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A STUDY OF FIBRE BUNDLES' FORMATION REGULARITIES DURING THE IMPACT INTERACTION OF SPIKES WITH RAW COTTON PARTICLES

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The article describes a study of the dynamics of interacting between loosening roller spikes and particles of raw cotton as well as the conditions for the raw cotton particles' bundling. The process of movement of raw cotton particles was considered on the mesh surface of a fine impurity cleaner; a search was made for ways to intensify the process and to increase its stability.

The conditions for imparting a rotational motion to the flyer were determined when the flyer was connected with the supplied layer of raw cotton. Turning the flyer against the axis will twist the fibre bundle that binds the particle to the rest of the cotton mass, and this is a prerequisite for the fibre to bundle. The value of the twist angle will depend on both the frictional force and the time of the force action, which together determine the energy spent on twisting.

By piecewise linearization of the P(t) curve, the processes of shock loading and unloading of the flyer during interaction with the spike are described in good agreement with the experimental oscillograms of the process.

The eccentric interaction of the spike with a particle of raw cotton was considered. The relationship of this interaction with the formation of soft defects in the fibre – bundles – was proven experimentally and theoretically. It is recommended to install spike rollers having a flat front face in the system of raw cotton pre-cleaning. The use of spikes of this shape of the front edge ensures a steady reduction in the number of bundles in the raw cotton fibre, which increases the quality of the fibre and reduces the amount of defects and impurities.

As a result of the experimental and theoretical studies, data have been obtained to make it possible to organise the efficient operation of cleaning machines in the cotton ginning industry

Keywords: fine impurity cleaner, feed rollers, spike rollers, blade, number of bundles

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1. Introduction

An important reserve for improving the process of cleaning raw cotton from weed particles is a new direction in the technology of processing raw cotton – preparing raw cotton for cleaning processes by a directed change in its technological properties.

The section for preliminary cleaning of raw cotton from small impurities is essentially an element of the roller-type fine impurity cleaner built into a large impurity cleaner. Its main purpose is to remove fine impurities from the mass of raw cotton through a mesh surface, but at the same time it performs a number of auxiliary functions. For example, it increases the uniformity of the feeding of the machine, changes to some extent the technological characteristics of raw cotton, and separates coarse and fine impurities from cotton, which prepares their further removal.

A number of studies [1–7] highlighted some of the technological aspects of impurity extraction in this type of a cleaner. A number of new problems were identified, the study of which became possible due to the use of modern means of experimental research and processing of its results.

After the feeding device, the particles of raw cotton enter the area of movement of the spikes and slats of spike rollers or spike-slatted rollers. The first technological impact on them is the impact of the spikes and slats, and due to the high relative speed of the spikes (7.85–11.5 m/s), the value of the impact force can be significant.

So far, the process has been analysed only descriptively, that is, the theory of the process used to be described by the Newtonian model of impact. This impact makes it possible to estimate the kinematic characteristics of the process before and after the impact, as well as the value of the complex characteristic of the impact-impulse. The state of the product before and after cleaning has been experimentally studied, but it only indirectly characterises the correctness of the adopted process models.

It is of great national economic importance to solve the problem of establishing a theory of the behaviour of raw cotton in the process of its impact and the use of the basic laws of mechanics in relation to the technological processes of the primary processing of cotton in order to select their most rational parameters that ensure an improvement in the quality of fibres and seeds.

2. Literature review and problem statement

It is proposed to consider raw cotton containing structural particles of a spherical shape with several flyers in the processes occurring in cleaners of large and small impurities [1].

Indeed, the conditions for such cotton bundles to form occur in the pre-cleaning section. On the basis of this model, an attempt is made to reveal the conditions to throw material on the serrated surface and fix it with a brush roller, taking into account the deformation of the raw cotton slices. While solving the problems under consideration, it is necessary to pay special attention to the need for uniform supply to the cleaners, which is a problem that has not been largely resolved yet.

The results considered in [1] were supplemented by study [2], where elements of the process of transporting raw cotton were researched experimentally. The air velocity in the transporting channel affected the quality of the fibre, and thus the property of the fibre was damaged. It was found that the geometric parameters of the transporting channel had changed the physical characteristics of the fibres. At a minimum, the values of the impact force obtained in this work were an order of magnitude higher than the actual ones.

As shown in studies [1, 2], subsequently and obviously from the elementary calculation, the energy balance of the shock process and the nature of the change in the energy consumed by the flyer from the spike were not confirmed experimentally. However, the experiments described in this work were performed incorrectly in the sense of choosing the frequency of natural vibrations of the system.

In study [3], it was noted that fibre characteristics constitute an important factor in determining yarn properties. Cotton, whose physical properties vary depending on the region of cultivation, is still the main raw material used in the textile industry. Properties such as fibre length, thickness, strength and ripeness of raw cotton grown in different regions affect its processing.

The framework of the analysis prevents from dwelling in more detail on a number of studies [4, 5] and others. It is essential to add, however, that many studies follow the path of intensifying processes, increasing their technological reliability, and in the direction of creating conditions that prevent a natural decrease in the ability of raw cotton to release impurities.

Studies [6, 7] are also noteworthy. In particular, it is of interest to research auger cleaners, due to which it becomes possible to use special 'pockets' that help bring down the monotony of the process and revive the ability of raw cotton to release small impurities.

Work [8] discloses in-depth tests of the effect of surface roughness parameters of the working bodies of machines on the conditions of contact with fibrous material. It was shown that the class of roughness of the working surface of the performing body such as spikes cannot objectively characterise the conditions of interaction of the surface with the fibre. The parameters of the contact process – friction and capture of individual fibres by the surface – depend on the ratio of the pitch and height of the microroughness, the magnitude of the radii at the tops and grooves of the microrelief, and the presence of any submicron unevenness.

Technological properties of raw cotton as a material for cleaning have not been disclosed in practice in order to control the cleaning processes and improve product quality [9]. Studies indicate that for many years the quality of cotton has been assessed organoleptically, but it is planned to replace subjective visual assessment with objective instrumental measurements.

In [10], the ways of increasing the efficiency of cleaning raw cotton from small impurities by improving the spike-slatted rollers were researched. However, changing the profile of the mesh surface did not improve the effect of cleaning cotton from coarse impurities. Practical tests have shown that when the spike hits cotton at a speed of more than 12 m/s, seeds are damaged, which leads to an increase in the amount of defects in the fibre.

In [11], the issue of increasing the efficiency of cleaning raw cotton from impurities was studied only for raw cotton of machine harvesting. The author did not consider the friction forces and the influence of the elastic characteristics of raw cotton under shock loads. As a result, the desired cleaning effect was not achieved. Therefore, it should be taken into account that the issues of the influence of the elastic characteristics of raw cotton on the formation of bundles in the fibre, as well as ensuring uniform supply of the cleaners of the feed rollers, remain unsolved.

A conclusion can be made that the problems of the influence of the elastic characteristics of raw cotton and a study of the dynamics of the interaction of the spikes of a loosening roller with particles of raw cotton should still be considered. The process of fibre bundling conditions and ensuring uniform feeding of fine impurity cleaners are the issues to be researched.

3. The aim and objectives of the study

The aim of the study is to reveal the regularities of the formation of bundles of raw cotton fibres resulting from the impact interaction of the flyer on the grate surface.

To achieve the aim, the following tasks were set and done:

– to study experimentally the impact of the process of splitting on a particle of raw cotton;

– to develop an approximate method for describing the process of shock loading and unloading of raw cotton particles;

– to research the conditions for the formation of bundles of fibres from an eccentric impact of a spike on a cotton particle.

4. An experimental study of the impact of splitting on a particle of raw cotton

The complexity of an experimental study of the processes of shock interaction of the working bodies of cotton machines with the processed product lies in the transience in time. The process is carried out within 0.002–0.004 s, and its registration requires high-frequency converters of mechanical values into electrical ones.

Moreover, the practice of scientific research recommends the choice of such a natural frequency of the system that it is 5–10 times higher than the highest frequency from the expansion of a real process into a harmonic Fourier series [14]. If this frequency is unknown, which is most often the case in practice, the choice of the frequency response of the measurement equipment is carried out by sequential enumeration of the options for the natural frequency of the elements of the strain-gauge system. The dynamic estimate of the error of such a system can be given by an approximate method [8].

Searches were made for systems with a high natural frequency (2,500–3,500 Hz), easy to manufacture and suitable for the use of conventional strain gauges. These requirements are met by a thin-walled tubular sensor with a diameter of 10–20 mm and a wall thickness of 0.4–0.5 mm, which is brought up to 0.08–0.1 mm at the place where the strain gauge is glued (Fig. 1). The working length of the sensor and, consequently, its frequency are regulated based on the specified sensitivity of the system and the value of the output signal by a rod that can move along the axis of the tube.

Due to the thinness of the sensor, low weight and, at the same time, high resilience, the sensor has a high natural frequency of transverse vibrations, determined for the first (lowest) frequency [12]:

$$f = \left(\frac{1.85}{\ell}\right)^2 \sqrt{\frac{EJ}{m}}, \quad (1)$$

where l is the length of the console part of the sensor; E is Young's modulus, for steel $2.06\cdot10^{11}$ n/m; J is the moment of inertia of the section; and m is the mass per unit length of the tube.

For a spike of the section of preliminary cleaning of cotton, the calculated parameters of the tubular element were $l=0.07$ m, $J=1.688\cdot10^{-9}$ m^4, and $m=0.1225$ kg/m; the natural frequency was $f=2{,}549.3$ Hz.

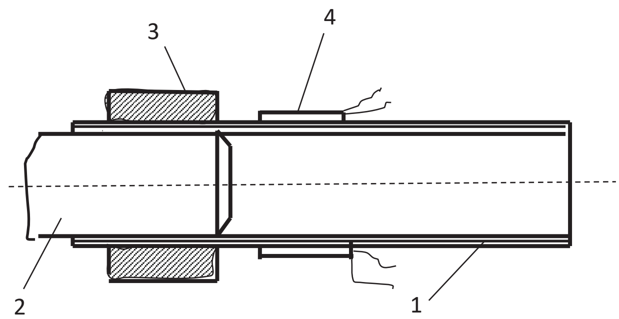

Fig. 1. A tubular converter of the magnitude of the impact force into an electrical signal: 1 – a thin-walled tube; 2 – a rod; 3 – a clamp; 4 – a strain gauge

For the tube simulating a grate with $l=0.08$ m, $J=1.4557\cdot10^{-9}$ m^4, and $m=0.2450$ kg/m, we had $f=2{,}979$ Hz. At $l=0.04$ m, the value was $f=11{,}900$ Hz; however, the sensitivity of the system sharply decreased.

Since the amplifier had the carrier frequency of 5,000 Hz, the bandwidth of 2,000 Hz, and the frequency range of natural oscillations of the loops of 900–6,000 Hz, this system can be considered suitable for studying processes with a lower frequency of 300–600 Hz, that is, for shock peaks with time of sinusoidal peak at 0.0025–0.0035 s.

Fig. 2 shows the diagram of a unit for measuring the force of a splitting impact on a particle of raw cotton, and Fig. 3 shows the typical oscillogram of the process.

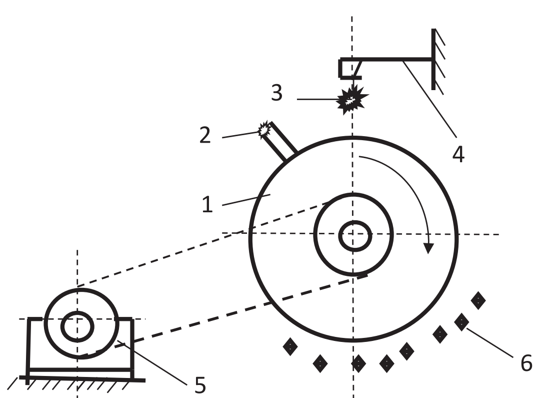

Fig. 2. The diagram of the unit for studying the conditions of dynamic interaction of the spike with the cotton: 1 – a roller; 2 – a tubular spike with strain gauges; 3 – a particle of raw cotton; 4 – a clamp; 5 – a variable drive; 6 – a mesh surface

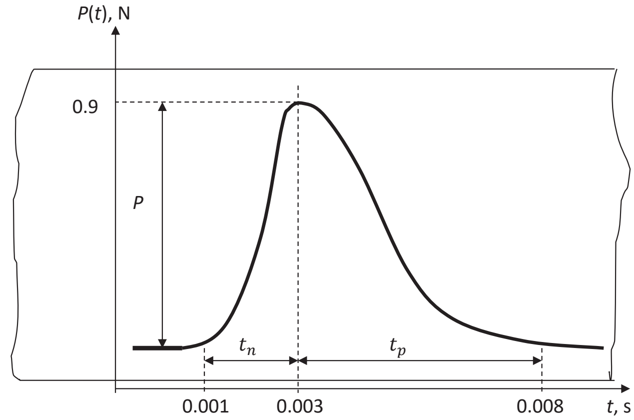

Fig. 3. A typical oscillogram of the process of a spike impact on cotton particles

Table 1 shows the values of the impact force P of a spike on a single flyer, with the time of the load rise t_n at different splitting speeds. The parameters of the impact on a particle consisting of two flyers are also given.

Table 1

The parameters of the process of impact interaction of a spike with particles of raw cotton

Impact parameters	Cotton particles with					
	one flyer			two flyers		
	8.2 m/s	10.5 m/s	12.8 m/s	8.2 m/s	10.5 m/s	12.8 m/s
Impact force P, N	0.598	0.780	0.966	0.801	1.05	1.31
Load rise time t, s	0.0022	0.0023	0.0023	0.0024	0.0025	0.0026
Total impact time, s	0.026	0.03	0.037	0.041	0.049	0.052

In article [10], it was stated that the fixed time of the load increase when the flyer hit the grate was much shorter than the load fall time. The same phenomenon was noted in the study of the impact of a spike on particles of raw cotton.

The nature of this phenomenon, associated with the properties of a tubular element as a thin-walled shell, is the manifestation of the material microflow mechanism during its unloading (if the fibre length is $l\leq12$ mm, then the material microflow occurs). With shock unloading, this phenomenon is inherent in steel, but especially for thin-walled shells made of it [11] (if the fibre length is $l\geq26$ mm, it is the thin-walled shell that is considered during shock unloading of the spike against raw cotton particles).

Therefore, the total impact time can be considered equal to $(2.2–2.3)\cdot t_n$, and the time of the load drop on the oscillogram can be attributed to the properties of the tubular element.

The established series of values of the force of the splitting impact of the spike on the raw cotton flyer helps describe the dynamic properties of flyers under impact. In this case, some change in the load rise time can be a consequence of the nonlinearity of the loading characteristics as a function of both the shape of the deformable cotton particle and the properties of cotton as a multicomponent material.

5. The processes of shock loading and unloading of raw cotton particles and approximate methods of their description

The processes of convergence and retreat of a fibrous cotton particle relative to the surface of a spike or grate are described by a nonlinear differential equation (in the absence of friction):

$$m\frac{\mathrm{d}^2y}{\mathrm{d}t^2}+cy^n=0, \tag{2}$$

the solution of which in the general case for $n\neq1$ presents significant difficulties.

It is possible to analyse the impact process by replacing the sections of the curve with straight lines – chords or tangents. In turn, they deviate slightly at the final length of an i-th section from the curve $P(y)$ when y changes from y_{i-1} to y_i and for which the linear differential equation of motion is valid:

$$m\frac{\mathrm{d}^2y}{\mathrm{d}t^2}+k_i\left(y-\delta_i\right)=0, \tag{3}$$

where k_i is the coefficient of proportionality of the linear relationship; $P=k_i(y-\delta_i)$ for this section; δ_i is the coordinate of the point of intersection of the straight line $P(y)$ with the y-axis.

Solution (3) with initial conditions: $t=0$, $y=y_{(i-1)}$ and $\mathrm{d}y/\mathrm{d}t=V_{i-1}$ will be written for the i-th section as follows:

$$y=\left(y_{i-1}-\delta_i\right)\cos p_it+\frac{V_{i-1}}{p_i}\sin p_it+\delta_i, \tag{4}$$

$$\frac{\mathrm{d}y}{\mathrm{d}t}=V_{i-1}\cos p_it-\left(y_{i-1}-\delta_i\right)p_i\sin p_it, \tag{5}$$

where

$$p_i=\sqrt{\frac{k_i}{m}} \tag{6}$$

is the natural frequency. At the end of the period of movement corresponding to the i-th section, (4) and (5) take the values of y_i and V_i, respectively. One of them is given by dividing the curve, and it serves to determine the time of movement t_i; the other is obtained by substituting t_i into one of the listed equations.

It is easier to divide the displacement y_i into several linearized sections, that is, to get the values of y_i and to determine V_i from the found t_i:

$$t_i=\frac{1}{p_i}\times$$

$$\times\arccos\frac{1+\sqrt{\left(1+\dfrac{V_{i-1}^2}{p_i^2\left(y_{i-1}-\delta_i\right)^2}+1\right)\left(\dfrac{V_{i-1}^2}{p_i^2\left(y_{i-1}-\delta_i\right)^2}-1\right)}}{\left(y_{i-1}-\delta_i\right)\left(1+\dfrac{V_{i-1}^2}{p_i^2\left(y_{i-1}-\delta_i\right)^2}\right)}, \tag{7}$$

$$V_i=V_{i-1}\cos p_it_i-\left(y_{i-1}-\delta_i\right)p_it_i. \tag{8}$$

The obtained value of V_i together with y_i will serve as the initial conditions for the next $(i+1)$-th section.

For the first loading section, (7) and (8) at $y_0=0$ and $\delta_1=0$ will be simplified:

$$t_1=\frac{1}{P_1}\arcsin\frac{y_1P_1}{V_0}, \tag{9}$$

$$V_1=\sqrt{V_0^2-y_1^2P_1^2}. \tag{10}$$

If the final value of y_r (during loading) is unknown in the last, r-th section, then the condition for the completion of the loading process will be zero velocity and

$$t_r=\frac{1}{P_r}\operatorname{arctg}\frac{V_{r-1}}{\left(y_{r-1}-\delta_r\right)P_r}, \tag{11}$$

and the value of y_r is found by substituting (11) into (4).

Relations (4)–(8) are similarly used for unloading a particle, and the initial conditions of the process will be different – $y_0=y_{\max}$ (or $y_{\max}-y_p$) V_0, and at $y_r=0$, the rebound velocity V_r will be found in the last section.

The values of the impact parameters depend on k_i, on δ_i, as well as on the method of approximating the $P(y)$ curve by a broken line. In the case of replacing a portion of the curve between $P_{i-1}=cy_{i-1}^n$ and $P_i=cy_i^n$ with a chord (chord method), the latter is described by the equation of a straight line (Fig. 4):

$$P=\frac{P_i-P_{i-1}}{y_i-y_{i-1}}\left(y-y_{i-1}\right)+P_{i-1}, \tag{12}$$

reduced evenly by dividing $y_{\max}$ into r equal parts to the form:

$$P=\frac{cy_{\max}^{n-1}}{r^{n-1}}\left[i^n-\left(i-1\right)^n\right]y-\frac{cy_{\max}^n}{r^n}\left[i^n\left(i-1\right)-i\left(i-1\right)^n\right]. \tag{13}$$

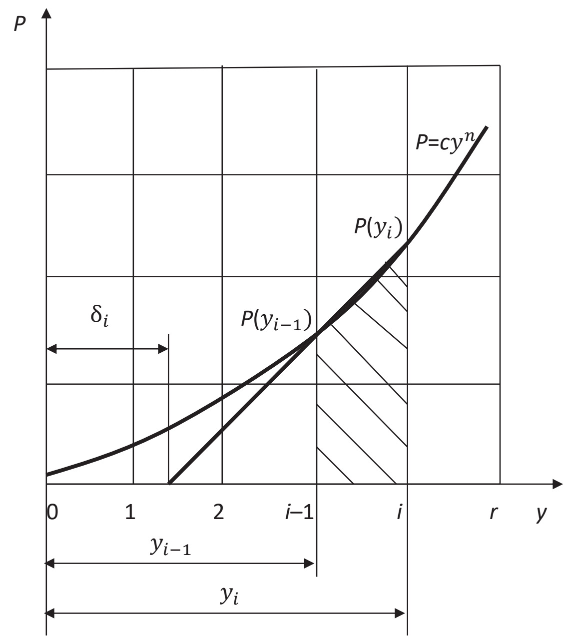

Fig. 4. The graph for approximating a portion of the $P(y)$ curve by a straight line (chord method)

The value of the segment cut off by the straight line from the oy axis is determined from the relation:

$$\delta_i = y_{i-1} - \frac{y_i - y_{i-1}}{P_i - P_{i-1}} P_{i-1} \tag{14}$$

or when dividing $y_{\max}$ by r equal parts:

$$\delta_i = \frac{y_{\max}\left[i^n(i-1) - i(i-1)^n\right]}{\left[i^n - (i-1)^n\right]}. \tag{15}$$

The value of the proportionality coefficient k_i is respectively determined from the equality:

$$K_i = \frac{P_i - P_{i-1}}{y_i - y_{i-1}} = \frac{c y_{\max}^{n-1}}{r^{n-1}}\left[i^n - (i-1)^n\right]. \tag{16}$$

In the calculated ratios with known c and for a given $P_{\max}$, it is not difficult to determine $y_{\max}$.

Fig. 5 shows the calculated oscillograms for cases of a spike impact on a single flyer with velocities of 8.2 m/s (curves 1), 10.5 m/s (2), and 12.8 m/s (3). In Fig. 5, the solid lines show the laws of increase in the load $P(t)$, and the dashed lines show the laws of change $y(t)$.

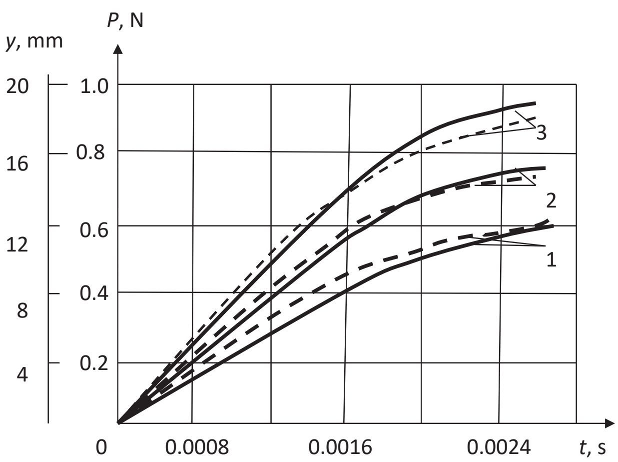

Fig. 5. The design graphs of the loading process: $y(t)$ (dashed lines) and $P(t)$ (solid lines) at 1 — V_0=8.2 m/s; 2 — 10.5 m/s; and 3 — 12.8 m/s

The total calculated impact time for all variants of t_n (respectively equal to 0.002285 s, 0.002241 s, and 0.002205 s) agrees well with the experimental values. It tends to decrease with an increase in the initial rate of the process V_0, which, of course, cannot be detected experimentally due to the small variation in t_n. In this sense (for n=1.174), the computational model is close to linear.

Fig. 6 shows the dependences of the particle velocity V and its acceleration a on time t for the corresponding values of the initial velocity. They show a significant role in the process of separating fibrous material and impurities, in loosening raw cotton, and disclosing the effective open surfaces of structural cotton particles by their deformation and downsizing.

The motion of the system with a nonlinear elastic element and viscous friction is described by the differential equation:

$$m\frac{d^2y}{dt^2} + c_b\frac{dy}{dt} + cy^n = 0, \tag{17}$$

where c_b is the coefficient of viscous friction. Using the chord method, replacing the i-th section of the curve with a chord contracting it, we bring (17) to a linear form by means of the substitution:

$$c_b = 2mn_b, \tag{18}$$

$$\frac{k_i}{m} = p_i^2 \tag{19}$$

and making the following transformation:

$$\frac{d^2y_i}{dt^2} + 2nb_i\frac{dy_i}{dt} + p_i^2 y_i = 0, \tag{20}$$

where k_i is determined from (16). Solving (20), we obtain for the i-th section the values of displacements and velocities:

$$\pm(y - \delta_i) = e^{-nb_i t}\sqrt{(y_{i-1} - \delta_i)^2 + \frac{nb_i(y_{i-1} - \delta_i) + V_{i-1}}{p_i^2 - n^2 b_i}} \times$$
$$\times \sin\left(\sqrt{p_i^2 - n^2 b_i t} + \varphi_i\right), \tag{21}$$

$$V = e^{-nb_i t}\begin{bmatrix} V_{i-1}\cos\sqrt{p_i^2 - n^2 b_i t} - \\ -\dfrac{(y_{i-1} - \delta_i)p_i^2 + V_{i-1}nb_i}{\sqrt{p_i^2 - n^2 b_i}} \times \\ \times \sin\sqrt{p_i^2 - n^2 b_i t} \end{bmatrix}, \tag{22}$$

$$\varphi_i = \operatorname{arctg}\frac{(y_{i-1} - \delta_i)p^2 + V_{i-1}nb_i}{V_{i-1} + nb_i(y_{i-1} - \delta_i)}. \tag{23}$$

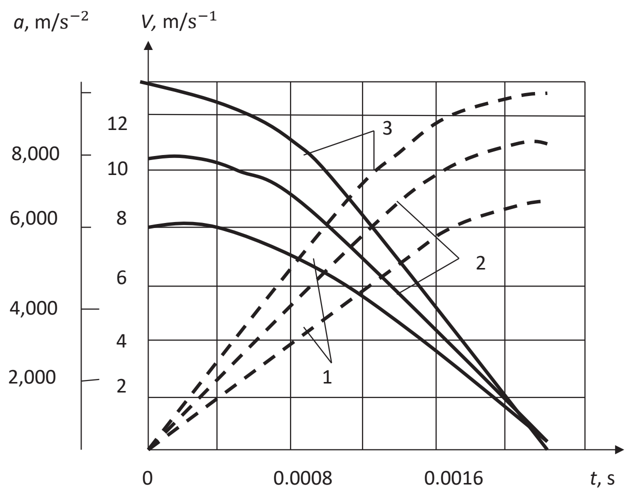

Fig. 6. The velocity $V(t)$ (solid lines) and acceleration $a(t)$ (dashed lines) of cotton particles relative to the spike during its impact: 1 — V_0=8.2 m/s; 2 — 10.5 m/s; and 3 — 12.8 m/s

Since k_i, P_i, and δ_i are taken for a system without friction, their definition is similar to the loading conditions and there is no need for additional calculations; only according to the accepted numbering during unloading, the i-th section acquires the values of the (r–i+1)-th loading section.

Here, in the first section, V_0=0 y_0=$y_{\max}$; in the last one at the end of the process, y=($y_{\max}$–y_m)=0 and V_{i0}=V_{0m}. In (21), the plus sign is taken for φ_i>0 and minus is for φ_i<0.

Fig. 7 shows the curves of changes in the load $P(t)$ and the particle velocity $V(t)$ for $n=1.174$, $c=105.04$, and $V_0=12.8$ m/s as the calculation results; the ratio of the time for the load rise and fall was $t_n/t_p=0.233$. In this case, the ratio of the coefficient of viscous resistance n_{bi} to the frequency P_i found from equation (23) was $\varepsilon=0.749$.

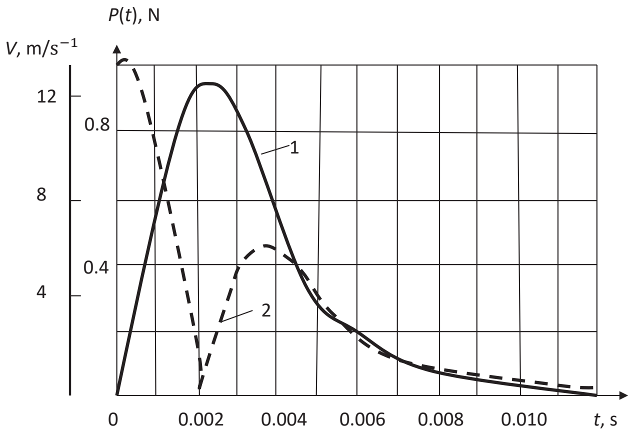

Fig. 7. The calculated curves for $V=12.8$ m/s with $t_p/t_n=4.3$ and $\alpha=2.84$: 1 — $P(t)$; 2 — $V(t)$

Let us note, firstly, a good coincidence of the nature of the curve, $P(t)$ obtained by calculation, with the oscillogram shown in Fig. 3 and removed when struck with a spike on a raw cotton flyer.

The processes of microfluidity of the sensor material, apparently, are well described by the model with viscous friction at sufficiently large values of ε, and at $\varepsilon \to 1$ the curve of the fall of P turns into an exponential.

6. A study of the conditions for the formation of fibre bundles as a result of an eccentric impact of a spike on a cotton particle

The previously considered axial impact of the spike on the raw cotton particles can be implemented in the presence of a round spike only in isolated cases. More often, the velocity vector of a spike of a radius r_k (Fig. 8) forms with the centre of the cotton flyer adopted in this consideration such eccentricity e that it has the shape of a ball of a radius r_l.

In this case, the angle between the spike velocity vector V_o and the velocity component V_n, directed from the centre of the spike to the centre of the spike, is:

$$\alpha = \arcsin \frac{e}{r_k + r_n}, \tag{24}$$

and the value of the indicated velocity component is:

$$V_n = V_0 \cos\alpha = V_0 \frac{\sqrt{(r_k + r_n)^2 - e^2}}{r_k + r_n}. \tag{25}$$

The velocity V_n determines the character of the impact interaction of the cotton particles with the spike. Equation (25), in the case of the nonlinear dependence of $P(y)$, can be used to find the relationship between the impact force and the splitting speed V_0 as a function of the eccentricity e:

$$P = \left\{ \frac{m(n-1)\left[(r_k + r_n)^2 - e^2\right]}{2(r_k + r_n)^2} \right\}^{\frac{n}{n+1}} c^{\frac{1}{n+1}} V_0^{\frac{2n}{n+1}}. \tag{26}$$

With $n \approx 1$, (26) is simplified and reduced to a linear dependence on V_0 and $\cos\alpha$:

$$P_1 = \sqrt{mc} V_0 \cos\alpha. \tag{27}$$

From (26) and (27) it is obvious that the impact force P decreases with increasing e and the corresponding increase in the angle α. The value of the impact force, recorded by the sensor and directed along the velocity vector V_0, changes even more:

$$P_y = P\cos\alpha, \tag{28}$$

taking the following form for nonlinear stiffness:

$$P_y = \left[\frac{m(n+1)^{\frac{n}{n+1}}}{2} c^{\frac{1}{n+1}} V^{\frac{2n}{n+1}} (\cos\alpha)^{\frac{4n}{n+1}} \right], \tag{29}$$

and at $n=1$,

$$P_y = \sqrt{mcV_0} \cos^2\alpha. \tag{30}$$

The nature of the change in the functions of P and P_y is seen in Fig. 9.

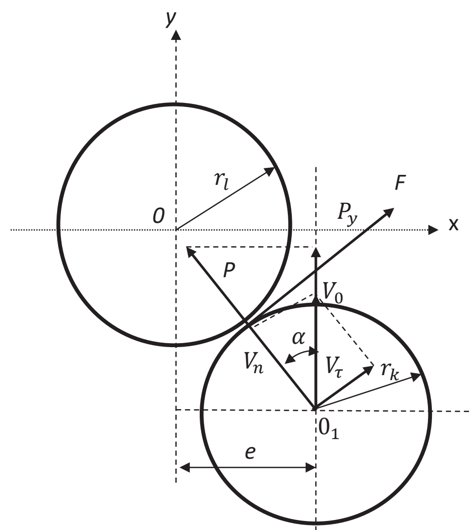

Fig. 8. The graph of the eccentric impact interaction of a spike with a particle of raw cotton

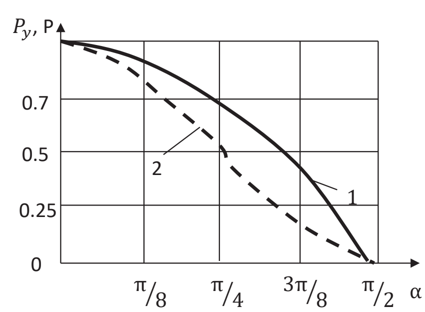

Fig. 9. The dependences of $P(t)$ (curve 1) and its component $P_y(t)$ (curve 2) on α and e

These dependences coincide with the experimental values of P_y, obtained at different values of e and given in Table 2.

Table 2

The experimental values of the impact force P_y, N at various values of e and V_0

Disaxial value e, mm	Velocity V_0, m/s		
	8.2	10.5	12.8
0	0.586	0.780	0.966
6	0.549	0.716	0.892
12	0.476	0.549	0.736

In an ideal model, in the absence of friction, the eccentric impact would not have negative consequences – the overall value of the shock load would decrease, and free or cohesive particles would be reflected in the direction of the velocity V_0.

In practice, the situation is somewhat different: during an impact, friction arises between the colliding surfaces due to the tangential component of the velocity V_τ and forming a moment relative to the centre of the flyer's gravity (with Amontons' laws of friction):

$$M \le \mu \Pr. \tag{31}$$

Between entangled fibres of a special nature of friction, where the reaction of the surface to the inclination of a tangible body interacting with it is to move tangentially at the point of contact, the equal sign takes place when friction reaches a threshold value, which is possible only with a significant value of V_τ.

Therefore, the function of M_o, in the case of equality in (31) monotonically decreases synchronously with P, which decreases with increasing α and e. In real conditions, with $\alpha=0$, P is equal to zero, and only when the splitting threshold is reached, the spike takes the calculated value (curve 1, Fig. 10).

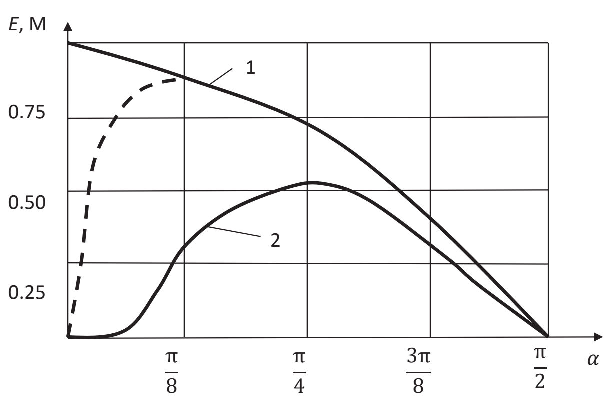

Fig. 10. The dependence of the moment of rotation M_0 (curve 1) and the energy E transferred to the rotation of the flyer on α and e during the impact

If the flyer, entrained in the rotational motion by the spike, has a tangential velocity at the point of contact close to V_τ, then the instantaneous value of the power transmitted to the flyer will be determined from the relation:

$$W(t) = \mu P(t) V. \tag{32}$$

The maximum power transmitted by the spike will be determined as:

$$W_{\max} = \mu P V \tag{33}$$

considering that V_τ changes insignificantly during the impact. The average value of the transmitted power at a small change of α during the collision period (t_n+t_p) can be determined as follows:

$$W_{op} = \frac{\mu V_r}{(t_n + t_p)} \int_0^{(t_n+t_p)} P(t)\,\mathrm{d}t, \tag{34}$$

and the total energy transmitted to the flyer will be:

$$E = W_{op}(t_n + t_p)\mu V_r \int_0^{(t_n+t_p)} P(t)\,\mathrm{d}t. \tag{35}$$

Taking into account the previously researched character of the shock peak, with a sufficient degree of accuracy, the integral in the latter relations can be replaced by the function of the maximum value of the impact force P, after which (35) is transformed to:

$$E = \frac{\mu V_r P (t_n + t_p)}{2}, \tag{36}$$

which can be transformed by the substitution:

$$V_r = V_0 \sin\alpha = \frac{V_0 e}{r_k + r_n},$$

and also the values of P from (26) or (27). For the nonlinear system, we have:

$$E = \frac{\mu(t_n + t_p) e}{r_k + r_n} c^{\frac{1}{n+1}} \left[\frac{m(n+1)\left[(r_k + r_n)^2 - e^2\right]}{2(r_k + r_n)} \right] V_0^{\frac{3n+1}{n+1}}, \tag{37}$$

and for linear, it is:

$$E = \frac{\mu(t_n + t_p)\sqrt{mc}V_0^2}{2} \sin\alpha\cos\alpha. \tag{38}$$

The nature of the change in the energy consumed by the flyer from the spike where the rotational movement takes place is shown in Fig. 10 (curve 2). It is obvious that the greatest twisting of the fibrous bond of the raw cotton particles should occur at $\alpha=\pi/4$, which was fully confirmed in experiments carried out at ginneries.

7. Discussion of the results of studying the process of fibre bundles' formation during the impact interaction with spikes

A general estimate of the value of the maximum twist angle of a fibre strand $\varphi_{\max}$ is possible as a result of analysing the solution of the differential equation of the rotational motion of a raw cotton particle with a moment of inertia J:

$$J\frac{\mathrm{d}^2\varphi}{\mathrm{d}t^2} + C_k\varphi = \mu P(t) r_l, \tag{39}$$

and from the equation of the energy balance of the system that follows from (39). Formulae (37) and (38) simplify the problem even more, reducing the calculation to the relation:

$$\varphi_{\max} = \sqrt{\frac{2E}{c_k}}, \tag{40}$$

whence it follows that the most dangerous for the process under consideration is the case of $\alpha=\pi/4$, when the rotational energy received by a cotton particle from the spike is maximum and the torsional rigidity c_k of the bonds is minimal. In this case, the maximum twist angle occurs in a time corresponding to a quarter of the full period of torsional vibrations of the system:

$$\varphi_{\max} = \frac{\pi}{2}\sqrt{\frac{J}{c_k}}. \tag{41}$$

Laboratory tests of rollers of a serial design and with spikes having a flat front surface and sharply reducing the probability of an eccentric impact on the particles of raw cotton have shown a steady decrease in the number of bundles in the fibre of raw cotton. For raw materials processed in an experimental fine impurity cleaner, the cleaning effect changed from 0.430 % to 0.337 % with an overall decrease in the amount of defects and contamination by 1–13 %.

Using flat side spikes in the fine impurity cleaner and optimising the surfaces of the fibre cleaner, as predicted by previous studies, have shown a significant decrease in the number of soft defects in the fibre. The studies of the new methods for cleaning raw cotton with optimal grate profiles according to the developed theory of their analysis and synthesis have not yet been implemented in production, but their application, as the results of this research show, has good prospects, and work in this direction continues.

8. Conclusion

1. The impact interaction of the spikes of a cleaning roller with particles of raw cotton was researched experimentally. The rise time and the magnitude of the shock load have been determined to be 0.0022–0.0026 s and 0.60–1.30 n respectively when the splitting speed changed from 8.2 m/s to 12.8 m/s.

2. The experimental data were used to describe the characteristics of the nonlinearity of the dynamic stiffness of the flyers upon impact, with the possibility of its approximation by a law of the form $P=cy^n$. It has been found that with a small difference in the load rise and fall times, the nature of the load fall almost completely coincides with the growth curves, whereas the accelerations and velocities have only the opposite sign. If $t_n < t_p$, the values of the accelerations and velocities of the flyer decrease due to energy dissipation, which can be established by analysing the corresponding model with viscous friction.

3. It has been established that the moment generated relative to the centre of gravity of the flyer creates conditions for imparting rotational motion to the flyer. In this case, its rotation against the axis will lead to twisting of the bundle of fibres connecting the particle with the rest of the cotton mass, and this is a prerequisite for the fibre bundle formation.

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