knife is also significantly affected by the uneven supply of the ginning zone and the structural composition of cotton φ. The amount of slippage φ may be characterized by a slippage coefficient:

$$\varphi = \frac{V_n}{V_0}, \qquad (28)$$

where V_0 is the circumferential velocity of the drum; V_n is the mean velocity of the fiber output.

In roller gins of the DV-1M type, the size of the entrance to the wedge-shaped gap between the knife and the drum is 0.5 mm. There is no gap in the center of the knife-drum contact, the knife is tightly pressed against the drum with a force of 10 kg/cm^2. The speed of the breaker body on the flyer is 3 m/s, and the impact time is 0.002 s. The coefficient of friction of the surface of the drum made of RKM material is 0.6, and for a steel knife – 0.2.

6. Discussion of results of the study on the effectiveness of increasing the productivity of the roller gin

The issues of capturing fibers at the edge of the knife were investigated in [1, 2, 3, 6]. However, these studies were not deep enough and were mainly based on assumptions without sufficient evidence. More detailed studies should be noted that consider the issue from the point of view of kinematic ratios on the surface of the working drum at the edge of the knife, as well as studies of the anisotropy of the frictional properties of the surface of the working drum. The choice of a more preferable ratio of speeds supplied to the ginning zone of the flyers and the working drum, as well as the process of capturing fibers, is considered in work [5]. As a result of studies (16), (20), an attempt was made to theoretically substantiate the conditions for capturing fibers by studying the process of stable penetration of part of the volatile fibers into the wedge gap between the knife and the surface of the drum at the edge of the knife. Unlike the well-known works [6, 14], the solution of the problem is carried out using the method of stability theory.

On modern roller gins, knives of different designs are installed. On the gin DV, steel plates of 9XG, 65G, 70G with a thickness of 2.0–2.5 mm with a one-sided sharpening of the blade, LDC hardness=35–40 [16], are used. The choice of the design parameters of the knife only from the conditions of strength and deflection during preloading [6, 7] is insufficient for a scientifically based choice of coefficients (μ_1, μ_2) of the parameters.

To increase the productivity of the roller gin, it is necessary to make fuller use of the working surface of the drum per unit of time, both along the length of the working drum (across the product ginning stream) and along the flow. The efficiency of ginning is affected by the coefficient of entanglement of the fibers, primarily from the frictional properties of the materials between the knife and the surface of the drum.

The efficiency of roller ginning and the coefficients of μ_1, μ_2 are also due to the completeness of the use of the length of the contact of the knife with the working drum at any given time. The loading of the machine along the length of the contact of the knife with the drum is primarily affected by the ginning ability of the knife-drum pair itself. This ability depends on the preservation of optimal conditions for capturing the fibers by the drum and the stability of the friction contact between the knife and the drum since the passing layer of fiber leads to deformation of the knife-drum system.

Under a stable mode, the requirement must be met that the energy flow in the ginning gap is less than the flow rate (12). In this case, it can be concluded that the system behaves as a dissipative and its oscillations fade. With this course of events, a stationary technological process becomes impossible.

According to the ginning condition (15), it can be considered that an increase in the pulling force P_z will reduce the amount of relative slippage. Slippage can be reduced by periodic active violation of the slippage condition $P_z<F_n$ by exposure to a breaking body.

However, despite the presence of a number of works [13, 15], the analytical description of the force effects that occur between a fixed knife and a working drum of gin during the passage of cotton fiber in the contact zone is still insufficiently represented in available literature.

As a result of the research, a mathematical model of the roller ginning process has been built, which makes it possible to determine the impact of technological and design parameters of the roller gin on the efficiency of the process. This allows the use of a variable periodic friction field between the knife and the working drum in order to intensify the process of roller ginning.

The disadvantages of the methods [13–16] are that the formula for the speed of movement of the flyer does not take into account the factors that determine the capturing and pulling ability of the working drum and knife of the roller gin. Also, the most important design parameters of the machine, the stiffness of the knife and the elastic properties of the surface of the working drum, the thickness of the tightened fiber bundles, the degree of attachment of the fiber to the flyer seed are not taken into account.

To eliminate these shortcomings, it is necessary to conduct theoretical studies to determine the factors that affect the performance of the roller gin. Based on the results obtained, it will be possible to change the most important design parameters of the machine.

7. Conclusions

1. When a flyer strikes, there are large impact forces P_0, the compression force of the flyer, and F_δ and F_n, the frictional forces of the drum and knife, which are large compared to the finite frictional forces in the stationary ginning process. On this basis, the action of the finite forces can be neglected compared to the mentioned impact forces. Due to the smallness of the impact time, it can be considered that that at this moment the rotation of the drum is negligible, and the drum is instantly motionless when struck. In this case, the directions of the impact force of friction F_δ from the side of the instantly stationary drum and the impact force of friction F_n from the side of the fixed knife will always be directed opposite to the speed of impact at any value of excess speed, small or large. In these moments, favorable conditions are created for capturing the accumulated raw materials at the entrance to the gap. The condition of stability of the system requires that the flow of energy into the ginning gap is less than the flow rate. Therefore, for roller gins, a combination of «hard knife – malleable» is more preferable, which makes it possible to increase the productivity of the machine through more efficient use of the friction surface of the drum.

2. The speed of the flyer at the beginning of the impact V_0 makes it possible to determine the capture of the raw material. A formula is derived that makes it possible to calculate the speed of movement of the flyer at the beginning of the impact, depending on the density of the raw material ρ (the mass of the flyer m) and the magnitude of the frequency of the flyer's natural oscillations (ω). This makes it possible to increase the efficiency of ginning since the performance of a roller gin primarily depends on the intensity of the fiber pulled behind the knife. In the process of capturing fibers at the edge of the knife, increasing the density of the raw material reduces the amount of speed at which it is possible to capture flyers between the knife and the drum. An increase in the density of raw materials can be achieved by selecting the value of the impact velocity of the breaker body and its direction relative to the entrance to the gap of the contact pair slit. In addition, the frequency of the natural oscillations of the inertial or elastic breaking body should be close to the frequency of the natural oscillations of the flyer's body. By selecting the frequency of the natural oscillations of the knife-drum system, close to the frequency of the volatile oscillations, it is possible to achieve an improvement in the conditions for capturing fibers at the edge of the knife.

Conflicts of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data will be provided upon reasonable request.

References

1. Khafizov, I. K. (2007). Novyi material rabochego valika. Khlopkovaia promyshlennost, 4, 15–16.
2. Khakimov, S., Makxammadiyev, Z., Khadjayeva, M. (2022). Study of durability of the clear grooves of the working drum of the roller jin. Universum: Technical Sciences, 3 (96). doi: https://doi.org/10.32743/unitech.2022.96.3.13300
3. Safarov, F. M., Korabelnikov, R. V. (2006). Optimizatciia rezhimov dzhinirovaniia novogo selektcionnogo sorta dlinnovoloknistogo khlopka 9326-V. Izvestiia Vuzov. Tekhnologiia tekstilnoi promyshlennosti, 5 (293), 49–51. Available at: https://ttp.ivgpu.com/wp-content/uploads/2015/12/293_13.pdf
4. Bavabekov, I. T. (1981). Vybor skorosti otboinogo organa valichnogo dzhina. Khlopkovaia promyshlennost, 2, 18–20.
5. Ibrogimov, Kh. I. Korabelnikov, R. V. (2009). Parametry dvizheniia chastitc khlopka-syrtca po poverkhnosti kolkov v ochistiteliakh melkogo sora. Izvestiia Vuzov. Tekhnologiia tekstilnoi promyshlennosti, 1 (313), 34–36. Available at: https://ttp.ivgpu.com/wp-content/uploads/2015/11/313_10.pdf
6. Akramov, A. (1982). Vliianie uliuchnoi kanavki na kachestvo volokna i semian pri valichnom dzhinirovanii. Khlopkovaia promyshlennost, 3, 4–5.
7. Umarzhonov, A. A. (1991). Issledovanie valichnogo dzhina s ochistitelem volokna individualnogo tipa. Khlopkovaia promyshlennost, 3, 14–15.
8. Novikov, E. V., Korabelnikov, R. V. (2004). Razrabotka modeli prognozirovaniia izmeneniia massovoi doli kostry v protcesse trepaniia dlinnogo volokna. Izvestiia Vuzov. Tekhnologiia tekstilnoi promyshlennosti, 6, 32–35.
9. Miroshnichenko, G. I. (1972). Osnovy proektirovaniia mashin pervichnoi obrabotki khlopka. Moscow: Mashinostroenie, 486.
10. Armijo, C. B., Whitelock, D. P., Thomas, J. W., Hughs, S. E., Gillum, M. N. (2017). Engineering and Ginning Roller Ginning. Journal of Cotton Science, 21 (3), 199–209. doi: https://doi.org/10.56454/vmim5000

11. Korabelnikov, R. V., Ibrogimov, Kh. I. (2009). Osnovy protcessa zazhguchivaniia voloknistykh sviazei chastitc khlopka-syrtca pri netcentralnom udare kolkov. Izvestiia VUZov. Tekhnologiia tekstilnoi promyshlennosti, 4 (318), 23–28. Available at: https://ttp.ivgpu.com/wp-content/uploads/2015/11/318_6.pdf
12. Zulfanov, S. Z., Safarov, F. M., Rudovskii, P. N. (2014). Vliianiia fiziko-mekhanicheskikh svoistv khlopka i tekhnologiia ego pererabotki na proizvoditelnost valichnogo dzhina. Vestnik Tadzhikskogo tekhnicheskogo universiteta im. akad. M. S. Osimi, 2 (26), 16–19. Available at: https://e.lanbook.com/journal/issue/294066
13. Tursunov, Kh. K. (1990). Issledovanie vliianiia proizvoditelnosti valichnykh dzhinov na produkty pererabotki semennogo tonkovoloknistogo khlopka selektcii T-14. Khlopkovaia promyshlennost, 6, 16–19.
14. Usmanov, D. A., Umarova, M. O. (2022). The process of cotton raw fine-fiber ginning. Universum: Technical Sciences, 4 (97). Availale at: https://7universum.com/ru/tech/archive/item/13494
15. Kudratov, O. O. (1992). Issledovaniia zhestkosti sistemy rabochego valika nepodvizhnogo nozha valichnogo dzhina i ee vliianie na nadezhnost protcessa. Khlopkovaia promyshlennost, 3, 14–15.
16. Miroshnichenko, G. I., Korabelnikov, R. V., Iakubov, D. Ia. (1992). Issledovanie plotnosti rabochego valika valichnogo dzhina i ee vliianiia na usilie zatiagivaniia za nozh. Khlopkovaia promyshlennost, 2, 7–8.
17. Turakhonov, Kh. Kh. (1991). Issledovanie vliianiia konstruktivnykh parametrov otboinogo organa na tekhnologicheskie pokazateli raboty valichnogo dzhina. Khlopkovaia promyshlennost, 3, 14–15.