Technological clearances in machines for mechanical processing of cotton seeds

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Abstract. The paper considers the issues of the possibility of damage to sowing cotton seeds during mechanical processing. Sowing cotton seeds can be processed in various technological processes and devices. In most cases, seed processing takes place between the processing surfaces in the technological gaps between them. The paper considers cases of jamming and damage of seeds in the technological gaps of delintering machines with metal- brush working bodies when delintering cotton seeds. Seed damage depends on the size of the seeds, the configuration of the gaps and the type of processing surfaces. Theoretically, the optimal sizes of technological gaps are determined from the condition of preventing the possibility of jamming of seeds in them during processing, which leads to damage and destruction of seeds. The data obtained are confirmed by experimental data and the optimal values of technological gaps are established based on the prevention of seed damage, plant productivity and changes in the germination of cotton seeds.

1 Introduction

Increasing crop yields has always been one of the priority areas for economic development to increase agricultural production. The yield of agricultural crops production primarily depends on the quality of the seed material, i.e. damage, germination, germination energy, evenness in size, cleanliness from weeds, density, seed weight, and so on [1].

Seed damage can be external and internal. External damage can be determined organoleptically by various methods, including temporary immersion of seeds in water. Internal damage is more difficult to determine. One of the ways is the germination of seeds and damage in the form of various spots is determined on the germinated cotyledon leaves. It can be assumed that the main cause of internal damage is, ultimately, mechanical damage to seeds obtained during their processing as a result of impact or squeezing by excessive loads [2]. Therefore, recognizing the importance of breeding work to improve the quality of seeds as a paramount factor, the prevention of visible and invisible mechanical damage to seeds will be considered one of the main ways to preserve the sowing qualities of seeds.[3]

Since there are many cultivated plant species, we will consider the conditions for preventing seed damage based on a widely used industrial crop such as cotton seeds. The results obtained can be used in the processing of other agricultural crops, such as wheat, rye, rice, and others, taking into account their size features [4,5].

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2 Methods

Cotton is one of the main agricultural products in the world. To obtain large yields of high-quality cotton, the preparation of high-quality sowing seeds is of paramount importance. Seed preparation is carried out in specialized seed companies [6]. In the states of Central Asia, including Uzbekistan, seeds are sown with pubescent cotton seeds with lint (pubescent seeds) and the so-called bare (bare seeds) from the down of their covering cotton seeds with lint removed (Fig.1) [7]

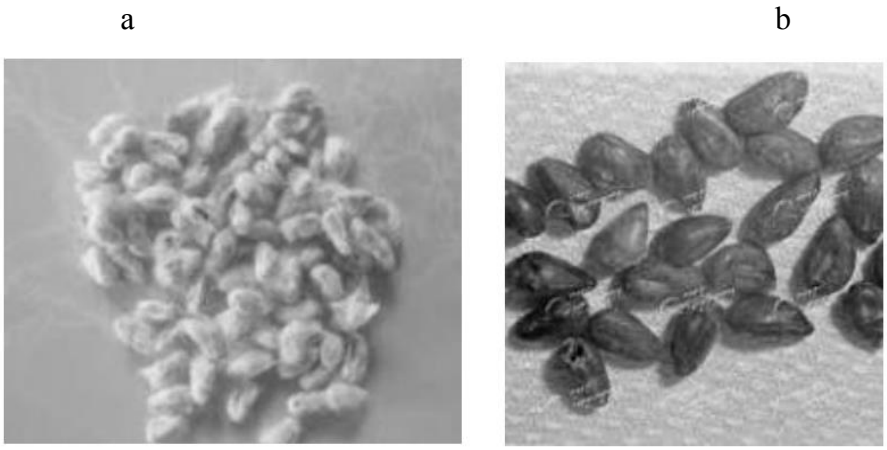

Fig. 1. a - cotton seeds with lint, b- s cotton s eeds with lint removed (bare)

Down or lint (fibrous cover) covering the seeds (lint (fibrous cover) covering the seeds) reduces the flowability of seeds due to the adhesion of seeds to each other and the formation of lumpiness, which makes it difficult for them to be sown by precision seeders in a given amount in a nest. For this reason, it is necessary to sow downy seeds in an ordinary continuous way with an increased consumption of seeds (up to 60-100 kg/ha) for guaranteed seedlings. And then their expensive manual thinning after germination. In addition, the presence of lint on seeds makes it difficult to sort them according to such physical and mechanical indicators as seed density, absolute seed weight, seed size, their fulfillment (filling with the core), grouping by seed size, seed maturity. All this leads to uneven maturation of plants, lengthening of the growing season, a decrease in varietal indicators of cotton, and a decrease in yield. There are no listed disadvantages when using seeds that are bare from lint. However, the preparation of the bare delintered seeds of seeds is associated with an increase in damage to seeds and a decrease in their other indicators in the process of exposure, affecting their sowing qualities.

There are various methods of exposure (delintering seeds) cotton seeds: mechanical, chemical, aerochemical, as well as singeing with fire at 2000 -3000 degrees. It is not always possible to adjust the temperature and time spent by the seed in the flame. The check showed that during singeing, incomplete combustion of fluff on the seeds occurs and the germination capacity and energy of seed germination somewhat decrease. To summarize, all these methods, except for mechanical methods, do not completely remove the fluff from the seeds and they have to be additionally exposed to some extent mechanically. In addition, their disadvantages include a large destruction of the lint and the difficulty of recycling the lint. Seeds in these methods, in most cases, are subjected to high-temperature treatment after wetting, which worsens their sowing qualities.

In the states of Central Asia: Uzbekistan, Tajikistan, Kazakhstan, Kyrgyzstan, Turkmenistan mainly use the mechanical method of delintering on special machines [8]. The most progressive of them are machines for delintering grades 1LB figure and OC created for one - stage and more promising two-stage exposure [6].

Mechanical delintering of cotton seeds, in turn, is subdivided into delintering with rigid (saw drums, abrasive drums, metal meshes) and elastic working bodies (metal brush drums). Treatment of seeds with rigid working bodies at low seed hairiness leads to an increase in mechanical damage to seeds, making them practically unsuitable for sowing [9, 10].

Mechanical exposure of cotton sowing seeds on machines with elastic working bodies, such as metal -brush drums, has great advantages over other methods of delintering [11]. With an appropriate mild seed treatment regime and a well-established, in relation to the preparation of seed material, the technological process of the entire cotton gin plant and the bare seed preparation shop in particular, mechanical damage to the latter will be insignificant , and such sowing qualities as germination and germination energy can be significantly improved compared to the initial values through efficient sorting by density, weight, windage, elasticity and calibration by width, thickness and length of seeds.

However, there are many unresolved issues in the class of mechanical exposure with metal- brush working bodies: in particular, the theoretical basis for determining the technological regime, technological gaps and force effects on cotton seeds have not been studied. The study and solution of these issues will significantly increase the efficiency of cotton ginning.

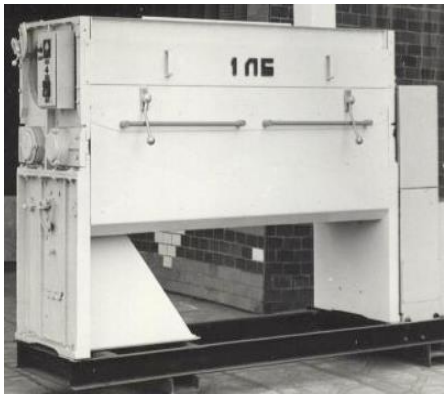

Fig. 2. Cotton seed delintering machine 1LB.

Fig. 3. Cotton seed delintering machine OC.

Seeds are loaded into the delinter 1LB through the feeder 5 and under the influence of rotating metal brush drums 1 are carried away into the technological gaps between the drums and the smooth shell and fill the working chambers of the machine. The density of the mass of seeds in the chambers is created by a pressure damper 10, which creates an obstacle to the free movement of seeds. Seeds are subjected to delintering when moving through the working chambers of lint removal. From the working chamber 11, the seeds are ejected into the free separating zone, where they are separated from the free lint by means of an air flow. The separated lint is carried away by the air flow into the diffuser. Requirements for the quality of cotton seeds [12] are presented in Table 1.

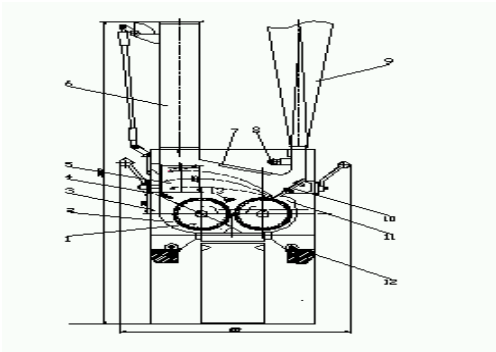

Fig. 4. The device of the machine 1LB: 1- metal brush drums; 2- working seed chamber; 3-left wall; 4-handle; 5-feeder; 6-mine of pubescent seeds; 7-window; 8-lamp lighting; 9-suction diffuser; 10-clamping damper; 11-working seed chamber; 12-device for opening the walls of the chamber; 13-shutter of the working chamber.

Table 1. Requirements for the quality of cotton seeds.

Indicators	**Regulations**		
	Hairy seeds	**Low hairy seeds**	**Bare seeds**
Germination, not less	90. 0	90. 0	90. 0
Humidity, no more	10. 0	10. 0	10. 0
Contamination, no more	0. 7	0. five	0. 3
pubescence , no more	-	2. five	0. five
Mechanical damage, no more	7. 0	8. 0	8. 0

3 Results and discussion

The process of delinterovapy of cottonseeds includes [13]:

1.giving the seeds the necessary movement relative to the working surface;

2.removal of the delint when the seed comes into contact with the working surface;

3. separation and removal of the removed delint from the working volume.

Implementation of the delintering process is complicated by the high and different in some areas of the seeds, the strength of attachment of the down to the peel, the short length of the down fiber, the small size and irregular shape of the seeds.

In addition, seeds are biological formations that are sensitive to mechanical and temperature influences. Compression or impact on them can lead not only to external mechanical damage, but also to internal damage to the kernel (they are found on the cotyledons of germinated seeds in the form of dark spots). Plants grown from damaged seeds have pathological deviations in biological development.

For the implementation of the elementary act of removing the delint, it is necessary to press the seed to the working surface and give it a relative speed. These technological operations in most types of machines with metal- brush working bodies are carried out in working chambers and annular gaps between the metal- brush drums and the shell surrounding them.

delint is carried out by a sharpened edge of the end surface of the steel rods of the working drums by cutting or scraping the fibers from the surface of the seed peel according to the principle of external elastic centerless grinding. [13]. In addition, the delint is removed from the seeds due to friction forces in contact both with the working bodies and with each other.

Pressing the seeds to the working surface, necessary for removing the delint, is regulated by changing the mass density of the seeds in the working volume of the delinter. In machines of the 4C0M type (see Fig. 3) with a closed working volume, this is done by closing the seed discharge openings. In the 1LB axial delinter with an open working volume (see Fig. 2 and 4), the seed mass density is controlled mainly by changing the technological gap between the pressure gate 10 and the drum at the exit of the seeds from the seed chamber 11 into the open part of the working volume.

In both types of machines, the forces of pressing the seeds to the working surfaces also depend on the size of the annular technological gap between the metal brush drums and the shell around them . With its excessive increase, the mixing of seeds, which is the basis for uniform delintering, deteriorates. With a decrease in the gap less than the corresponding optimal value , increased damage to the seeds will begin.

Values of technological gaps should be selected from the condition of minimal damage to seeds by the rods of the working bodies during intensive removal of the delint. The calculations are based on the prevention of jamming of seeds in the limiting cases of their location in these gaps.

According to static studies [14] the sizes of bare seeds of variety 108F and their standard deviations (σ) are equal to:

length l C = 9.16 mm, σ(l C) = 0.5 mm ;

width b C =5.14 mm, σ(b C) = 0.36 mm ;

thickness h C = 4.77 mm, σ(h C) = 0.44 mm.

For the thickness and width of the seed, the maximum dimensions of the seed in the corresponding sections are taken.

Upon contact with the surface of the metal- brush drum, the seeds bend its rods. It is from the condition of obtaining the smallest value of the deflection of the rods that the technological gaps of the delinters should be selected, and the process of removing the delint should not worsen.

Location of several seeds in the annular gap ε. High-speed filming of the movement of seeds in the annular gap between the surface of the metal- brush drum and the shell around it showed that the seeds do not move in a continuous mass, but mostly separately from each other. In a gap of 15 mm there is one or two seeds, three seeds are almost never found.

When one, two or several seeds are located in the annular gap ε, with a continuous (non-perforated) shell concentric to the surface of the working drum (Fig. 5), forces N, P, NO _ and T O - normal and tangential components of efforts, respectively, from the side of the drum - R and shells - R O .

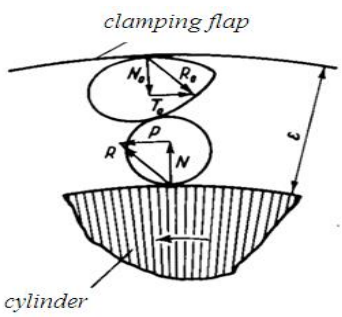

Fig. 5. The location of two seeds between the drum and the shell.

The forces of inertia of the movement of seeds, due to the insignificance of their mass (≈0.1 g), are neglected. In this case –

$$N_O = N; \quad P = N f b ; T_O = NO f O ,$$

where fb and f O - friction coefficients of seeds, respectively, on the surface of the metal plate of the precise drum and on the shell.

Since the coefficient of friction of the seeds on the steel shell is f O less than on the metal surface of an accurate drum - f b , then T O < P . Consequently, the seeds slide over the surface of a solid steel shell concentric to the surface of the drum, and their jamming in the gap ε is unlikely. With a decrease in gap ε, the movement of seeds becomes single layer And the best conditions for their mixing and removal are achieved delinta . For the free movement of seeds in this gap, its value must be at least the size of the seed in length.

So, with a solid steel shell of delinter machines with metal brush working bodies, the gap between the surface of the drums and the shell with a reliability of 0.95 is taken equal to the upper limit of the corresponding confidence interval for the length of the seed

$$\varepsilon = l C + 2\,\sigma(l C); \qquad (1)$$

$$\varepsilon = 9.16 + 2\ 0.5 = 10.16\text{mm} \approx 10\text{ mm}.$$

Location of two seeds in the gap μ. In technological gap μ between the metal brush drum and the pressure gate that regulates the density of the seed mass in the working chambers (Figure 6), the seeds come from two directions - from below, entrained by the metal brush drum, and from above, from the delinter seed chamber, so that almost always in the gap μ there are two seeds and their jamming is possible. Two seeds should fit freely in this gap. However, the purpose of the pressure gate is to create a compaction of the seeds in the working chambers. Er o can be created due to the resistance to simultaneous advance through the gap μ one seed with the lateral part, the second in length, provided that two seeds simultaneously move freely with the lateral parts.

Assuming that in the gap μ seeds can be equally probable in width and thickness, we find the size of the corresponding thickened place of the lateral part of the seed, which in this case is equal to the arithmetic mean of the width and thickness.

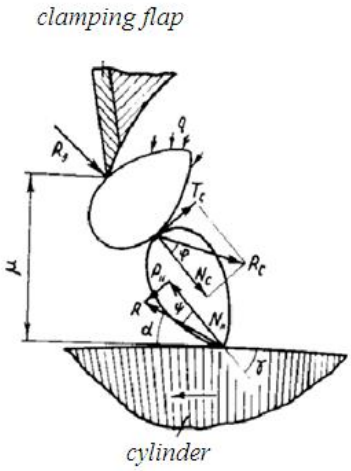

Fig. 6. The location of two seeds between the drum and the pressure gate.

$$d_c = (b_c + h_c)/2; d_c = (5{,}14 + 4{,}77) / 2 = 4{,}96\text{mm} \qquad (2)$$

where d_c - the size of the thickened part of the lateral part of the seed, hereinafter referred to as the diameter of the seed.

Since the width and thickness of the seed are dependent quantities, the standard deviation of the seed diameter is σ (d_c) we take equal to the arithmetic mean value of the standard deviations of the width and thickness of the seed

$\sigma(d_c) = (0.36 + 0.44)/2 = 0.4$ mm

With a reliability of 0.95, for the free movement of two seeds simultaneously with lateral parts, the gap must be greater than the upper limit of the confidence interval for the sum of the diameters of two seeds. Since the positions of the seeds in the gap are independent of each other, then

$$\mu > 2d_c + 2\sigma(2d_c) = 2d_c + 2\sqrt{2\sigma^2(d_c)}; \quad (3)$$

$$\mu > 2\ 4.96 + 2\sqrt{2}\ 0.4 = 11.1\text{mm}$$

The location of two seeds in the gap μ - one along the length, the other with the side, if the seed located along the length rests against the micropyle (pointed part) against another seed or against the clamping valve, it will be unstable, since due to the sharpness of the micropyle, point contact occurs. If the seed rests against the surface of the metal- brush drum with the micropyle (see Figure 6), then the position of the seed will be stable, since the - deflection of the drum surface under the micropyle will not allow it to move. The upper seed interacts with the lower one over a certain surface and, in addition, is affected by the pressure gate R_3 and adjacent seeds - q, which push it into this gap. The forces of inertia of the movement of seeds, due to the insignificance of their mass, are neglected.

Force direction R from the surface of the drum to the adjacent seed at the initial moment of contact can be different depending on the activity and density of the contacting area of the drum surface, the pubescence and configuration of the seed at the contact point. It has been experimentally determined that the angle α between the tangent to the surface of the drum at the point of contact and the direction of the force *R* is in the range from 15° to 60°. .

Consider the possible conditions for jamming of seeds. Let us decompose the force R into two mutually perpendicular forces: N_{II} - parallel to the normal component N_c reactions from the top seed to the bottom - R_c, and P_{II} _ - parallel to the friction force T_c of seeds against each other. For jamming, the condition must be met - $T_C \geq R_{II}$, that is, there will be no sliding of seeds against each other. Here (see Fig. 6)

$$P_{II} = R\sin\psi; \quad N_{II} = R\cos\psi \quad (4)$$

Since the mutual movement of seeds in the direction of the seeps N c no, then

$$N_C = N_{II}\ \text{and}\ T_C = N_C\ tg\varphi = P\cos\psi \cdot tg\varphi, \quad (5)$$

where φ - the angle of friction of seeds against each other (for pubescent seeds ($\varphi_{OP}=30^O$ for bare seeds $\varphi_{OG}=24^O$) [15].

When jammed

$$R\cos\psi\ tg\varphi \geq R\sin\psi; \quad tg\varphi \geq tg\psi; \quad \psi \leq \varphi. \quad (6)$$

So, when the seeds are located between the pressure gate and the drum, jamming can occur at an angle γ between the normal component of the reaction from the top seed to the bottom and the tangent to the surface of the drum at the point of contact equal to

$$\gamma = \psi + \alpha < \varphi + \alpha, \qquad (7)$$

where the maximum values of the angles $\varphi_{max} = 30°$, $\alpha max = 60°$. Therefore, at $\gamma < 90°$, seed jamming is possible.

The forces R and R_c acting on the lower seed should move in direction and coincide with the BG line connecting the contact points of the seeds with the drum and the upper seed and further, with the point of contact with the clamping damper (Fig. 7).

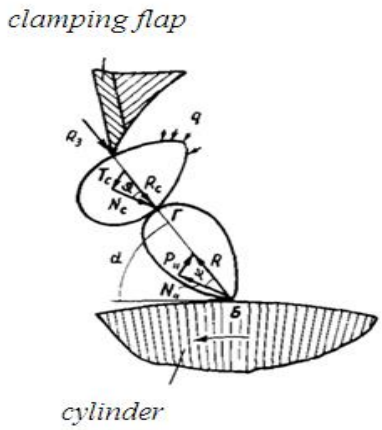

Fig. 7. Jamming of two seeds between the drum and the pressure gate.

We decompose the force R_c into the normal force N_c and friction force T_c. Force R decompose into force N_{II} and P_{II} _ parallel , respectively, to the forces N_c and T_s.

Mutual movement of seeds along the line of action of the seep N with no, therefore N_c = NII . Jamming is maintained as long as the friction force T_c, preventing the seeds from sliding over each other, there will be more force P_{II} , that is, as long as $\psi < \varphi$, since

$$P_{II} = N_{II} tg\psi, \qquad a \quad T_C = N_{II}\_ tg\varphi.$$

When wedging, the lower seed, carried away by the surface of the drum, rotates around the upper seed, bending the rods of the metal-brush drum. If the BG line passes to the left of the edge of the pressure gate (see Figure 7), then the upper seed rotates around the point of contact with it and the jamming is broken.

Jamming of three seeds by the side parts is not desirable, since in this case, due to the large contact surface of the seed with the drum, significant forces are developed that are sufficient to damage the seeds in the gap μ . Seeds have the most favorable opportunities for jamming in thickened places of seeds, in which the contact surface is maximum.

According to the calculation scheme (Figure 8) , the lower limit value of the distance of jamming of three seeds with thickened places is selected. The upper seed is affected by the pressure damper R_s, pushing its seeds - q and from the middle seed. The middle seed is affected by the top seed - R_{c2} and bottom. Force direction away from drum - R when jammed, it coincides with the B3 line .

At the limiting moment of wedging, the angle ψ between the line of action of the force R and the normal to the surface of contact of the seeds with each other is equal to the angle of friction between the seeds φ . The value of φ is taken for bare seeds, since even if they are pubescent, then when squeezing with great effort and sliding, the fluff will be removed and play the role of an intermediate layer. According to S.P. Ka ra lovsky _ [15] the angle of friction between bare seeds $\varphi = 24^{O}$. For $\psi > \varphi$ jamming does not occur, because

$$N_{C1} = N_{II} \quad \text{and} \quad P_{II} = N_{II}\, tg\psi > T_C = N_{II}\, tg\varphi \qquad (8)$$

To prevent jamming, it is required (see Fig. 8):
$\mu < B3 \sin\alpha$,
where $\alpha = 90 - \psi$;

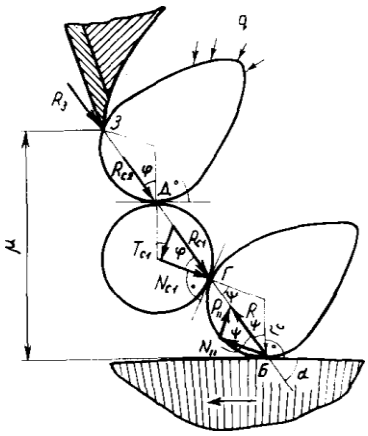

Fig. 8. Calculation scheme for the arrangement of three seeds in the gap between drum and pressure gate.

$B3 = 3d\ BG = 3 \cdot 2\, r_c \cos\psi = 3\, d_c \cos\psi$;
$r_c = d_c/2$; $\psi = \varphi$.
From here,

$$\mu < 3d_C \cos 2\varphi\,. \qquad (9)$$

With a reliability of 0.95, to prevent jamming of three seeds by the lateral parts, the gap must be less than the lower limit of the corresponding confidence interval for the sum of the diameters of three seeds multiplied by the square of the cosine of the angle of friction of the seeds between them –

$$\mu < [3\, d_C - 2\sigma(3\, d_C)]\cos 2\varphi = [3\, d_c - 2\sqrt{3\sigma^2(d_c)}]\cos 2\varphi, \qquad (10)$$

$$\mu < (3\ 4.96 - 2\ 0.4)\cos\sqrt{3}2\ 24° = 11.3\ \text{мм}.$$

Therefore, the best limiting permissible design values of the gap between the pressure gate and the drum (formulas 3 and 10) will be equal to:

$$11.1\ \text{mm} < \mu < 1.13\ \text{mm}.$$

Permissible for practical circuits, the permissible values of the gap μ can be taken equal to

$$\mu = 11 \div 12\ \text{mm}$$

Average value for calculations

μ = 11.5 mm

Cases of seed jamming in the gap μ and its limiting dimensions also apply to the gaps between the metal- brush drums and the shell, which creates resistance to the movement of seeds (perforated, mesh, abrasive, etc.), since the reaction acting on the seed from their surface can lie in line with the force from the surface of the drum.

For experimental verification of the theoretical conclusions on the laboratory installation of the 1LB delinter, a full factorial experiment [16,17] was carried out on three factors: the circumferential speed of rotation of the metal-brush drums - n, the gap between the drum and the surrounding shell -ε, the wedge gap between the clamping damper and the drum m - μ. Based on these experiments, to study and visualize the picture of the relationship of factors and their influence on the increase in mechanical damage to cotton seeds - ΔM, on the change in seed germination Δ B and on the performance of the P plant according to the obtained mathematical models (not presented here) for experiments with the circumferential speed of the drums n = 750 rpm, two-dimensional sections of the response surfaces (Fig. 9) were obtained and built within the limits of these experiments.

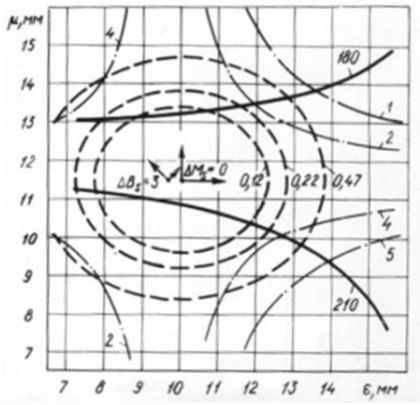

Fig. 9. Two-dimensional sections of response surfaces at n = 750 rpm; ____ - performance, _ _ _ - increase in mechanical damage to seeds Δ M, __ . __ . - increase in seed germination Δ B.

Based on the data obtained, the process of delintering of cotton seeds was optimized in terms of reducing mechanical damage to seeds. Surfaces of equal value of mechanical damage to seeds are ellipsoids. Mechanical damage to the seeds is minimal in the center of the ellipsoids, which has the coordinates μ = 11.5 mm, ε = 10 mm and is equal to zero, ΔM = 0.

The germination of seeds according to the presented graphs changes in the form of hyperbolic paraboloids and increased in the optimal case by Δ B = 3%. This can be explained by the optimal mode of delintering and partial winnowing of feeble seeds together with the removed lint. And also the increase in germination can be explained by heating the seeds from friction forces during delintering up to 40-45 ^{o}C.

Regarding the performance of the laboratory installation of delintering according to Fig. 1, it can be stated that a decrease in the gap μ between the pressure gate and the drum leads to a significant increase in productivity, and the effect of the gap ε between the smooth shell and the drum on productivity is not so significant within the selected range of change in this gap.

The data obtained correspond to the theoretical conclusions on the determination of the technological clearances of delinter machines when delintering cotton seeds.

4 Conclusion

The work carried out has led to the following conclusions.

1.based on an analytical review of the methods and methods for preparing bare sowing seeds, the most rational is the mechanical method of exposing cotton sowing seeds with elastic working bodies - metal brush drums on devices with adjustable parameters.

2.mechanical method of delintering of cotton sowing seeds does not use seed moistening, the seeds are not exposed to high temperatures, a commodity lint is obtained, and it does not require neutralization of processed products compared to chemical methods.

3.The nature of the movement of seeds during processing and theoretically the conditions for jamming of seeds during delintering by elastic working bodies leading to damage to the seeds are considered.

4. Theoretically determined based on the conditions of mechanical delintering and seed sizes are the maximum allowable technological clearances of delintering machines, which are taken into account in regulating the operation of delintering machines 1LB and OC. The gaps between the smooth shell (casing) and the surface of the metal- brush drums are assumed to be $\varepsilon \approx 10$ mm. The gaps between the pressure gate and the surface of the metal- brush drum, which provide the necessary mass density of the seeds in the working chambers and prevent jamming and damage to the seeds, are taken equal to 11.1 mm $< \mu <$ 1.13 mm.

5. Complete factorial experiments were carried out on the 1LB delinter test bench, showing the relationship between delintering factors and optimization criteria and confirming the results of theoretical justifications. The response surfaces of the experimental results were built, on the basis of the analysis of which the optimal values of technological gaps equal to ε=10mm and μ=11.5 mm were determined. At the same time, there was no increase in mechanical damage to the seeds. Seed germination due to partial separation of feeble seeds in the sedimentary chamber of the linter and heating of the seeds under the influence of friction forces up to 40-45°C increased by 3%.

6. Reducing the gap between the pressure gate and the working drum leads to an increase in the productivity of the installation. The size of the gap in the annular space between the smooth shell and the working drums has little effect on the productivity of the delinter.

7. The recommendations received will improve the performance of 1LB and OC linters.

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