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Investigation of the Process of Separation of Fibers From Seeds During Roll Ginning

Rahib Aqaqul Sailov[1]*

[1] Azerbaijan State Economic University (UNEC), Faculty of Engineering, Department of Engineering and Applied Sciences, Istiglaliyyat str. 6, Baku, Azerbaijan, AZ1001
* Corresponding author. E-mail: rahib.sailov@yandex.com

Abstract
In the initial position in the process of roll ginning, the seed is drawn to the slot of the contact gap of the knife-drum due to the tension of the fibers. Subsequently, the seed is struck with a certain impulse. The separation of the fibers from the seed after the impact of the beater occurs sequentially, not simultaneously.
As a result of theoretical and experimental studies, the optimum frequency of the shock pulse on the seed (*f* = 18-20) was found to be the most technologically successful in terms of providing the best quality indicators of seeds and fibers. Beating in the resonance mode allows to reduce the magnitude of the shock impulse on the seed, leading to a reduction in the degree of damage to the seeds. At this moment, the seeds at the end of the strand move only under the action of an elastic restoring force. The active part of the fiber bundle section in a dynamic process can be as little as 0.001 or less.
The average value of the compliance coefficient for the raw cotton variety BA-440 was determined experimentally. This allowed to determine the stiffness coefficient of the volatiles indirectly. According to the parameters obtained, the dynamic state of the system practically falls into the region of parametric resonance, where the motion is unstable. This means that the damaged seeds at the end of the strand enlarge significantly after the impact of the beater, causing the seeds to separate from the fibers.

Keywords
knife-drum, cotton seeds, fiber strands, coefficient of elasticity, roller gin.

1. Introduction

Many scientists have been engaged in issues of capturing fibers at the edge of a knife in a ginning machine. [1, 2, 3, 4]. Another paper considers the speed ratio of the flyers that are delivered into the ginning zone and the working drum, as well as the process of capturing fibers. [5]

In a number of works [6, 7], there is an analytical description of the force effects arising between the stationary knife and the gin working drum during the passage of cotton fiber in the contact zone.

To compile a differential equation of the specific pressure forces from the drum and the knife on the raw material between them, we will use the following method [8].

The issue of the safety of cotton seeds during the roller ginning process is one of the subjects of research on the dynamic processes of the primary processing of raw materials.

It is of interest, both theoretically and in applied terms, to analyze the process of seed beating in the so-called resonance mode. This mode allows to reduce the magnitude of the shock pulse on the seed and, consequently, the degree of damage to the seeds. At this moment, the seeds at the end of the strand move only under the action of an elastic restoring force - *cx*, where *c* is the elasticity coefficient of the fiber strand, and *x* – the coordinate of the displacement of the seed along the line of the strand tension.

2. Methods

The equation of natural vibrations of the seed at the end of the fiber strand has the form

$$m\frac{d^2x}{dt^2} + cx = 0 \qquad (1)$$

This kind of movement inevitably occurs in the production process during vibrations of the machine body, which creates conditions for the occurrence of own vibrations of the system.

The coefficient of elasticity *c* of the fiber strand can be approximately obtained using Hooke's law in the form [12, 13]:

$$P = \frac{EF}{l}\Delta l$$

where: *P* – external force, *l* – length of the fiber, *E* – modulus of elasticity, and *F* – cross section of the fiber.

$$C = \frac{EF}{L}; \qquad (2)$$

Subsequently, the seed is hit with an impulse *S* for a short period of time *t* = 0.001 s. In this case, the strand fibers receive an additional small length increment l_1 for the period before the next hit, so that

$$l = l_0 + l_1 \qquad (3)$$

where l_0 –initial length of the fiber.

Putting (2) and (3) in (1) we obtain

$$m\frac{d^2x}{dt^2} + \frac{EF}{l_0+l}x = 0 \qquad (4)$$

For the value

$$\frac{1}{l_0+l};$$

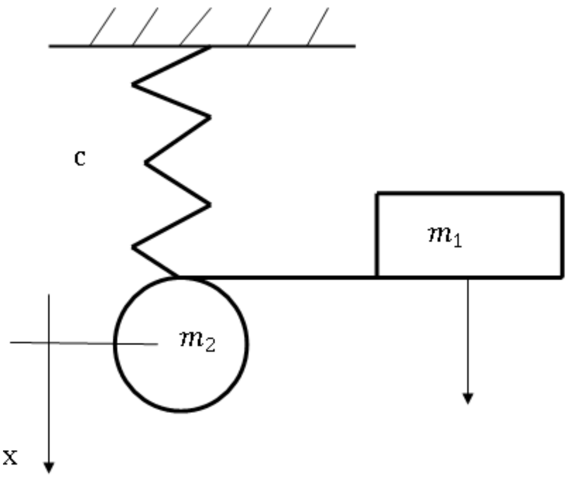

Fig. 1. Scheme of impact when the fibers are separated from the seeds, where m_1 is the mass of the blade of the inertial beater at the interaction point and m_2 the mass of the seed with a fiber

in (4), factorization is used for a small quantity l_1/l_0 as follows:

$$\frac{1}{l_0+l} = \frac{1}{l_0}(1+\frac{l_1}{l_0})^{-1} = \frac{1}{l_0}(1-\frac{l_1}{l_0}+....); \quad (5)$$

Putting (5) in (4), we obtain

$$m\frac{d^2x}{dt^2} + \frac{EF}{l_0}(1-\frac{l_1}{l_0})x = 0 \quad (6)$$

Let us further represent the pattern of small deformation of the thread l_1 in (6) in the form

$$l_1 = A \cdot \cos\omega t \quad (7)$$

where ω – the circular frequency of impacts of the beater on the seed, and *A* is the amplitude of the vibrations. Then from (6) we obtain

$$m\frac{d^2x}{dt^2} + \gamma^2(1-\frac{A\cos\omega t}{l_0})x = 0 \quad (8)$$

$$\gamma^2 = \frac{EF}{l_0 m} = \frac{c}{m}; \quad (9)$$

the square of the natural frequency of the system vibrations.

For further transformations of (8) we use 2t = ωt.

Then, from (8) we obtain

$$m\frac{d^2x}{d\tau^2} + \frac{4\gamma^2}{\omega^2}(1-\frac{A\cos 2\tau}{l_0})x = 0 \quad (10)$$

If we put parameters *a* and *q* in (10)

$$a = 4\frac{\gamma^2}{\omega^2}\ ;\ 2q = 4\frac{A\gamma^2}{l_0\omega^2}; \quad (11)$$

we get the final form:

$$m\frac{d^2x}{d\tau^2} + (1-2q\cos 2\tau)x = 0 \quad (12)$$

This is the Mathieu differential equation in its generally accepted form (3).

According to (12), it is possible to analyze the problem considered in the process of roller ginning.

First, we note the following fact: The direct calculation of the value of *c* according to [12,14,15] is difficult and can lead to errors for the following reasons.

When calculating the dynamic separation of the fibers from the seed upon the impact of the beater, it should be considered that in the real process the fibers in the strand are very heterogeneous and unevenly stretched when they are pulled into the slot of the contact gap of the knife-drum. The separation of the fibers from the seed after the impact of the beater does not occur simultaneously, but sequentially, either by individual fibers or by their groups, as a rule, after 3-4 strokes of the beater [12]. Therefore, the active part of the fiber bundle section in a dynamic process can be as little as 0.001 (or less) of the total fiber bundle section.

Therefore, in the future, a more accurate calculation will be carried out using experimental data for the value of *c*. In research by R. Korabelnikov [16, 17, 18], the so-called coefficient of compliance d of volatile (seeds with fibers) in the process of roller ginning was determined experimentally. This coefficient is defined as the reciprocal of the stiffness coefficient *c*; δ = 1/*c* mm/N.

The average value of the compliance coefficient was d = 0.17 mm/N for raw cotton of the VA-440 variety. This allowed to perform further indirect determination of the stiffness coefficient of volatiles *c*.

In [13] it is also shown that in the process of ginning, the contact of the seed and the blade of the inertial beater is not destroyed, i.e. the motion of the blade and seed is accomplished jointly. Therefore, in the calculations, it is necessary to assume that according to [19,20], $m = m_1 + m_2$, where m_1 is the mass of the blade of the inertial beater at the interaction point, and m_2 is the mass of the seed with fiber (smaller compared to m_1, Fig. 1).

Then the sought circular frequency g of the natural vibrations of the system is as follows:

$$\gamma = \sqrt{\frac{1}{\delta \cdot m}} \quad (13)$$

When the compliance coefficient d = 0.17 mm/N and the given mass of the blades are m = 1g, the circular frequency of the natural vibrations of the systems will be g = 750 rad/s.

In modern designs of roller ginning machines of the DV-1M type, the frequency of impacts of the beater on the seed is Z = 24-30 strokes/sec.

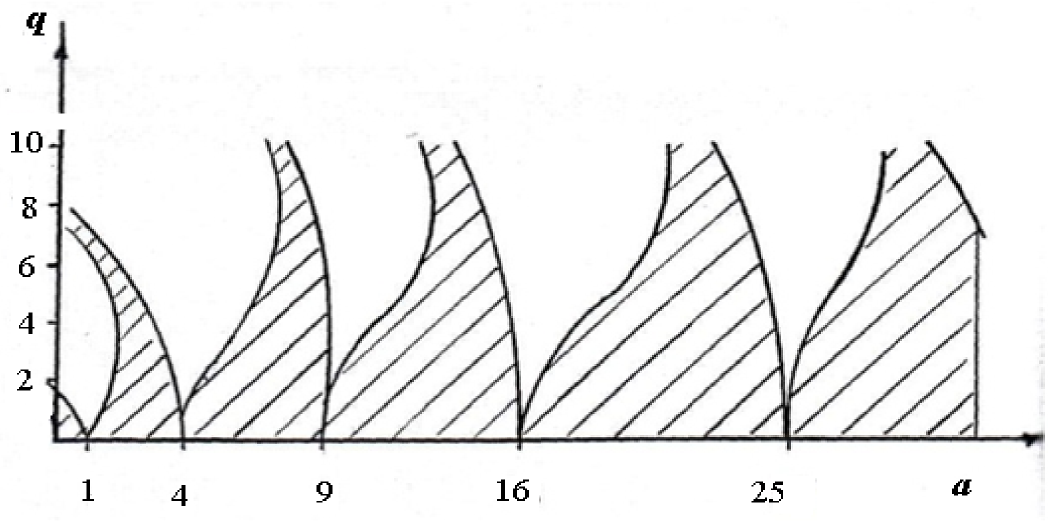

Fig. 2. Ains-Strett chart

Then the circular frequency ω of these impacts will be 2π·Z = 6.28 (24-30) = 150-190 rad/s. The calculations assume that ω = 200 rad/s. The length of fiber *l* stretched between the seed and the contact gap slit is *l* = 3-15mm. The calculations assume that *l* = 10mm.

The amplitude A in (7) is determined from A=V/ω;

The speed of impact of the blades of the beater with the seed is 2.5 m/s. Considering that the impact is inelastic, we will assume that the velocity acquired by the seed is V = 0.5 m/s. Then A = 0.002 m.

Given all these data for the following system parameters: γ = 750 rad/s, ω = 200 rad/s, *l* = 0.01 m, and *A* = 0.002 m, we obtain that in (11) and (12) the values of the parameters are as follows *a* = 56-100; *q* = 5.6-10.

Solutions of the Mathieu equation (12) are oscillatory in nature; their main properties depend on the specific values of parameters *a* and *q*. In some cases of this combination, *a* and *q* correspond to oscillations limited in amplitude, and in other cases, oscillations with increasing amplitude.

If the amplitudes remain limited, then the system is stable; otherwise, parametric resonance takes place and the system is unstable.

The boundaries between the regions of stable and unstable solutions are presented in the form of an Ains-Strett diagram (Fig. 2), constructed in the plane of parameters *a* and *q*. If the image point with coordinates *a* and *q* is within the shaded fields of the diagram, then the system is stable. In the unstable system, the image points are located in white fields.

The area of stable movements on the Ains-Strett diagram is practically concentrated in the small segment of the *a* axis, where $q < 1$. With the exception of points $a = 1^2; 2^2; 3^2; 4^2$.., where $q = 0$.

According to the values of parameters *a* = 56-100 and *q* = 5.6-10 obtained, due to large values of $q > 1$, the dynamic state of the system practically falls into the region of parametric resonance, where the motion is unstable. This means that the oscillations of the seed at the end of the strand increase significantly after the impacts of the beater, which leads to separation of the seed from the fiber.

3. Discussion

From (11) it can be seen that *a* and *q* parameters can be controlled by changing the g and ω frequencies, as well as the speed of the impact on the seed *V* and the length *l* of the pinched fiber. In this case, both a stable and unstable state of the system can be achieved.

Separation of the seed in the resonant mode allows to use a relatively small impact force of the beater, which reduces the possibility of damage to cotton seeds. The combination of specific values of the *a* and *q* parameters from (11) are significant for the occurrence of parametric resonance, rather than the magnitude of the beater force.

It is known that for the static separation of the seed from the fiber, a force of P = 30 N is required [14]. The average force is p = 12 N/cm for a rigid beater [13] when ginning raw cotton of the BA-440 variety. For comparison, the critical force leading to the damage to the seed is p = 45 N/cm.

The method presented for the separation of fibers from seeds by an element beater was used in further research [15]. The experiments were carried out to find the optimal value of the parameters for the so-called method of the lower striking of seeds from the edge of a fixed knife.

Using the previously given values for g, *l*, *F* and the new value for ω = 113-126 1/s, the parameters of the oscillating system in this case will be *a* = 140-176 and *q* = 14-17.6. These *a* and *q* parameters (quite a large value for *q*) on the Ains-Strett diagram (Fig. 1) correspond to a state of instability that facilitates the separation of seeds with a small force.

Based on the above values for the parameters, the operating parameters of the beater in a modern roller ginning machine of the DV-1M type allow to conduct the separation in a resonant mode quite favorable for the preservation of seeds. Apparently, the selection of optimal parameters of the mechanism for the separation of seeds mainly occurs empirically.

4. Conclusions

1.The theoretical results obtained for the generalization of the technological process in roller ginning can be used in the design and construction of cotton processing machines and in choosing optimal parameters for the construction of beater mechanisms.

2. The optimal frequency of vibrational striking turned out to be in the range f = 18-20 Hz (or $\omega = 2\pi f$ = 113-126 1/s) for a roller gin of the DV-1M series. For the experiment, raw cotton of the VA-440 variety, of first industrial grade (manually collected), was used.

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