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Improvement in the Design and Methods of Calculation of Parameters of Vibration Multifaceted Gridirons of Natural Fibre Cleaners

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Abstract

The article outlines the operating concept of the recommended multifaceted gridirons on an elastic bearing support, analyses the excursion of the gridiron, justifies the characteristics and gives the results of comparative production tests. As well as the effective scheme and principle of work of cotton cleaner from large impurities are presented based on the research of fluctuations in the parameters of a grid-iron on an elastic support system. The obtained results of the recommended cotton cleaner were provided. Experiment results showed that the cleaning purificatory effect increases on average by up to 8.11% in comparison with the existing option of a fire grate; mechanical damage to seeds decreases by up to 1.09%, and free fibre in the seed-cotton decreases two times, to 0.113%. With an increase in the resistance of cotton from 19.7 H up to 60 H (average value), the movement of the gridiron increases from $0.65 \cdot 10^{-3}$ m up to $3.2 \cdot 10^{-3}$ m. This is due to the fact that in the interaction of raw cotton with vibroisolating conical grates, cotton-yarn is additionally shaken, increasing their direction of movement due to the taper rate of the gridirons, which leads to an increase in the cleaning effect.

Key words: *fibre, cotton cleaner, gridiron, multifaceted, rubber bushing, stiffness.*

Introduction

Today, the demand for natural fibres is very high. Keeping their natural properties is one of the most pressing problems. Cotton is the purest form of cellulose found in nature and cotton fibres have considerable economic significance. There are numerous findings from the world's scientists on the quality of cotton fibre preservation and improving the efficiency of purification. The effectiveness of these studies is related to technology development [1, 2].

Maximum preservation of the natural qualities of cotton should be based on the improvement of machine design and equipment for the preliminary treatment of cotton and of the creation of movable operating elements of the machine affecting the cotton. The main indicator of cotton cleaning machine operation is their ability to isolate rubbish, motes and various impurities from seed-cotton by maximally preserving the natural qualities of the fibre and seeds [3].

The "Universal Cotton Cleaning Complex (UCC)" cotton cleaning unit includes several consecutive cleaning sections, both of small litter and large litter, and has a common helical drain (***Figure 1***). The cleaning serrated section of the UCC cotton-cleaning unit contains a body, two successively installed transporting brush drums, two serrate drums, grate gridirons beneath them, a removable drum (interacting) between the serrated drums, lapping brushes rigidly installed in the body, and augers for removing weed contaminants. The transporting brush drums can rotate in two directions: clockwise in the operating mode and counterclockwise in the case of excluding the power supply with cotton of the serrate cleaning section [4].

One of the drawbacks of the existing machines and devices intended for the cleaning of seed-cotton is the low efficiency of the impact of the movable operating elements on the treated material. This leads to an increase in cleaning frequency. Multiple exposure of seed-cotton to the existing devices and machines damages the fibres and seeds, decreasing their natural quality [5]. Therefore, the creation of new, highly-effective vibrant multifaceted gridirons on the elastic bearing supports of cotton cleaners of large litter, and the development of methods of calculation of their main characteristics is an actual scientific-technological task of the industry.

Design of multifaceted gridirons for an elastic bearing support

For the reduction of the frequency of cotton cleaning of small litter by intensification of the influence on the cotton of the cleaning zone elements, a gridiron structure was developed [6, 7].

The structure consists of multifaceted gridirons (1), which are installed in aciform straps (4), by means of an elastic bushing and rotating saw cylinder (2) (***Figure 2***). In the design proposed the purification process of the fibrous material is performed in the following way: In the operation process the seed-cotton (fibrous material) enters the serrate drum (2), the jags of which clench the seed-cotton and pull it through the fire grate. In the operative range of the serrate drum (2), the cotton strikes against the diamond gridiron (1). Herein, the force and direction of the strikes along the rotation motion of the drum (2) will be different due to the different number of faces of the gridiron (1). In this case with an increase in the number of gridiron faces, the impulsive strike force f of the cotton against the gridiron faces 1 also increases, and with a decrease in the number of faces of the gridiron (1) and vice versa, the strike force increases. Such a contact of the cotton with diamond (of different number) gridirons (1) favours the prom-
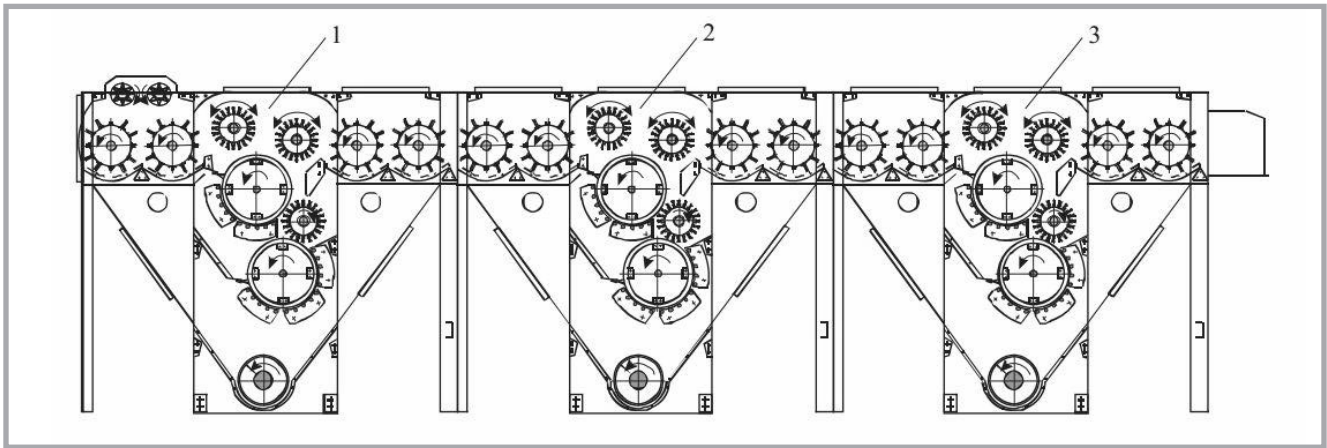
Figure 1. *Scheme of UCC cotton cleaning machine. 1 – UCC.01. Starting section; 2 – UCC.02. Intermediate section; 3 –UCC.03. Final section.*
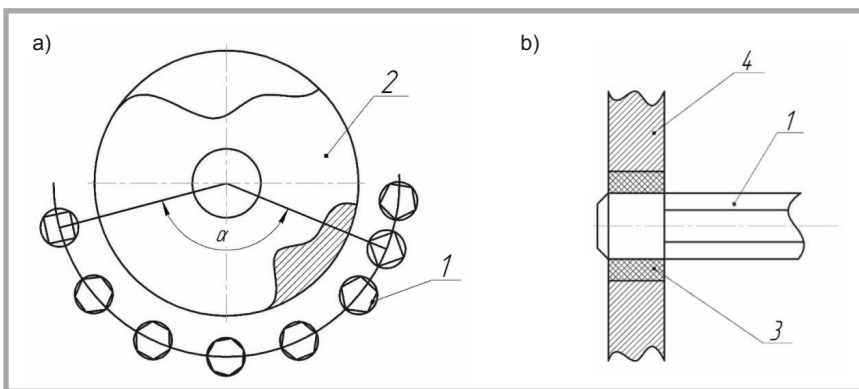

Figure 2. *Fire grate of the fibrous material cleaner.*

inence of admixtures of various weights from the seed-cotton and with various depths of locations in the seed [8, 9].

For control of the seed-cotton cleaning process, the installation of gridirons 1 along the drum rotation motion (2) is performed according to the sinusoidal law. Herein, the smoothness of the process is eliminated, where the scope of the direction of impulsive strikes against the various gridiron faces will change periodically (2), which leads to the prominence of drossy admixtures from the seed-cotton (*Figure 2.a*).

Generalised expressions, by which it is possible to determine the gridiron faces take the following form:

$n_{i+1} = n_i + 1; n_{i+2} = n_i + 2; n_{i+3} = n_i + 3;$
$n_{i+4} = n_{i+2}; n_{i+5} = n_{i+1}; n_{i+6} = n_i;$
$n_{i+7} = n_i + 1; n_{i+8} = n_i + 2; n_{i+9} = n_i+3;$
$n_{i+10} = n_i + 8$ and s.m.,

where, n_i, n_{i+1} ... n_{i+10} – the number of faces *i, i + 1..., i + 10* – the gridirons.

The period of changes in the iron face is chosen depending on the size of the grid-

irons (1), the inter- gridiron gap, drum size 2 and on the gap between the gridirons (1) and the drum (2).

The installation of gridirons (1) in the aciform straps (4) by means of elastic (rubber bushing) (3) allows to increase the process of litter elimination from cotton due to additional vibration of the gridirons (1) (*Figure 2.b*).

Calculation of gridiron parameters

Taking into account the random function of the perturbing force from the seed-cotton, the nonlinearity of the restoring force of the elastic bearing support, and its dissipative characteristics on account of the operation [10-13], it is possible to form an equation for the oscillatory movement of the diamond gridiron as follows:

$$m\frac{d^2x}{dt^2}+в\frac{dx}{dt}+c_1x+\frac{c_2}{\mu}x^3 = M(F_в)\pm\delta(F_в)$$

(1)

where, b – coefficient of the internal resistance of the gridiron elastic bearing support.

Herein, the following estimated values of the parameters were taken into consideration:

$M = 4.0\ Hc^2/m;\ c_1 = 2.5\cdot10^4\ H/m;$
$c_2 = 0.12\cdot10^4\ H/m;\ b = 60\ Hc/m;$
$\mu = 1.0\ m^2$

$M(F_k)=19.67+0.98sin(x+55°12') +$
$+ 7.83sin(2x + 112°14') +$
$+ 1.8sin(3x + 103°23') +$
$+ 3.37sin(4x + 4°39') +$
$+ 6.96sin(5x + 93°24') + 2.7cos6x$

From an analysis of the data observed and treatment of them by the method of mathematical statistics, the expected value of the perturbation force was determined for the cotton on the gridirons, as well as its possible variations, not only by frequency but also according to the amplitude.

A fragment of the movement, speed and acceleration of the diamond gridiron on an elastic bearing support is given in Figure 3., with the nonlinear restoring force at $M = 3.0\ Hc^2/m$ and $c_1 = 2.5\cdot10^4\ H/m$, $c_2 = 1.2\cdot10^4\ H/m$, $M(F_b) = 12.5H$, $\delta(F_b) = (0.8÷1.1)\ H$. It should be noted that the oscillation frequency of the gridiron is *(40...55)* Hertz. In this case the high-frequency component of the oscillation of the gridirons is *(147...178)* Hertz.

The low-frequency component of the forced oscillations complies with the rotational frequency of the saw cylinder of the UCC unit, and the high-frequency component conforms to the consideration of the number of gridirons in the section. From *Figure 3* it is visible that at the forced oscillations of the multifaceted gridiron, the gridiron inclines on average to the degree $X_{av} = (1.4÷1.6)\cdot10^{-3}\ m$, and the peak-to-peak amplitude at the calcu-

lated values of the characteristics makes $\Delta X = (1.8 \div 2.1) \cdot 10^{-3}$ m.

For the cylindrical gridirons on the elastic bearings according to the operation, the peak-to-peak amplitude makes $\Delta X = (2.2 \div 2.5) \cdot 10^{-3}$ m. Comparison of the results shows that in the structure of the diamond gridiron proposed, the amplitude of oscillation decreases to $(20 \div 25)\%$ due to the nonlinear hardening characteristics of the elastic bearing support (Nonlinear hardening characteristic – bearing hardening). The meanings of $\dot{X}$ and $\ddot{X}$ change similarly. The peak-to-peak amplitude of the speed goes from *0.6 m/s* to *1.25 m/s*, and the amplitude of the oscillation of acceleration at the design values of the system is within the range of the limits $(6.5 \div 10)$ m/s². Speed and acceleration oscillation frequencies comply with the high-frequency component of the technological load from cotton.

Characteristic curves of the amplitude are given in *Figure 4*, showing the speed and acceleration due to the increase in weight of the fire grate. It is known that with an increase in the weight of the oscillating system, a great force is necessary for its perturbation, that is, with an increase in weight the oscillation amplitude of the multifaceted gridirons decreases. With an increase in the weight of the gridiron from *1.0 ns²/m* up to *5.0 nc²/m*, the peak-to-peak amplitude of the multifaceted gridiron drops from $1.85 \cdot 10^{-3}$ *m* to $0.65 \cdot 10^{-3}$ *m* along the nonlinear pattern. Regarding the oscillating system, it should be noted that with an increase in the weight of the gridiron, the decrease in speed and acceleration is also nonlinear. What is noteworthy is that the intensity of the increase in the pea-to-peak amplitude ΔX, $\Delta \dot{X}$ and $\ddot{X}$ decreases with an increase in the weight, which is due to the nonlinear hardening characteristic of the elastic bearing. In this case, with an increase in load to the gridiron, the intensity of deformation of the elastic bearing decreases, which leads to a reduction in the oscillation amplitude of the gridiron. The recommended weight values of the multifaceted gridirons are $(3.5 \div 4.0)$ *ns²/m*.

In the process of cleaning of the seed-cotton of large litter, important is the gridirons' oscillating amplitude limitation, as these oscillations directly influence the gap width between the gridirons and the saw cylinder. The value of the oscillation amplitude of the multifaceted gridirons
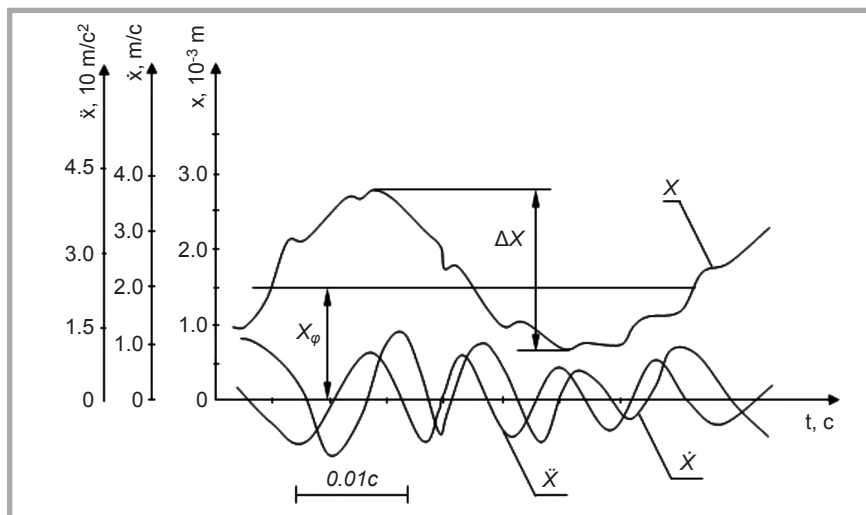

Figure 3. Change in the movement, speed and acceleration of the multifaceted gridirons on the elastic bearing at random perturbation (at M = 3.0 Hc²/m; c_1 = 2.5·10⁴ H/m, c_2 = 1.2·10⁴ H/m, M(F_b) = 12.5 H, δ(F_b) = (0.8÷1.1) H).
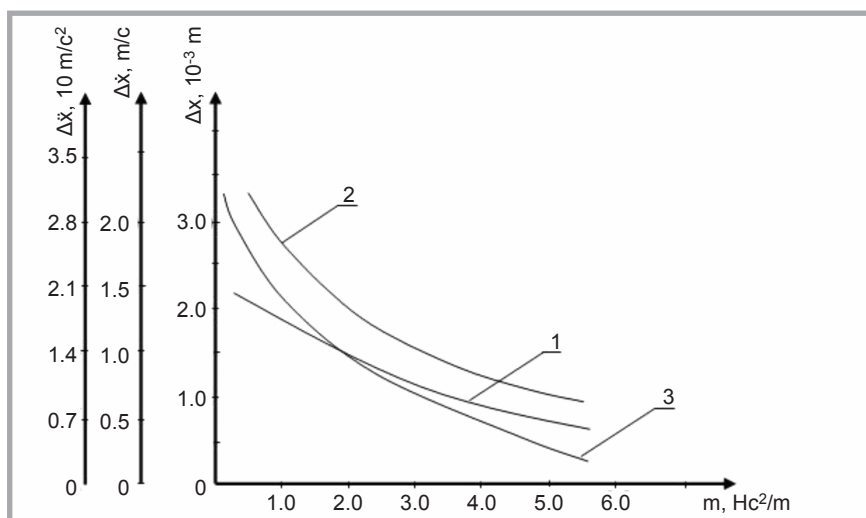

Figure 4. Characteristic curves of the change in the peak-to-peak amplitude of the movement, speed and acceleration of the multifaceted gridirons due to a change in their weight (where, 1 – ΔX = f(m); 2 – ΔẊ = f (m); 3 – ΔẌ = f(m) at c_1 = 2.5·10⁴ H/m, c_2 = 1.2·10⁴ H/m frictions δΔX, δΔẊ, δΔẌ = (10÷12) %).
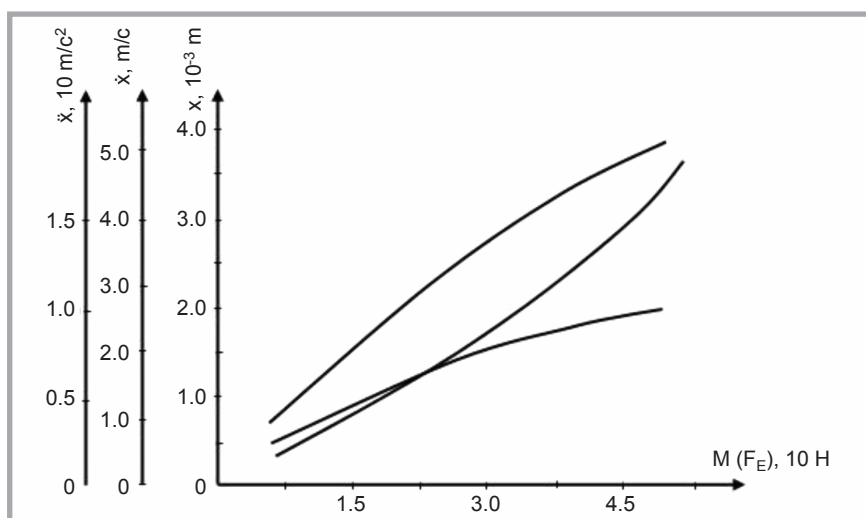

Figure 5. Dependence of the movement change, speed and acceleration of the multifaceted gridirons as a function of resistance from cotton (here in, frictions δx, δẋ, δẍ = (8.0÷10) %; c_1 = 2.5·10⁴ H/m, c_2 = 1.5·10⁴ H/m).

Table 1. *Results of comparitive production tests.*

Indicators, %	After the cleanser with multifaceted gridirons on the elastic bearing supports in the 1-line of UCC	After the cleaner with commercial gridirons in the 1-line of UCC
Humidity	8.7	8.7
Content of impurities	4.2	4.2
After cleaning purificatory effect	67.95	59.84
Impurity content of seed-cotton	1.41	1.83
Mechanical defects of seeds	2.07	3.16
Free fibres	0.107	0.22

in our case is controlled by the nonlinear hardening characteristics of the elastic bearing support.

It is found from the studies that an increase in the coefficient of stiffness c_1 of the elastic bearing leads to a proportional decrease in the oscillation amplitude of the multifaceted gridirons. For the provision of oscillation of the multifaceted gridirons with an amplitude of $(0.5 \div 1.0) \cdot 10^{-3} \ m$, the nonlinear component of the stiffness coefficient of the elastic bearing should take values of $(1.4 \div 2.0) \cdot 10^4 \ H/m$, where the stiffness coefficient is $c_1 = (2.5 \div 3.5) \cdot 10^4 H/m$. The change in the width of the rubber bushing amounts to $3.0 \cdot 10^{-3} \ m$ (for rubber band HO-68).

Dependencies of the movement change speed and acceleration of the multifaceted gridirons on the elastic bearing supports with nonlinear hardness at the load variation of the seed-cotton are given in **Figure 5**. With an increase in resistance from the cotton from *19.7 H* up to *60 H* (average value), the movement of the gridiron increases from $0.65 \cdot 10^{-3} \ m$ up to $3.2 \cdot 10^{-3} \ m$. In this case, the hunting speed increases according to the nonlinear regularity up to *2.45 m/s*, and the acceleration rises to *21 m/s²*. Herein, frictions δ_x, $\delta_{\dot{x}}$ and $\delta_{\ddot{x}}$, which depend on the random component of the load, are within the range $(8.0 \div 10)\%$. For prevention of the dilation of briefings between the gridirons due to the substantial oscillating amplitudes of the gridiron and decrease in the technological gap between the saw cylinder and gridirons, the amplitude of the multifaceted gridirons, according to the results of the experiments, should not exceed $(0.8 \div 1.2) \cdot 10^{-3} \ m$.

Thus, for the provision of necessary oscillation amplitudes of the multifaceted gridirons, it is advisable to choose a seed-cotton resistance within the range *(25÷35)H*, which complies with the *(5.0÷7.0)T/h* of the UCC machine [14, 15].

Results of the application of multifaceted gridirons on the elastic bearing supports

According to the results of the full factorial experiment conducted, the following optimum values of characteristics of the large-scale cleaning cone are recommended: rotary velocity of the serrated drum – *300 min⁻¹* , taper on the elastic bearing *-0,015*, and stiffness of the elastic bearing support (rubber brand) – *HO – 68* ($c_1 = 3.0 \cdot 10^4 \ H/m$, $c_2 = 1.6 \cdot 10^4 \ H/m$).

At these parameter values of the large cleaning zone, the UCC machine achieves a high effect of cleaning as well as decreased mechanical defects of the seeds and free fibres in the seed-cotton. A fire grate for the large cleaning section of the UCC cleaner was made with the above-mentioned parameters.

Results of the comparative tests conducted on in-line systems with commercial gridirons and the conical ones proposed herein on the elastic bearings are shown in **Table 1**.

In the conduction of experiments, the recommended structure of the fire grate with conical gridirons on the elastic bearings showed high reliability and consistency of operation. Experiment results showed that the cleaning purificatory effect increased on average by up to *8.11%* in comparison with the existing option of the fire grate, mechanical damage of seeds decreases to *1.09%*, and free fibre in the seed-cotton decreases two times, to *0.113%*. This is due to the fact that in the interaction of raw cotton with the vibroisolating conical grates, the cotton yarn is additionally shaken, increasing their direction of movement due to the taper rate of the gridirons, which leads to an increase in the cleaning effect. Besides this, the contact of the seed-cotton briefings with the gridirons will be elastic [16], which leads to a decrease in mechanical damage to the seeds as well as to a decrease in the formation of additional free fibres [17].

◼ Conclusions

A new effective structure of the fire grate with conical gridirons on elastic bearing supports with tapered thickness was developed. On the basis of the numerical solution of the study, the characteristics and form of oscillations of the diamond gridiron of a cotton cleaner of large litter were obtained. From the results of comparitive production tests, it is determined that at the recommended parameters of the cleaner, with the application of the multifaceted gridirons on the elastic bearings. the cleaning effect increases by up to *8.11%*; the mechanical damage decreases to *1.09%*, and the number of free fibres to *0.113%* in the seed-cotton.

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