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CONSTRUCTION OF A THEORETICAL METHOD FOR ESTIMATING THE CALCULATION OF POWER USED BY FEED ROLLERS IN THE CLEANERS OF RAW COTTON FROM FINE DEBRIS

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Визначено величини розпірних зусиль, що діють на живлячі валики і є одним з найважливіших факторів визначення потужності, що витрачається живлячими валиками, умови міцності лопатевих валів і, що найбільш істотно, збереження якості матеріалу, що переробляється. Створення ефективних очищувачів бавовни-сирцю, підвищення очисного ефекту при мінімальній кількості очисних машин – вельми актуальне завдання.

Досліджено етапи взаємодії кілочка з поверхнею волокнистого матеріалу – від моменту торкання колком недеформованою поверхні шару до граничного значення деформації W(0) в точці, поки кілочок не проникнув в матеріал.

На відміну від раніше запропонованих рішень, що розглядали деформацію шару умовними, круглої форми, валиками, а хлопок-сирець як матеріал, що деформується одновимірно, що відповідає в теорії пружності матеріалу з коефіцієнтом Пуассона $\nu=0$***, в запропонованій схемі за тієї ж умови безперервності потоку передбачається описати деформацію бавовни-сирцю лопатевими валиками методами контактних задач теорії пружності. Сумарну потужність, що витрачається або отримується живлячим валиком, можна визначити з матричного рівняння. В результаті досліджень встановили, що якщо бавовна – середовище абсолютно пружне, то вся енергія здавлювання шару буде повернута валику і сумарний витрата енергії лопатями за цикл деформування буде дорівнювати нулю. Якщо вважати бавовну пластичною, то при*** $\varphi_i=\pi/2$ ***лопать відійде від шару і накопичена енергія лопатей повернена не буде.***

Результати розрахунку споживаної валиком потужності наведені у вигляді графіків (при середньому значенні кутової швидкості $\omega_{cp}=1{,}047\ c^{-1}$***). Представлені результати відносяться до потужності, споживаної валиком на осьове транспортування шару бавовни.***

Вирішення цих питань дасть можливість знайти оптимальні величини конструктивних елементів лопатей живлячих валиків в очисники бавовни-сирцю від дрібного сміття

Ключові слова: волокнистий матеріал, дрібне сміття, що живлять валики, колкові валики, деформація шару

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1. Introduction

Processing large amounts of raw cotton, as well as stricter requirements to the quality of cotton industry such as fiber, lint, sowing and technical seeds, necessitates re-equipment of enterprises in this industry with new machinery, equipping ginning plants with production lines for drying and cleaning raw cotton, high-performance gin plants and automated pressing units.

Th plants producing machines and units for processing raw cotton plan to increase, over these years, the volumes of production by 1.4 times. They must systematically update the nomenclature of assembled machines in order to reach the level of the best samples of foreign technology in terms of their techno-economic indicators.

Along with the construction of new ginning factories and collection points, an almost complete modernization is implied for 40–50 % of enterprises in the industry, while all enterprises must replace obsolete machines new high-performance machinery. Addressing these issues would make it possible to find an optimal variant for harvesting raw cotton, which could lead to improving the harvested cotton, as well as enhancing the effect of cleaning raw cotton from weeds.

It has been already proven that in cleaning machines the electric power consumed is much higher than estimated, which requires undertaking a theoretical study. Resolving these tasks requires joint efforts from scientific and design organizations, machine-building enterprises, and ginning companies in improving the equipment and technology of cotton ginning.

Given that exploration and improvement of designs for cotton cleaners that separate raw cotton from large and fine waste is one of the most important tasks in the industry, the following fields of research are relevant:

– methods for determining the power consumed by feed rollers in raw cotton cleaners from fine debris;

– methods for designing cleaners in the technological flows at primary processing of cotton;

– establishment of relationship between the physical-mechanical properties of raw cotton, elastic characteristics of raw cotton, and the power consumed by feed rollers.

Resolving all these issues would make it possible to find the optimal design of raw cotton cleaning mechanisms that could enhance the effect of cleaning raw cotton from waste.

2. Literature review and problem statement

Paper [1] reports results of research into cleaning fine fiber raw cotton. It is shown that strength of holding cotton fly on the gear depends on the speed of the drum; a theoretical formula has been proposed for calculation of efforts required by a cotton fly to detach from blades. However, the issues that were left unresolved relate to detecting the influence of elastic characteristics of raw cotton on the magnitude of spreading efforts acting on feed rollers.

Study [2] addressed the improvement in a feeder mechanism of pin rollers. The authors investigated the interaction between a pin and a piece of raw cotton with a fibrous connection to the canvas formed by feed rollers. The study findings did not achieve the desired cleaning effect for large debris as the authors did not deal with the issues on a possibility to find the optimal magnitudes for structural elements of blades at feed rollers in the cleaners of raw cotton from fine debris.

Article [3] examined the selection of parameters for the geometry of blades at feeder rollers by using a model of the process that could explain both the interaction between a cotton fly and a pin drum of the cleaner and a series of causes that lead to the process failure. However, the author did not investigate the influence of elastic characteristics of raw cotton on qualitative indicators.

Paper [4] studied the process of cleaning raw cotton in order to improve its quality indicators; in particular, the authors described the kinetics of change in the structure of raw cotton at its processing in cleaners. A new procedure for calculating the cleaning effect of cleaners has been suggested, as well as a new technique to feed cotton machines implying the pre-treatment of a material prior to the process and a series of new designs for working bodies.

However, the authors did not consider the process of dragging the raw cotton by a pin over the netted surface and determining the conditions when a pin captures and keeps raw cotton to assess the twisting capability of the pair «pin-netted surface».

Study [5] reports a research into raw cotton that contains structural particles of spherical shape with multiple cotton flies emerging in cleaners from fine debris. Indeed, the conditions for forming such lumps of cotton occur in a pretreatment section. Based on this model, the author attempted to reveal the conditions when a material is thrown upon the blade to be fixed by a brush drum, taking into consideration the deformation of slices of raw cotton. While solving the set tasks, the author does not take into consideration the deformation of a layer of cotton canvas and raw cotton is regarded as a one-dimensionally deformed material.

Work [6] investigated a repeated cleaning of raw cotton and established a correlation between the degree of cotton contamination and a cotton fly content in the waste of a cleaner, which represents a linear function. It was shown that the use of two-time regeneration of waste from a large debris cleaner makes it possible to reduce by 2.5 times the release of cotton fly with the waste. The issues about influence of elastic characteristics of raw cotton on spreading efforts, as well as on determining the power consumed by feed rollers at cleaners, remain to be investigated.

Paper [7] empirically determined the optimum peripheral speed of drum pins (8–10 m/s) and the gap between pins and the netted surface (14–15 mm). It was shown that the best cleaning capability was demonstrated by a combination of a pin- slatted drum with a grate at the section where the pre-treatment of raw cotton takes place. The paper failed to give a comprehensive explanation of conditions for throwing raw cotton upon the gear of a pin drum, though it includes a series of recommendations, in particular on a zero gap between the pin and grid. The issues about influence of elastic characteristics of raw cotton on spreading efforts, as well as on determining the power consumed by feed rollers at cleaners, remain to be examined.

Work [8] investigated ways of enhancing the efficiency of cleaning raw cotton from fine burrs by improving the slatted pin drums. However, changing the profile of the netted surface does not strengthen the effect of cleaning cotton from large debris. Practical tests have shown that at impact between a pin and cotton with the speed exceeding 12 m/s the seeds are damaged, which leads to an increase in the number of defects in fiber.

Study [9] addressed the issue of improving the effectiveness of cleaning raw cotton from fine burrs only for the raw cotton gathered by machines. The authors did not consider the friction forces and the influence of elastic characteristics of raw cotton. The result was that the desired cleaning effect had not been achieved. Therefore, it should be recognized that the issues on influence of elastic characteristics of raw cotton on spreading efforts, as well as enabling a uniform feed to cleaners at feed rollers, remain to be investigated.

Papers [10, 11] examined the influence of elastic characteristics of raw cotton on qualitative indicators for raw cotton. This work is continuation of the research into constructing a model of the process of contact interaction between blades and raw cotton; it describes the process both quantitatively, based on magnitudes for spreading efforts, and qualitatively. However, the author does not take into consideration that the criterion for capturing capability of the roller should be the angle $\gamma_0+\varphi$, formed by the pin's working surface and a layer surface at moment when the pins capture the particles of raw cotton.

All this suggests that the issues about influence of elastic characteristics of raw cotton on spreading efforts, as well as ensuring a uniform feed to fine debris cleaners, remain to be studied.

3. The aim and objectives of the study

The aim of this study is to determining the power consumed by feed rollers that enable quality cleaning of raw cotton from weedy impurities at fine debris cleaners.

To achieve the set aim, the following tasks have been solved:

– to reveal the mechanics of interaction process between a pin and a layer of cotton and analyze the shapes of a deformed layer of raw cotton;

– to assess the interaction between a pin and the surface of a fibrous material taking into consideration the elastic characteristics of the transported layer of cotton;

– to devise a procedure for estimating the power consumed by feed rollers carrying a layer of raw cotton.

4. Studying the mechanics of interaction process between a pin and a layer of cotton and analyzing the shape of a deformed layer of raw cotton

In order to optimize choosing the parameters for a pin roller, consider the conditions that arise when the pin meets a layer of cotton, as well as when the pins receive and throw the particles.

The criterion for capturing and loosening capability of a roller should be the angle formed by the pin's working surface and the layer surface at moment when the pins capture the particles of raw cotton. In a general case, denote this angle through γ and its value at $\alpha=0$ through γ_0 (Fig. 1).

The α angle reduces in proportion to the displacement along the axis of the pin to values α_1 at its free end:

$$\alpha_1=\arcsin\left(\frac{r_1}{r_2}\sin\alpha\right), \qquad (1)$$

and the larger the difference between r and r_2, the less α. From the diagram in Fig. 1:

$$\gamma=\gamma_0-\alpha_1=\arcsin\frac{A_1-S_1}{2r_2}-\arcsin\left(\frac{r_1}{r_2}\sin\alpha\right), \qquad (2)$$

and, to achieve the most efficient penetration of pins to a cotton layer, fed at low speed, it is required that the value for γ should be maximal. An increase in γ leads to a more efficient capturing of structural particles of cotton. However, the larger α_1 and α, the less the value for γ and the magnitude for α affects the conditions for throwing cotton particles by the pin rollers, which improve with an increase in its value.

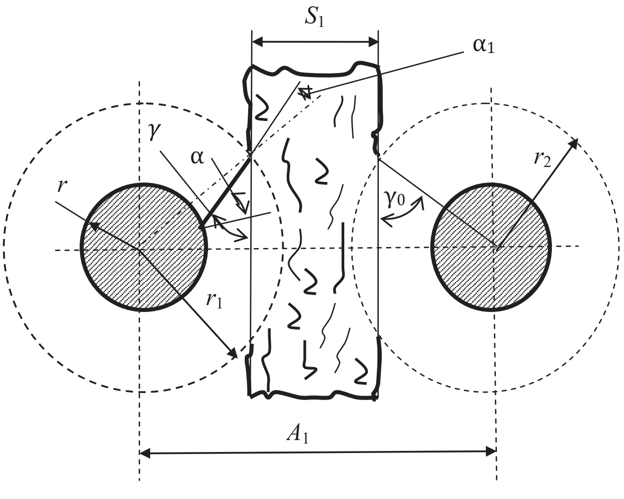

Fig. 1. Schematic showing the encounter between a pin and the surface of a raw cotton layer

Freed from the values of circular functions, transform (2) to the form

a) at

$$A_1-S_1\geq 0;\ \sin\alpha\geq 0\left(\text{or } A_1-S_1<0;\sin\alpha<0\right),$$

$$\sin\gamma=\frac{1}{2r_2^2}\left[\begin{array}{l}\left(A_1-S_1\right)\sqrt{\left(r_2^2-r^2\sin^2\alpha\right)}-\\-r\sqrt{\left(4r_2^2-\left(A_1-S_1\right)^2\right)}\sin\alpha\end{array}\right]; \qquad (3)$$

b) at

$$A_1-S_1\geq 0;\ \sin\alpha\leq 0,$$

$$\sin\gamma=\frac{1}{2r_2^2}\left[\begin{array}{l}\left(A_1-S_1\right)\sqrt{\left(r_2^2-r^2\sin^2\alpha\right)}-\\-r\sqrt{\left(4r_2^2-\left(A_1-S_1\right)^2\right)}\sin\alpha\end{array}\right]. \qquad (4)$$

Take the partial derivative of (2) for α:

$$\frac{\partial\gamma}{\partial\alpha}=-\frac{r\cos\alpha}{\sqrt{r_2^2-r^2\sin^2\alpha}},$$

that has a negative value at $r_2>r$ and $-\pi/2\prec\alpha\prec\pi/2$.

This means that the angle γ at an increase in the angle α decreases from a maximum value at $\alpha=-\pi/2$,

$$\sin\left(\pi-\gamma_{\max}\right)=$$
$$=\frac{1}{2r_2^2}\left[\left(A_1-S_1\right)\sqrt{r_2^2-r^2}+r\sqrt{4r_2^2-\left(A_1-S_1\right)^2}\right], \qquad (5)$$

to a minimum value at $\alpha=\pi/2$:

$$\sin\gamma_{\min}=$$
$$=\frac{1}{2r_2^2}\left[\left(A_1-S_1\right)\sqrt{r_2^2-r^2}-r\sqrt{4r_2^2-\left(A_1-S_1\right)^2}\right]. \qquad (6)$$

When $\alpha=0$, we obtain:

$$\sin\gamma=\frac{A_1-S_1}{2r_2}.$$

The partial derivative of γ for (A_1-S_1) at $(A_1-S_1)<2r_2$ is positive, implying a growth in γ with an increase in (A_1-S_1). At $(A_1-S_1)=2r_2$:

$$\left(A_1-S_1\right)=2r_2,\quad \frac{\partial\gamma}{\partial\left(A_1-S_1\right)}=0$$

and we obtain maximum:

$$\sin\gamma_{\max}=\frac{\sqrt{r_2^2-r^2\sin^2\alpha}}{r_2}, \qquad (7)$$

and at $\left(A_1-S_1\right)=-2r_2$:

$$\sin\gamma_{\min}=\frac{\sqrt{r_2^2-r^2\sin^2\alpha}}{r_2}. \qquad (8)$$

At $\left(A_1-S_1\right)=0$:

$$\sin\gamma=-\frac{r}{r_2}\sin\alpha.$$

Radius r of the body of a loosening roller affects the value for angle γ in two ways, because a partial derivative's sign depends on angle α.

When $\pi>\alpha>0$, increasing r decreases the angle γ; at $-\pi<\alpha<0$, it grows.

If angle $\gamma=0$, which corresponds to the pin penetrating the surface of raw cotton under the most adverse conditions – by the side cylindrical surface. An optimum for value γ is, obviously, equal to $\pi/2$.

4. 1. Estimation of interaction between a pin and the surface of a fibrous material, taking into consideration the elastic characteristics of the transported layer of raw cotton

Consider the first stage of interaction between a pin and the surface of a fibrous material – from the moment the pin touches the undeformed layer surface layer n–n at point B_1 (Fig. 2) to the limit strain value W at point B_2 until the pin penetrates the material.

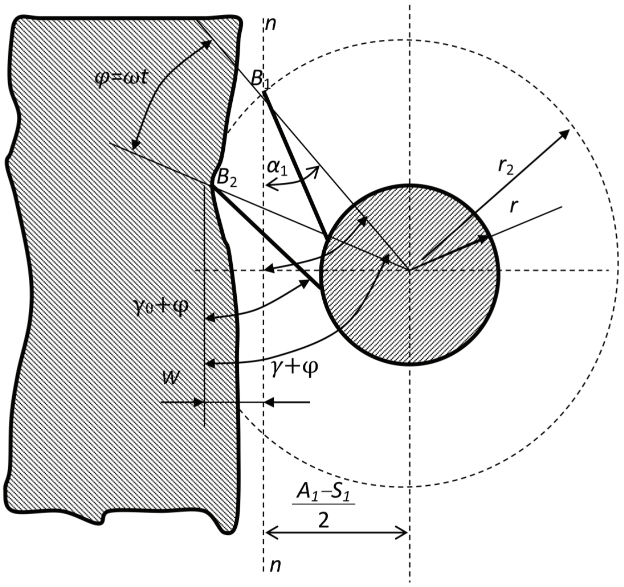

Fig. 2. Schematic showing the deformation of a surface layer by the pin of a loosening roller

The value for maximum deflection W in a function of the turning angle $\varphi=\omega t$, counted from the moment a pin touches the raw cotton surface is determined from the geometry of scheme:

$$\omega = r_2\left[\sin\left(\gamma_0+\varphi\right)-\sin\gamma_0\right]=\frac{A_1-S_1}{2}\left[\frac{\sin\left(\gamma_0+\varphi\right)}{\sin\gamma_0}-1\right]. \quad (9)$$

This displacement, according to [11], is matched with load distributed over the surface of contact that depends on the shape of the pin's end surface.

Accept, in agreement with [15], that the magnitude for a mean displacement of the contact surface of round shape from the uniformly distributed load at the assigned total force P, coefficient of generalized properties of a material k, and the pin's radius r_3:

$$W(0)=1.696\frac{kP}{r_3}. \quad (10)$$

Displacements of the surface points outside a contact zone at a distance t from the point of load application can be similarly derived from:

$$W(t_1)=\frac{kP}{t_1}. \quad (11)$$

By excluding from (11) and (10), we obtain:

$$W(t)=0.589W(0)\frac{r_3}{t_1}. \quad (12)$$

Taking into consideration the accepted directions of displacements W and counting the angle λ of the tangent inclination to the curve, we obtain (Fig. 3):

$$\lambda=\operatorname{arctg}\frac{\partial W(t)}{\partial t_1}=\operatorname{arctg}0.589W(0)\frac{r_3}{t_1^2}. \quad (13)$$

The amount of deformation $W(0)$ defines the maximum pressure of a pin on the layer:

$$P=0.589\frac{r_3 r_2}{k}\left[\sin\left(\gamma_0+\varphi\right)-\sin\gamma_0\right]. \quad (14)$$

Of interest is the extent to which, depending on the magnitude for the penetration of a pin into a fibrous material $W(0)$) and the inclination angle to the surface of layer $\lambda_c=\gamma_0+\varphi$, the pin would additionally deform raw cotton with its lateral surface (Fig. 3).

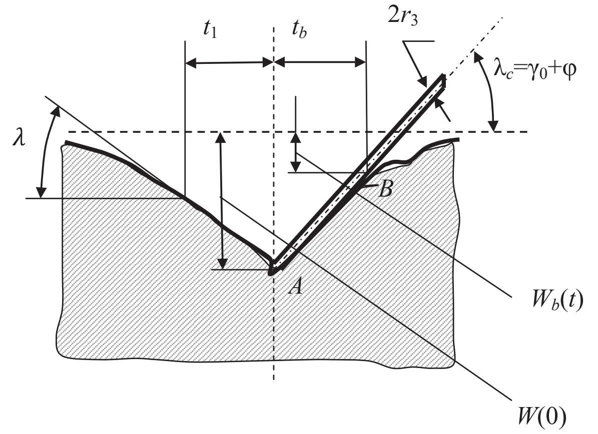

Fig. 3. Deformation of the surface of a raw cotton layer by the inclined pin

From the diagram in Fig. 4, using (12), we obtain:

$$\operatorname{tg}\lambda_c=\operatorname{tg}\left(\gamma_0+\varphi\right)=$$
$$=\frac{W(0)\left(t_B-0.589r_3\right)+t_B r_3\left[\dfrac{1}{\cos\left(\gamma_0+\varphi\right)}-1\right]}{t_B^2}, \quad (15)$$

where t_B is the distance from the point of load application to a point along the axis of the layer.

Expression (15) is approximate and, at $\lambda_0\approx\pi/2$, it must not be used. When $r_3<r_2$, one can use the simplified expression:

$$\operatorname{tg}\lambda_c=\frac{W(0)\left(t_B-0.589r_3\right)}{t_B^2}, \quad (16)$$

not taking into consideration the influence of r_3 on the geometrical pattern of the process. By solving (15) relative t_B, we find the length of section:

$$AB=\sqrt{t_B^2+\left[W(0)+r_3\left(\frac{1}{\cos\lambda_c}-1\right)-0.59W(0)t_B^3\frac{r_3}{t_B}\right]^2}. \quad (17)$$

Analysis of the derived ratios shows that at constant $W(0)$ an increase in λ_c decreases the AB secant magnitude. Thus, at $r_3=2.5$ mm; $W(0)=20$ mm, at values $\lambda=5°$; 15°; 25°; 45°; 60° the length of section AB, respectively, accepts values of 228.1; 76.1; 46.3; 27.2; 23.0 mm. At low thickness of the pin, these estimated magnitudes are somewhat different – 228; 75.7; 45.6; 26.0; 19.6 mm.

The analyzed scheme considers only local contact deformations in the absence of a common motion of the barb and a symmetric arrangement of pin rollers. Under an asymmetric scheme, due to a possible departure of the layer surface from the left and right pins, the conditions for penetration drastically worsen.

The motion of a pin into a mass of cotton occurs in two stages, matched with a first diagram (Fig. 4), until the layer surface is not destroyed and, in addition to a spreading effort P, the lateral surface of the pin (at $\lambda_c\neq\pi/2$) is exposed to load q, distributed over section AB, and with a second diagram (Fig. 5), when, as a result of destruction of the boundary layer, a pin penetrated the bulk of raw cotton, making the effort P insignificant. Both stages follow one after another; in both cases, it is important that the product should be able to slip along the axis of the pin and the structural particles should be captured by pins. One should not allow for a simple compression of the barb (under a symmetric scheme) or its deviation by the pin.

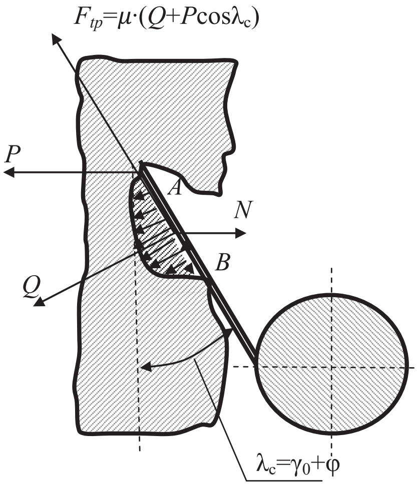

Fig. 4. Penetration of the pin into a fibrous mass without breaking the surface

To determine the power consumed by feed rollers, denote through:

$$Q=\int_A^B q\,\mathrm{d}z$$

the pressure of the lateral surface of the pin on a layer of raw cotton in the direction of normal to the axis of the pin and accept, according to Amonton, that the friction force of a layer against the surface, whose maximum value at the threshold of sliding at friction coefficient μ, would equal $F_{TP}=\mu Q$. The total pressure of spreading forces acting on a cotton layer near the surface of the pin is denoted via N. Force N is small for the first diagram (Fig. 4) and would increase for the second diagram (Fig. 5), where the lateral surface of the pin carries out a local deformation of the destroyed layer. For the generality of analysis, the designations for forces of the same nature are assumed to be identical in the diagrams.

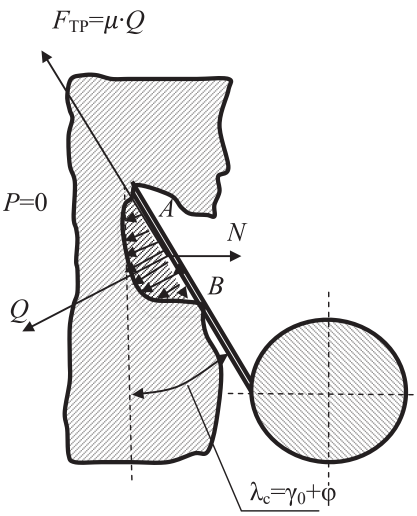

Fig. 5. Penetration of the pin into a fibrous mass when the pin penetrates the layer

The conditions for cotton slip along the axis of the pin towards the center of the pin roller for the first scheme takes the form:

$$Q=(N-P)\cos\lambda_c,$$

$$\mu(Q+P\cos\lambda_c)\leq(N-P)\sin\lambda_c, \quad (18)$$

hence, we obtain the condition:

$$\mu\leq\frac{\mathrm{tg}\,\lambda_c}{\ell+\dfrac{P}{Q}\cos\lambda_c}. \quad (19)$$

For the second scheme (Fig. 5), at $P=0$, we obtain from (16):

$$\mu\leq\mathrm{tg}\lambda_c \quad (20)$$

or, considering $\rho=\mathrm{arctg}\mu$, we obtain:

$$\rho\leq\lambda_c=\gamma_0+\varphi. \quad (21)$$

If conditions (19) to (21) are met, the pin slides over a fibrous material, going deeper into the barb and creating favorable conditions for subsequent capture and deformation of structural particles. The higher the value of γ_0, the smaller the value of φ at which the pin penetrates raw cotton. And because increasing α contributes to a decrease in γ_0, then at this stage of the process it is desirable that α_1 should be minimal – positive or even negative.

4. 3. Devising a procedure for estimating the calculation of power consumed by feed rollers carrying a layer of raw cotton

The above-mentioned studies [10, 11] calculated the energy consumed by feed rollers based on the condition for deforming a layer of raw cotton by rollers of round shape. At the same time, such a model does not take into consideration the power consumed for the displacement of a layer along the axis.

Consider the cyclic power consumed by rollers according to the model of the process suggested above.

The *i*-th blade, which deforms a layer of raw cotton, is exposed (Fig. 6) to spreading effort P_i and axial effort T_i. The blade has an angular velocity ω, which is variable (when applying a pulsed variator) or permanent.

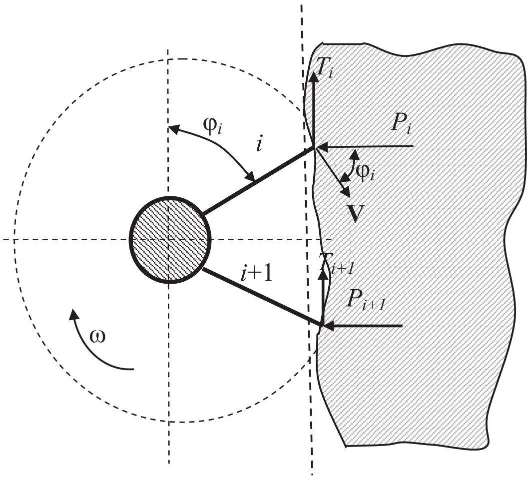

Fig. 6. Calculation of power consumed by feed rollers

The power spent by the *i*-th blade for the deformation and displacement of a layer is equal to (considering $\varphi_i=\varphi_0+\alpha+2\pi(i-1)/n$):

$$E_i=\frac{D\omega}{2}\begin{Bmatrix}P_i\cos\left[\varphi_0+\alpha\frac{2\pi(i-1)}{n}\right]+\\+T_i\sin\left[\varphi_0+\alpha\frac{2\pi(i-1)}{n}\right]\end{Bmatrix},\tag{22}$$

hence, it follows that the energy is returned to the layer in the direction of forces P_i only those blades for which $\varphi_i<\pi/2$. At $>\pi/2$, there occurs the inverse transfer of the accumulated deformation energy from cotton to the blade. If cotton is an absolutely elastic medium, then the entire energy of layer compression will be returned to the roller and the total consumption of energy by blades per a cycle of deformation will be zero. If cotton is considered to be plastic, then at $\varphi_i=\pi/2$ the blade abandons the layer and the accumulated energy will not be returned to blades. In the presence of elastic and plastic deformations, only that portion of energy would be returned to the roller that was spent on the elastic deformation component. It is possible to consider this phenomenon, reproduced in experiments [10], by a proportional decrease in the layer thickness at the output from a feed pair, or by reducing a medium rigidity coefficient under conditions of its unloading.

Work on the axial displacement of the flow in (22) is naturally positive throughout the entire range of change in φ_i from 0 to π. Based on the experience of using feeders and analyzing the processes occurring in a mine-collector [11], it can be considered that:

$$T_\Sigma=\sum_{i=1}^{i=r}T_i=\text{const},\tag{23}$$

at a constant height of mine loading and unchanged characteristics for the physical-mechanical properties of raw cotton.

Consider the distribution of power to transport a layer along the blades in the first approximation to be uniform, though accurate calculation requires the consideration of a statically undetectable system when $r\geq 2$. Then:

$$T_i=\frac{T_\Sigma}{r}.\tag{24}$$

At $T_i\neq T_j$, the values for T_i can be used to construct a column matrix.

$$\left\|T_i\right\|=\begin{Vmatrix}T_1\\T_2\\\dots\\T_r\end{Vmatrix},\tag{25}$$

and the values for $\cos\varphi_i$ and $\sin\varphi_i$ are used to build row matrices:

$$\left\|\cos\left[(\varphi+\alpha)+\frac{2\pi(i-1)}{n}\right]\right\|=$$

$$=\left\|\cos(\varphi+\alpha);\cos\left(\varphi+\alpha+\frac{2\pi}{n}\right);\ldots;\cos\left[\varphi_0+\alpha+\frac{2\pi(r-1)}{n}\right]\right\|,\tag{26}$$

$$\left\|\sin\left[(\varphi+\alpha)+\frac{2\pi(i-1)}{n}\right]\right\|=$$

$$=\left\|\sin(\varphi+\alpha);\cos\left(\varphi+\alpha+\frac{2\pi}{n}\right);\ldots;\sin\left[\varphi_0+\alpha+\frac{2\pi(r-1)}{n}\right]\right\|.\tag{27}$$

The total power, spent or received by a feed roller, can be determined from the matrix equation:

$$E_\Sigma=\sum\nolimits_{i=1}^{i=r}E_1=$$

$$=\frac{D\omega}{2}\begin{Bmatrix}\left\|P_i\right\|\cdot\left\|\cos\left[\varphi_0+\alpha+\frac{2\pi(i-1)}{n}\right]\right\|+\ldots+\\+\left\|T_i\right\|\cdot\left\|\sin\left[\varphi_0+\alpha+\frac{2\pi(i-1)}{n}\right]\right\|\end{Bmatrix}.\tag{28}$$

Under condition (23), expression (27) is simplified:

$$E_\Sigma=\frac{D\omega}{2}\left\{\left\|P_i\right\|\cdot\begin{Vmatrix}\cos\left[\varphi_0+\alpha+\frac{2\pi(i-1)}{n}\right]+\\+\frac{T_\Sigma}{r}\sum\nolimits_{i=1}^{i=r}\sin\left[\varphi_0+\alpha+\frac{2\pi(i-1)}{n}\right]\end{Vmatrix}\right\}.\tag{29}$$

The magnitude for angular velocity of a feed roller, which is set in motion by a pulsed variator, in the presence of three roller overrunning clutches, is described by a non-elementary function [12]:

$$\omega=\begin{cases}A\sin\left(pt-\frac{\pi}{6}\right)-\frac{A}{2}\ \text{at}\ \frac{2\pi m}{p}\leq t\leq\frac{2\pi}{p}\left(m+\frac{1}{3}\right),\\A\sin\left(pt-\frac{\pi}{2}\right)-\frac{A}{2}\ \text{at}\ \frac{2\pi}{p}\left(m+\frac{1}{3}\right)\leq t\leq\frac{2\pi}{p}\left(m+\frac{2}{3}\right),\\A\sin\left(pt-\frac{7\pi}{6}\right)-\frac{A}{2}\ \text{at}\ \frac{2\pi}{p}\left(m+\frac{2}{3}\right)\leq t\leq\frac{2\pi}{p}(m+1),\end{cases}\tag{30}$$

where $m=0,\ 1,\ 2,\ \ldots$ – integer.

This function (Fig. 7) consists of three separate segments of the sinusoids and its complete period is $r_1 = 2\pi/P$.

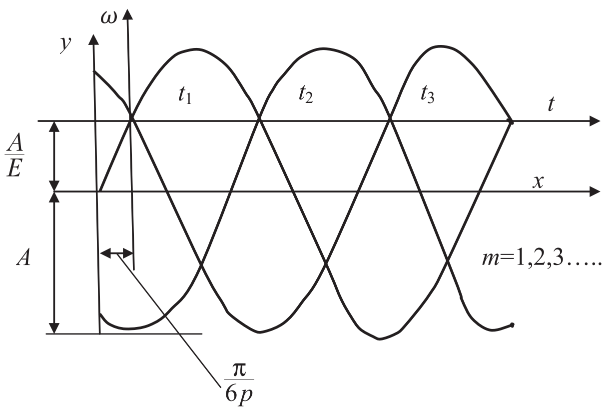

Fig. 7. Characteristic of change in the angular velocity of feed rollers set in motion by a pulse variator: $t_1 \geq \frac{2\pi m}{p}$, $t_2 \geq \frac{2\pi}{p}\left(m+\frac{1}{3}\right)$, $t_3 \geq \frac{2\pi}{p}\left(m+\frac{2}{3}\right)$

The function E_Σ is periodic, due both to the cyclic work of blades and the cyclical change in angular velocity and ω, whose mean value is derived from:

$$\omega_{cp} = \frac{P\int_r \omega \mathrm{d}t}{2\pi}, \tag{31}$$

employing (30).

To obtain the mean value for power consumption, one needs to integrate (30) and (29) over the period of a full cycle of change in speed ω and the deformation of a layer of raw cotton by roller's blades and divide the result by the period of the cycle. If τ and $\tau_2 = 2\pi/n\omega_{cp}$ are simple numbers, τ is taken as the least common multiple of their values; if these numbers are trailing decimals, one should take the least common multiple of the numbers derived from these ones by discarding commas, dividing it by 10 with the power equal to the smallest possible number of decimal digits in one of the numbers. Irrational numbers are matched with an infinite value for τ.

In the latter two cases, due to the considerable magnitude of the entire period and at ω=const, it is more convenient to use the approximation:

$$E_{cp} = \frac{\omega_{cp}^2 Dn}{4\pi}\int_0^{\frac{2\pi}{n\omega_{cp}}}\left\{\begin{array}{l}\left\|P_i\right\| \cdot \left\|\cos\left[\varphi_0+\alpha+\frac{2\pi(i-1)}{n}\right]\right\| + \\ + \frac{T_\Sigma}{r}\sum_{i=1}^{i=r}\sin\left[\varphi_0+\alpha+\frac{2\pi(i-1)}{n}\right]\end{array}\right\}\mathrm{d}t. \tag{32}$$

The obtained value (32) should be doubled for the case of estimating the power consumed by feed rollers.

Consider at an example applying the data from previous calculations and the diagram shown in [11], at symmetrical arrangement of feed rollers. Accept values: $K = 23$ mm^2/m and $\sum T_i = 100n$. The complete deformation cycle of raw cotton by pin rollers is the angle of π/3 rad. in which 0.682 rad (39°4′) is the layer deformed by two rollers. The rest of the cycle is the layer deformed by a single roller.

The matrix of values for spreading efforts [11]:

$$\left\|P_i\right\| = \left\|\delta_{ij}\right\|^{-1} \cdot \left\|W\right\|_j \tag{33}$$

equals, at $r=2$,

$$\left\|\begin{matrix}P_1\\P_2\end{matrix}\right\| = \frac{\left\|\begin{matrix}\delta_{22} & -\delta_{12}\\ -\delta_{21} & \delta_{11}\end{matrix}\right\|}{\det\left\|\begin{matrix}\delta_{11} & \delta_{12}\\ \delta_{21} & \delta_{22}\end{matrix}\right\|} \times \left\|\begin{matrix}W_1\\W_2\end{matrix}\right\|. \tag{34}$$

When $\delta_{ij}=\delta_{ji}$ and $\delta_{11}=\delta_{22}$, that makes it possible to determine reactions P_1 and P_2 in the function of angle α.

$$P_1 = \frac{\delta_{11}W_1(\alpha) - \delta_{12}(\alpha)W_2(\alpha)}{\delta_{11}^2 - \delta_{12}^2(\alpha)}, \tag{35}$$

$$P_2 = \frac{-\delta_{12}W_1(\alpha) + \delta_{11}(\alpha)W_2(\alpha)}{\delta_{11}^2 - \delta_{12}^2(\alpha)}. \tag{36}$$

The period when only a single blade deforms a layer of raw cotton is also described by these matrix equations that take the form pf simple algebraic ratios. In this case, a single blade starts to stretch the layer with the entire force T_Σ passed onto it. At such a transition, there is a surge in the transmitted power to enable the axial transportation of a layer due to the inequality of projections of velocities onto the direction of transportation.

Fig. 8 shows the results from calculating the power used by a roller in the form of charts (at a mean value for angular velocity $\omega_{av}=1.047$ s^{-1}). The power used by a roller for the axial transportation of a layer of cotton is denoted via 1. The curve demonstrates the spikes due to the transition of the system from $r=2$ to $r=1$, and vice versa; the reason for their occurrence is explained above. The mean value for power consumption here is ~ 6.5 W per a single roller.

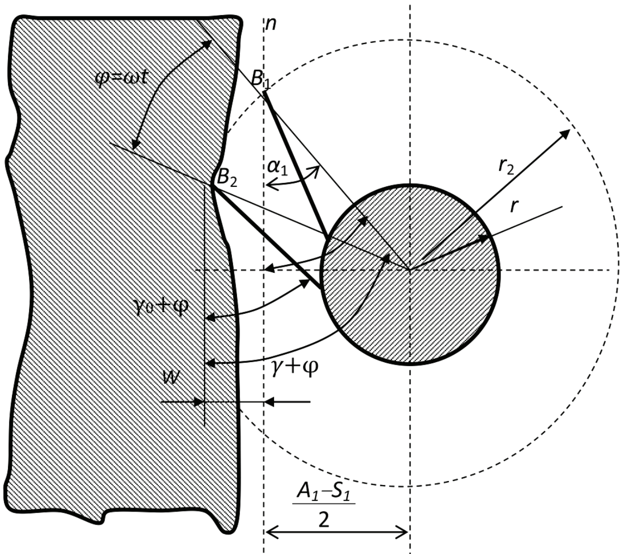

Fig. 8. Dependence of power used by a roller on rotation angle (at K=23 mm^2/n; $\sum T_i$= 100n): 1 – power for transporting a product; 2 and 3 – total power consumed by rollers during deformation of the plastic and elastic product, respectively

The total power spent on the reversible contact deformation of a perfectly elastic material and its transportation along the axis is shown by curve 2.

Over periods *CA* and *BC* the blade rollers receive kinetic energy from the layer (shaded regions in the figure). Over period *CB*, they give it to the layer, converting it into potential energy for the deformation of cotton in the direction of displacements W_i. Here, the mean magnitude of power consumption is the same –6.5 W.

For the case of an absolutely plastic material, the power consumption by a roller is defined by curve 3. Here, the blade, upon reaching maximum layer penetration, should not be exposed to spreading efforts at leaving, resulting in that over period BD the roller consumes power only for the axial transfer of the layer. Over period FB, it is obvious that curves 2 and 3 should coincide because the layer is deformed by only a single blade. It is obvious that here one obtains a large value for the mean power (under an asymmetric scheme, a layer is deformed by two rollers) amounting to 9.33 W, due to irreversible contact deformation of the layer.

Curves 2 and 3 (Fig. 8) demonstrate two characteristic points at which the energy consumed on contact deformation of a layer is zero – *A* and *B*. These are positions for the system's equilibrium – one is stable (*A*), as exiting this state requires energy costs, another is unsteady (*B*), since exiting it is accompanied by the release of the accumulated energy.

5. Discussion of results of studying the influence of elastic characteristics of raw cotton on power consumed by feed rollers

In the course of the study, various variants of parameters for the scheme of pin penetrating raw cotton have been considered. That allows us to conclude that at the predefined r_2 and γ_0, by increasing φ and by an according increase in λ and (at process phase I, at an increase in $W(0)$, one observes first an increase in $\overline{AB}$, along section AB (Fig. 8), which grows as γ_0 increases.

Next, section AB reduces to a certain minimum at $W(0)=\max$ near the position of maximum deflection (Fig. 4). Thus, at $r_2=45$ mm; $\alpha_1=0$ and $\gamma_0=30°$, $\alpha_1=10°$ and $\gamma_0=20°$ and at $\alpha_1=0$ and $\gamma_0=45°$ we obtain a series of values for φ and $\overline{AB}$.

At the same γ_0, increasing α_1 decreases the magnitude for $\overline{AB}$ reduced with a natural decrease in the power consumed by feed rollers – when $\gamma_0=30°$ and $\alpha_1=30°$, the series $\varphi=\{0;\ 15°;\ 30°\}$ is matched with a series of values $\overline{AB}=\{0;\ 6.28;\ 6.32\}$.

For cases when $\lambda_c=(\gamma_0+\varphi)\succ\pi/2$, in expressions (15) to (17), due to the negativity of terms containing the trigonometric functions, one should take their modulo. The mechanics of interaction between the blades of a feed roller and the transported layer of raw cotton has been revealed.

It follows from the reported calculations that one third of the time required to clean raw cotton involves a single blade of the roller. The most effective penetration of pins into a layer of raw cotton supplied at low speed requires the value of $\gamma_0 \gg 30°$. Therefore, the effective penetration of pins into a layer of raw cotton supplied at low speed requires that the value for γ should be as large as possible.

The merit of the current research compared with analogs is the fact that in order to improve existing designs and enhance the cleaning effect the influence of elastic characteristics of raw cotton on the power spent by feed rollers has been investigated. A series of highly effective methods have been devised to study the influence of elastic characteristics of raw cotton on the power spent by feed rollers, which would make it possible to maximally retain the natural qualities of cotton and seeds.

6. Conclusions

1. The considered model of the process of contact interaction between blades and raw cotton describes the process both quantitatively (based on the magnitudes for spreading efforts, power consumed) and qualitatively. That is not less important because this makes it possible to esimate the cyclic character of occurring phenomena, the steadiness in position of feed rollers, the impact of asymmetry on the system's force specifications. The cyclic power used by rollers has been determined according to the proposed model of the process when the mean value for power consumption is ~6.5 W per a single roller.
2. It was established that a raw cotton layer with a thickness from 170 to 380 mm and a width of 700 mm was loaded with a force of 3–10 N along concentrated along the line. Based on the reported calculations, it was found that 38.89 % of the time required to clean raw cotton involves a single blade of the roller; thus, the most effective penetration of pins into a layer of raw cotton supplied at slow speed requires that the value for $\gamma_0 \gg 30°$ should be as large as possible.
3. The matrix equations have been proposed to determine the total power spent or received by feed rollers. During periods when blade rollers receive the kinetic energy from a layer, when the blade reaches maximum layer penetration, the total power consumed by the rollers at the deformation of plastic and elastic products is reduced by 17 %, respectively. Over the rest of the period, the blade rollers return it to the layer, converting it into the potential energy of cotton deformation in the direction of displacements W_i.

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DESIGN OF PARALLEL LINK MOBILE ROBOT MANIPULATOR MECHANISMS BASED ON FUNCTION-ORIENTED ELEMENT BASE

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Для створення ефективних маніпуляторів мобільних роботів запропонована функціонально-орієнтована елементна база. Вибір елементної бази здійснено на основі аналізу схемних рішень маніпуляторів мобільних роботів. Обгрунтовано, що ефективними схемними рішеннями маніпуляторів є механізми з паралельними кінематичними зв'язками. Раціональною конструктивною схемою прийнято механізм, що має шість штанг змінної довжини (гексапод). Розглянуті схеми маніпуляторів мобільних роботів із різним числом і видом суміщених опор штанг. Доведено, що для реалізації різноманітних схем може бути застосована однотипна елементна база у вигляді сферичних шарнірів. Розглянуті різні варіанти реалізації схемних рішень маніпуляторів, побудованих на запропонованій функціонально-орієнтованій елементній базі. Сформульовані основні вимоги до елементної бази маніпуляторів мобільних роботів. Показано, що задоволення поставленим вимогам забезпечує функціонально-орієнтована елементна база на основі гідростатичних або аеростатичних шарнірів різного виду.

Запропоновано ряд варіантів схемних і конструктивних рішень регульованих сферичних гідростатичних та аеростатичних шарнірів. Високими точністними характеристиками відрізняється гідростатичний сферичний шарнір, що включає точну кулю із кераміки (карбід бора). Проведена технологічна апробація даного схемного рішення шляхом виготовлення експериментального зразка.

Розроблено регульований гідростатичний шарнір, оснащений мехатронною системою встановлення просторового положення сфери. Дане конструктивне рішення дозволяє регулювати положення сфери шарніра в межах діаметрального зазору.

Запропоновано комбінований аеростатично-гідростатичний опорний вузол агрегатований з приводами маніпулятора. Вузол має струменеву систему регулювання опорних реакцій аеростатично-гідростатичних опор сферичного шарніра. Проведена технологічна апробація розробленого пристрою.

Для підвищення ефективності запропонованої елементної бази розроблено спеціальні алгоритми системи керування положенням сферичних шарнірів маніпуляторів. Алгоритми розроблені на основі математичного моделювання динамічних процесів у шарнірних пристроях. Алгоритми включають реалізацію просторових полігармонічних переміщень сфери із цілеспрямованим вибором напрямку результуючих переміщень, що забезпечує необхідну точність та швидкодію процесу регулювання положення шарнірів маніпулятора

Ключові слова: мобільні роботи, схеми маніпуляторів, гідростатичні шарніри, аеростатичні опори, алгоритми керування

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1. Introduction

Parallel link manipulators have a high load capacity at low mass compared with traditional constructions. Such manipulators are effectively used in terrestrial robotic complexes designed to work with hazardous objects because they can significantly improve their mass and dimensional characteristics. The use of devices of this type is constrained by the