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Research on the Method for Determining the Interaction of Cotton With the Working Bodies of Cotton Gins

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Abstract

A theoretical regularity of the general behaviour of raw cotton as a porous medium in the technological processes of its mechanical processing has been substantiated for the first time. The speed of sound in a porous cotton medium has now been determined. The effect of additional force stresses inside the cotton medium caused by the filtration of the air component from cotton raw materials during the introduction of the working body, has been disclosed. A generalized equation that describes the force stress in a cotton medium when exposed to a variety of shapes of working bodies of cotton machines has been worked out. A method for calculating the damage to seeds and cotton fibers caused by their interactions with the working bodies of processing machines has been proposed.

The resultant theory that describes the stress state of cotton raw materials during processing allows us to use it practically to solve all important issues pertaining to the damage of fiber and cotton seeds that occur by using technological solutions in primary processing of cotton operations.

Keywords

fiber damage, cotton seeds, sound speed, fiber cleaning, density of cotton raw materials.

1. Introduction

The technical requirements and conditions necessary to process raw cotton are so complex that they demand the development of a mathematical model [1,2]. However, the absence of a general theoretical basis for the mechanics of the processes of the interaction of raw cotton with the various working bodies of technological machines has led to the present empirical path of development of engineering and technology for the primary processing of cotton raw materials.

The fibres and seeds of raw cotton go through multiple dynamic changes during the cleaning process carried out by cleaning machines [3,4]. In practice, after the cleaning is completed, the fibres turn out to be significantly damaged as they have been subjected to deformations caused by excessive forces that went beyond possible limits, which means they lose physical and mechanical properties essential for obtaining high-quality products.

The main reasons for these and other imperfections during primary processing are the fact that the design of cleaning machines and the establishment of technological processes have basically neglected the basic physical, mechanical and other properties of raw cotton [5]. Research has not been completed in such fundamental directions as modelling the laws of deformation and shape change, the volume of raw cotton under the influence of static and dynamic loads. Existing models for calculating the design parameters of machines are often based on linear laws of mechanics. In contrast to the models of solids known in mechanics, which, under small deformations, obey linear laws, the mass of raw cotton only at very high densities can approach, viscoelastic media, in its law of deformation [6,7]. Obviously, the natural cotton mass is a heterogeneous, discrete and multicomponent medium, consisting, as it is known, of relatively short and randomly spaced fibers of different moisture, seeds, and extraneous impurities. In contrast to the models of solids known in mechanics, which, in small deformations, obey linear laws, the mass of raw cotton can only approach viscoelastic media at very high densities, due to the laws of deformation which control it [6,7]. It has already been established, and it is now well known that natural cotton mass is a heterogeneous, discrete and multicomponent medium consisting of relatively short and randomly spaced fibres of different moisture, seeds, and extraneous impurities.

In the process of processing raw cotton or cotton fibre, the pulp undergoes mechanical impacts from the working parts and surfaces of the processing machines in the form of compression or tension, which causes complex processes to occur inside the pulp that are associated with changes in the density of the raw material and pressure it is subjected to [8, 9]. Stresses in the fibres under certain conditions reach critical values, which can lead to plastic deformation, shortening of the fibre and a decrease in quality.

2. Methods

Let us consider the state of the fibre mass in the compression process with a conditional stamp. Similar conditions arise during the interaction of the feed rollers of cotton-ginning machines, the interaction of breeders and strands with grates, the interaction of the roller and the feeding table with fibre, etc. So, we consider the effect of an elementary stamp on the fibre (Fig. 1).

As the starting point of our hypothesis, we will consider the motion of a homogeneous cotton mass as the motion of an ideal fluid with the subsequent introduction of conditions characterizing the difference between the pulp and the fluid.

As already known, the steady one-dimensional motion of an ideal fluid or gas (without internal friction) can be described by the following differential equation (excluding weight) [10].

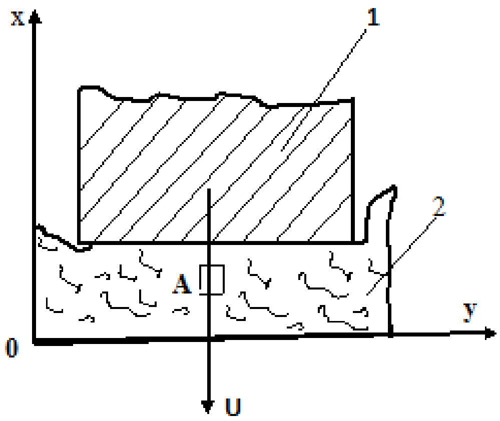

Fig. 1. Movement of a cotton particle under the influence of an intruding stamp; 1-stamp; 2- raw cotton

$$\frac{\partial \rho}{\partial x} = -\rho u \frac{\partial u}{\partial x} \qquad (1)$$

Here x is the coordinate of an arbitrary point A on the axis Ox, along which the medium moves; u is the velocity value of the material point of the liquid that passes through point A of space at time t; ρ is the density of the medium at the point under consideration; p is the pressure assumed to be the same for all directions at each point of the fluid. If the fluid is ideal and compressible, then in (1) the quantity ρ is variable.

In this case, the motion of a continuous compressible cotton mass, which has a variable density value, but which differs from an ideal fluid due to the presence of internal friction, the pressure p is not the same in all directions. Therefore, it is necessary to introduce the following expression instead of the left side of (1).

$$\frac{\partial p_x}{\partial x} = \frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau}{\partial \tau} + \frac{\partial \tau}{\partial z} \qquad (2)$$

where p_x is the pressure inside the cotton medium in the direction of the selected axis x.

From [7] it is known that the specific forces τ of internal friction in cotton are expressed as follows.

$$\tau = \mu P_b + G \qquad (3)$$

where P_b is the lateral pressure during cotton compaction; μ is the coefficient of internal friction of the material; G is the amount of total adhesion.

There is a pattern for lateral pressure P_b

$$P_b = k \cdot p \qquad (4)$$

where k is the lateral pressure coefficient; p normal sealing load.

Let us now consider the problem of introducing a flat stamp, which further simulates a variety of working organs of machines, in a compressible flat layer of fibre.

From (3) and (4) it can be seen that the value of p and the internal tangent force τ are proportional to each other.

$$\tau = \kappa_l p \qquad (5)$$

where κ_l is the coefficient of proportionality.

It follows from (5) that

$$\frac{\partial \tau}{\partial y} = k_1 \frac{\partial p}{\partial y}; \; \frac{\partial \tau}{\partial z} = k_1 \frac{\partial p}{\partial z}; \qquad (6)$$

From the point of view of fibre damage in the calculations for the stress p arising inside the cotton mass, the areas of its maximum area distribution (yz) are of the greatest interest (Fig. 2).

The condition for maximum stresses p, at the site (yz), leads to the fact that the following equation could be accepted

$$\frac{\partial p}{\partial y} = 0; \; \frac{\partial p}{\partial y} = 0; \qquad (7)$$

But, of course, for the x direction the magnitude. $\frac{\partial p}{\partial x} \neq 0$;

According to (6) then it will be

$$\frac{\partial \tau}{\partial y} = 0; \; \frac{\partial \tau}{\partial z} = 0; \qquad (8)$$

Thus, under the assumptions made, and taking into account (8), the quantity (2) is reduced to a single value.

$$\frac{\partial p}{\partial x} = \frac{\partial \sigma_x}{\partial x}$$

Now it can be seen that at the sites where p reaches the maximum (or minimum) value, we can assume that the internal friction of the medium does not manifest itself. This means that at such sites the motion of a non-ideal (with internal friction) medium is similar to the motion of an ideal (without internal friction).

Cotton is a compressible viscous (with internal friction) medium. It should be noted that the issue of the motion in such an environment has already received sufficient research attention. Practical tasks for this kind of media are solved by combining the results obtained separately

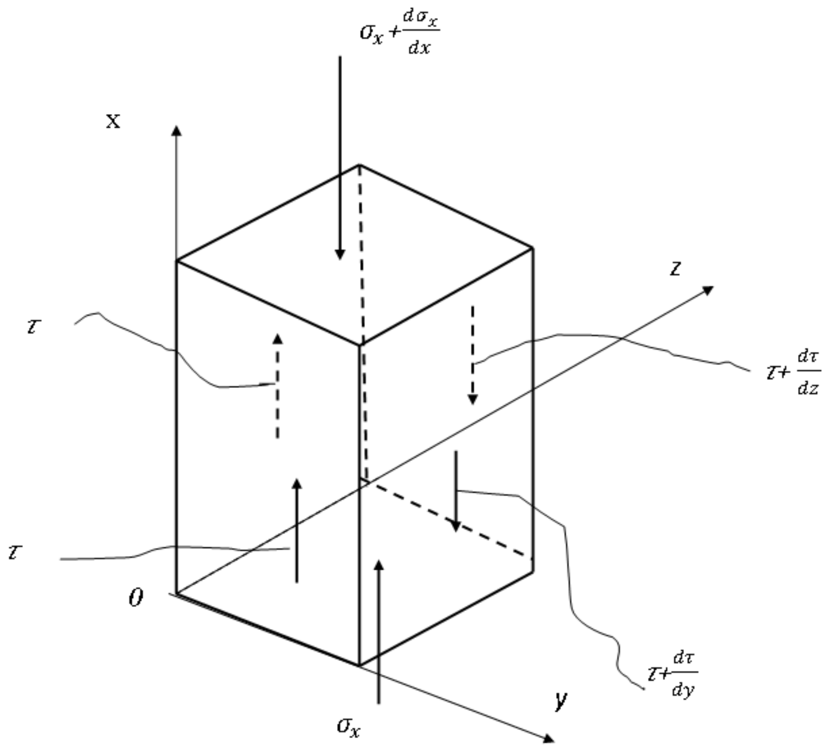

Fig. 2. The scheme of power stresses in the cotton environment during the implementation of the working body

for an ideal compressible fluid and for a viscous incompressible fluid.

At subsonic flow rates, the general picture of flow past solids in a compressible viscous fluid is approximately the same as for an incompressible viscous fluid.

As already mentioned, in areas where the pressure p reaches a maximum (or minimum) value, it is quite possible to use the system of equations of motion for an ideal compressible fluid (gas) to describe the movement of the cotton mass.

Therefore, in future, dynamic phenomena in a continuous squeezed-out medium such as cotton will be described by three equations that relate to each other for such system parameters as the medium density ρ, pressure p, and the velocity u of the movement of particles of the medium (10).

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}=-\frac{1}{\rho}\frac{\partial p}{\partial x}; \qquad (9)$$

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}(\rho u)=0; \qquad (10)$$

$$p=f(\rho) \qquad (11)$$

Here (9) is the equation of one-dimensional motion: (10) is the equation of continuity of

the medium; (11) is the equation of state relating pressure p and density ρ of the medium.

The system of equations (9), (10), (11) allows us to draw conclusions about the behaviour of pressure p and density ρ for the cotton mass when the working bodies of processing machines are embedded into it.

3. Results

When the working bodies of machines are introduced into the cotton environment at a rate equal to the spread of sound in the medium, a sharp increase in pressure and density in the processed raw materials should be expected. This effect is one of the causes of damage to the natural components of raw cotton materials.

We show the mechanics of such a phenomenon for steady motion when the addendum in (9) is $\partial u/\partial t=0$. The value p in (9) is the stress inside the medium. If we consider p as pressure from the working body on the raw materials, then now in (9) the sign of p will be the opposite. The equation (9) will look like this:

$$\frac{\partial p}{\partial x}=\rho u\frac{\partial u}{\partial x}; \qquad (12)$$

Now we multiply both sides of (12) by the value $\frac{\partial x}{\partial \rho}$,then we obtain

$$\frac{\partial p}{\partial \rho}=\frac{\rho}{\partial \rho}u\partial u; \qquad (13)$$

From the theory of acoustics, it is known that for small perturbations p and ρ, the quantity

$$\frac{\partial p}{\partial \rho}=c^2; \qquad (14)$$

The left side of (13) is the square of the velocity with sound vibrations of the medium. With that said, we rewrite (13) in the following form.

$$\frac{\partial \rho}{\rho}=\frac{1}{c^2}u\partial u; \qquad (15)$$

and we will assume that in the last expression the quantity p changes little, so that $\rho=\rho_0+\rho_1$, where ρ_0 is a constant, and ρ_1 is a small first-order quantity. Then in (15), one can use series expansion for a small quantity ρ_1/ρ_0

$$\frac{1}{\rho}=\frac{1}{\rho_0}\left(1+\frac{\rho_1}{\rho_0}\right)^{-1}=\frac{1}{\rho_0}\left(1-\frac{\rho_1}{\rho_0}+......\right);$$

Taking into account the last expression, the left-hand side of (15) takes the form

$$\frac{\partial \rho}{\rho}=\frac{\partial \rho}{\rho_0}\left(1-\frac{\rho_1}{\rho_0}\right)=\frac{\partial \rho}{\rho_0}; \qquad (16)$$

where the product of quantities is omitted from consideration $\partial\rho \cdot \rho_1$ as a second-order quantity of smallness.

If we substitute the last result from (16) into the left-hand side of (15) and integrate the expression obtained, then we get that

$$\rho = \frac{1}{2}\rho_0\left(\frac{u}{c}\right)^2 + const \qquad (17)$$

Here, for u = 0, the integration constant const = ρ_0 is the initial density of the system, and it finally follows from (17) that the dependence of the density ρ on the ratio u/c is

$$\rho = \rho_0\left[1 + \frac{1}{2}\left(\frac{u}{c}\right)^2\right] \qquad (18)$$

If we substitute further the found expression (18) for the density ρ in (12), then this equation will take the following form.

$$dp = \rho_0\left[1 + \frac{1}{2}\left(\frac{u}{c}\right)^2\right]udu \qquad (19)$$

After integration (19), we obtain that the value of pressure p is

$$p = \frac{\rho_0 u^2}{2}\left[1 + \frac{1}{4}\left(\frac{u}{c}\right)^2\right] + const \qquad (20)$$

Here, for $u = 0$, the integration constant *const* = p_0 is the initial pressure in the system, and then from (20)

$$p - p_0 = \Delta p = \frac{\rho_0 u^2}{2}\left[1 + \frac{1}{4}\left(\frac{u}{c}\right)^2\right] \qquad (21)$$

From (21) it is seen, that the addendum in square brackets is a correction for compressibility.

For example, at speed, when $u = c$, we obtain

$$1 + \frac{1}{4}\left(\frac{u}{c}\right)^2 = 1 + \frac{1}{4} = 1.25$$

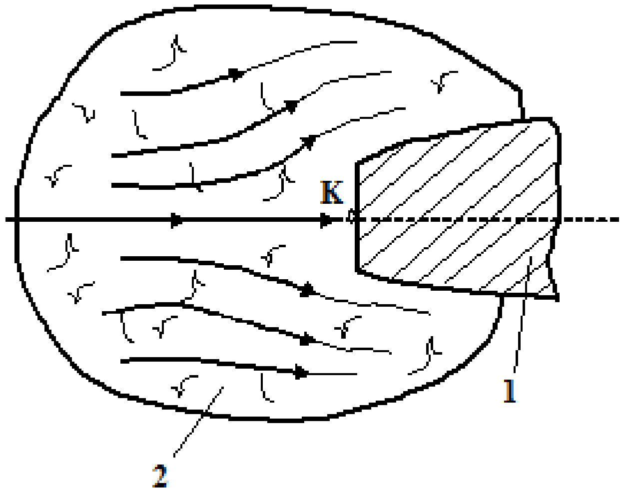

Fig. 3 Schematic for introducing a machine organ into cotton raw materials; 1-working body of the machine; 2-cotton medium

Taking compressibility into account gives a correction for p of 25%. With a more accurate calculation, this correction will be 32%.

In the same way, in (18), the addendum in square brackets reflects the degree of compaction of the medium. When $u = c$, it will be

$$1 + \frac{1}{2}\left(\frac{u}{c}\right)^2 = 1 + \frac{1}{2} = 1.5$$

Here, taking into account the compressibility gives a correction for the density ρ of 50%. A more accurate calculation shows that the correction will be 60%.

When the working bodies of cotton-processing machines are introduced into raw materials on the surface of organs, there are such sites K (points) on which the lines of trajectories of particles of incoming raw materials are perpendicular to the surface of the working body (Fig. 3). At such sites, the raw material particles are completely inhibited, their speed is zero, here the total pressure p_k is maximal.

It is known that when a solid body flows around an ideal incompressible liquid (gas), the pressure p_k at the critical point K, where the flow is inhibited, is equal to the total pressure of the flow.

$$p_k = p_0 + q_0$$

Here $q_0 = \frac{\rho_0 u^2}{2}$ velocity head of incompressible fluid (gas) flow; p_0– initial static pressure in the medium.

When a solid body flows around an ideal compressible liquid (gas) with a subsonic flow velocity, the pressure at the critical point K is p_k, and according to (21).

$$p_k = p_0 + \left[1 + \frac{1}{4}\left(\frac{u}{c}\right)^2\right]$$

is greater than the total pressure $p_0 + q_0$ of the flow, and an excess pressure at the critical point K equal to more than $p_k - p_0$ is greater than the pressure head q_0, and the difference between the excess pressure and the velocity head will be as great as the ratio for a given flow u/c.

In [10], it was noted that the temperature T_k at the critical point of zero velocity can be found from

$$\frac{T_k}{T_0} = 1 + \frac{k-1}{2}\left(\frac{u}{c}\right)^2 \qquad (22)$$

Here, T_o is the initial temperature of the medium; k is an indicator of the adiabatic compression of the medium. As a first approximation, we can take k = 3 for the cotton medium, since for the subsonic motion, the usual adiabatic dependence between pressure and density can be used. Then

$$T_k = T_0\left[1+\left(\frac{u}{c}\right)^2\right]$$

If, u=c then

$$1+\left(\frac{u}{c}\right)^2 = 1+1=2$$

and the temperature rises to $T_k = 2T_o$

Note that the results of (18), (21), (22) are valid only at a flow velocity u not exceeding the speed of sound c in the medium.

At a velocity u exceeding c, an abrupt change in the parameters p, ρ, u, T occurs and the continuity of the change in the indicated characteristics is violated, and the flow velocity decreases. Pressure, density and temperature rise sharply.

4. Discussion

The cotton medium has an essential compressibility property. At the introduction rates into the raw cotton of the working bodies of processing machines commensurate with the speed of sound propagation in such an environment, one should expect, according to the derived ratio (18), (21), (22), a significant increase in the density, pressure and temperature, and raw materials in the areas adjacent to the surface of the working bodies. The maximum increase in environmental parameters (at subsonic speeds) compared with their initial values can reach at $u = c$ the values: for density ρ by 1.6 times, for pressure p by 1.3 times, for temperature T by 2 times.

Such a local sharp increase in the characteristics of the cotton medium is a significant cause of fibre damage.

It follows from this, that when assigning a technological mode of processing, it is necessary to measure it with the value of sound speed for a given density of raw materials.

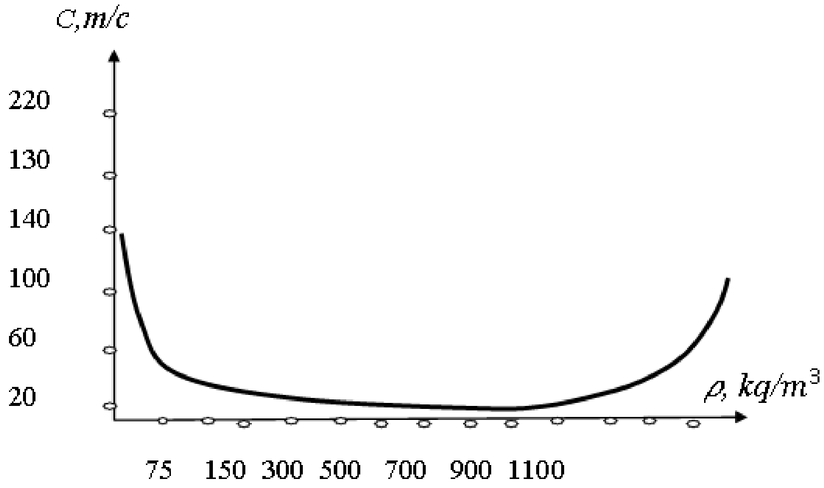

Fig. 4. The curve of the speed sound dependence c on the density ρ of raw cotton materials

Implementing the use of working bodies at such rates of speed with raw materials that are comparable to the speed of sound at a given raw material density should be avoided. In addition, the actual cotton mass is very heterogeneous in density and can vary significantly within a small volume from the nominal average density in the total volume. Further studies show that an increase in the density of raw materials within certain limits leads to a decrease in the speed of sound. At a density of 0 <ρ <350 kg / m^3, the speed of sound lies in the range 330> s> 30 m / s.

If lumps of increased density are found in raw materials, then the probability of their damage is greater in comparison with the main less dense mass of the processed raw material in question since the speed of sound in dense lumps is relatively low compared to the main medium. The conclusion is that the raw materials used should be as homogeneous as possible in density. This reduces fibre damage.

From the numerical results for the speed of sound, a curve is constructed of its dependence on the mixture density $c = f(\rho)$ in Fig. 4.

An analysis of the results for the speed of sound in the cotton mass shows that starting from for air without fiber impurities, this speed subsequently drops sharply in value even with a small amount of cotton fiber in the mixture.

So with a fibre content of 5 kg in 1 m^3 of the mixture, the speed of sound is c = 150m/s, and with a fibre content of 25 kg in 1 m^3 of the mixture the speed of sound c = 73m/s. The minimum value for c lies in the range of values c = 21-24m/s for a wide range of raw material densities ρ = 300-900kq/m^3.

Thus, the speed of sound in the two-component cotton medium studied turns out to be significantly less than in each of the two components in (air c = 330m/s and cotton fiber c = 1700m/s) taken separately.

5. Conclusions

1. The cotton mass is considered for the first time to be a compressible porous two-component medium consisting of a mixture of cotton fibres and air included in the gap between them. The influence of air included in the composition of the porous medium is essential in dynamic processing processes, and this must be taken into account when planning technological modes.

2. It has been theoretically and experimentally determined that the speed of sound in a mixture and air is relatively low, compared with the speed of sound and linearly oriented fibres (threads), where it is 1700 m/s. When the density of raw materials ρ = 250-300 kg/m^3,

the theoretically found speed of sound is 24-28 m/s, and the experimentally determined speed is 50-60 m/s.

3. When instilling the working bodies of processing machines into the cotton environment, one should expect the appearance of the compressibility of the medium. This significantly increases the pressure, density and temperature of the raw cotton. This effect is described by a system of three equations that interconnect the pressure, density and velocity of particles of a compressible medium.

4. The speed of instilling of the working body into the raw material medium may be small compared to the speed of sound in it, however, the local filtration rate of the air component on the surface of the working body may be comparable with the speed of sound, which leads to an increase in pressure and density, as well as an increase in the degree of mechanical micro damage to raw materials arising from contact with the solid surface of the working body.

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