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THEORETICAL AND PRACTICAL FOUNDATIONS OF IMPROVING THE UCHDM SEED DELINTERING MACHINE

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ABSTRACT: *The article presents the results of theoretical and practical experiments on the improvement of the seed delinter. The upper chambers of the existing seed delinter are multi-faceted, and the use of combined saw-metal brush cylinders in them allows the extraction of fluff instead of fluff from dehaired seeds, and a technical solution for its implementation has been developed. It was determined that if the short fibers scraped off in the upper chamber of the delinter move along the surface of the combined saw-metal brush cylinder, the fibers in such a mass will remain on the surface of the combined saw-metal brush cylinder, and if they do not, such short fibers will separate from the surface of the combined saw-metal brush cylinder and turn into free fibers. In the conducted multi-factor experiments, the optimal parameters of the delinter were obtained.*

Keywords: *delinter, cottonseed delinting, chamber, saw–metal brush, combined cylinder, force, factor.*

1. INTRODUCTION

The current seed dehulling machines are designed to dehull seed, ensuring that the hairiness is up to 0.5% for dehulled seeds and up to 2.0±0.5% for low-hair seeds. These seed dehullers are used in single-stage dehulling plant equipment, since the machine itself performs two stages [1, 2].

The structure of the existing seed cotton delinting machine is shown in Figure1. The seed cotton delinting machine consists of a frame and sidewalls (1), upper chambers equipped with saw drums (5) for delinting linted cottonseed, left (4) and right (2)

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chambers with pullers (3), and a lower working chamber (9) made of a perforated casing, which contains metal brush cylinders (11) for delinting the cottonseed. The unit is equipped with a feeder (6) to ensure uniform feeding of seed cotton into the working zone. A transfer chute (8) is installed to convey the delinted cottonseed to the lower chamber during the first stage, while an outlet chute (12) is provided to discharge the delinted cottonseed from the lower chamber.

During the first stage, openings for installing suction pipes to remove the lint released from the delinted cottonseed are located on the side where the feeder (6) is mounted. During the second stage, openings (10) are provided for installing suction pipes to remove short lint released from the cottonseed being delinted.

Brush drums with an initial diameter of 250 mm are installed inside adjustable rings with a clearance of 0.5–1.0 mm. Clearance adjustment is carried out by sliding the adjusting ring along the side support. The brush drums receive motion from drive motors through elastic couplings and rotate in the same direction within each working chamber.

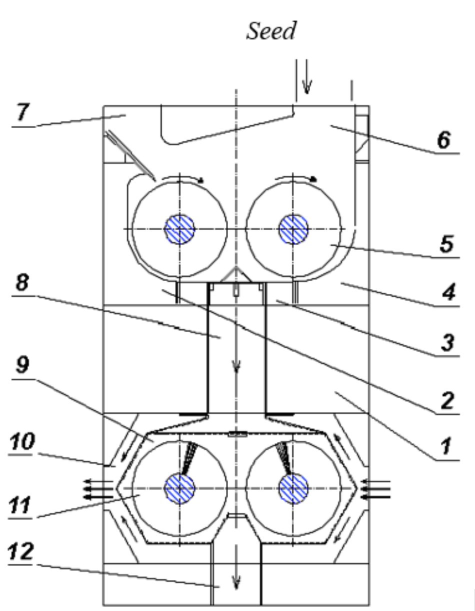

Figure 1. Schematic of a two-stage seed dehulling machine in use:
1- frame; 2- right chamber wall; 3- puller; 4- left chamber wall; 5- saw cylinder;

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6- feeder; 7- lint suction pipe; 8- transfer chute; 9-lower working chamber; 10- lint suction pipe; 11- metal brush cylinder; 12- cottonseed discharge chute.

Normal operation of the delinting machine is ensured only when seed cotton is uniformly supplied to the working chamber, when uniform density of the cottonseed rolls is achieved, and when a constant clearance between the drum and the perforated casing is maintained along the entire length of the chamber. The residual lint content of the cottonseed is adjusted by the position of the baffle installed at the outlet of the section.

The main objective of seed cotton delinting is to reduce lint content while preserving the essential properties of the seeds, such as germination capacity, resistance to mechanical damage, and other biological characteristics. One of the major challenges of mechanical delinting is achieving complete lint removal without causing damage to the seeds and while fully preserving their biological properties.

According to the material and design of the working elements, machines are classified into rigid, elastic–flexible, and combined types. Rigid working elements include saws and abrasive components, whereas elastic–flexible working elements include metal brush, plate, and needle-type components.

Experiments conducted at the “Cotton Industry Research Center” JSC together with the Electronic Research Institute made it possible to improve the working chamber of the seed delinting machine [3]. To increase the delinting effect of the seed, a machine design was developed - a multi-chamber delinting machine (MKO), in which the shape of the working chamber was changed, and in additional seed chambers, the seeds rotate and intensively mix, removing fluff from the seed coat. When experiments were conducted on these machines during the preparation of low-hairy seeds, an increase in the fluff residue by 2.0-3.0% led to blockages in the outlet of the delinted seeds and a decrease in work productivity. [4].

According to the technical solution developed by the “Cotton Industry Scientific Center” JSC (Figure 2), it is recommended that the upper chamber of the seed de-hairing machine also be of a multi-faceted type [4]. As a result of the experiments, it was found that when a saw cylinder was installed in the upper chamber of the seed de-hairing machine, the mechanical damage to the seed during de-hairing exceeded the established standards. Therefore, the researchers proposed installing an elastically flexible working body - a metal brush cylinder - in the multi-faceted upper working chamber [4].

The positive aspect of the technical solution developed by the Cotton Industry Scientific Center JSC is that it eliminates the possibility of seeds getting mixed into the suction pipe of the fluff separated from the upper chamber. However, replacing the sawn cylinders used in the upper working chamber of the seed delinting machine with metal brush cylinders may lead to a decrease in its productivity.

In addition, we believe that the closed multi-faceted chamber used in the upper working chamber of the seed de-integrator may have increased the risk of mechanical damage to the seed.

In order to ensure free movement of the flow of dehulled seeds in the upper chamber of the seed dehulling machine, it was proposed to leave the upper part of the multi-faceted working chamber open (Figure 2). Taking into account the results of the scientific research work of Abdurakhmonov O. [5], it was concluded that it would be appropriate to continue the experiments using sawn or sawn-metal brush combined working cylinders in the multi-faceted upper working chamber of the machine.

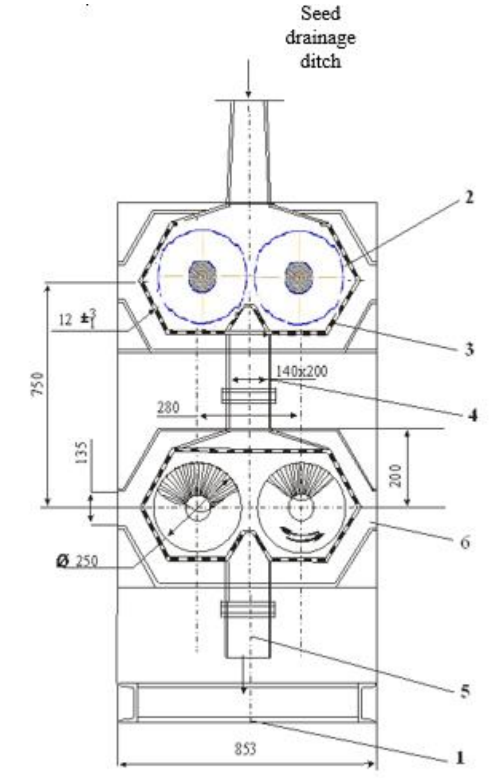

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Figure 2. Side view of the improved seed cotton delinting machine developed according to the proposed technical solution

1. frame; 2- saw or combined (saw–brush) cylinder; 3- chamber casing; 4- transfer chute; 5- cottonseed discharge chute; 6- lint suction nozzle.

Based on the above, a technical solution was developed to improve the seed delinting machine [6, 7].

2. MATERIALS AND METHODS

During the research process, theoretical and experimental methods from the theory of machines and mechanisms, mechanics, higher mathematics, and vibration theory were employed, along with mathematical modeling of technological machine operating processes, mathematical statistics, and computational mathematics.

Theoretical studies were carried out using the laws of mechanics, algebra, and descriptive geometry. Schemes were used to express the dependence of the weight and friction forces acting on the short fibers on the angle formed by the brush cylinder wire relative to the saw blade and the speed of the working cylinder.

Experimental studies were carried out on an experimental sample of delinter using relevant GOST standards, existing and specially developed methods. The experimental results were processed on a computer using mathematical statistics.

As a result of the preliminary experimental work, the main factors influencing the increase in mechanical damage to dehulled seeds were selected and full-factor experiments were conducted. To check the accuracy of the calculation results, a regression equation model was used, taking into account the Cochrane criterion and the Fisher criterion.

3. RESULTS AND DISCUSSION

Let us theoretically examine the process of separation of short fibers of various masses from the combined saw–metal brush cylinder in the upper multi-faceted chamber of the improved delinter. Let the radius of the saw disk be denoted by R (m), its rotational speed by ω (rev/s), and the length of the brush disk by l (m).

Let the air velocity in the suction pipe be v_0, and let the linted cottonseed enter the combined saw–metal brush cylinder at a velocity v_1.

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The following assumptions are adopted: the velocity of the air flow suctioning short fibers from the linted cottonseed is constant and acts on the short fibers in the direction of the metal brush wires; initially, the fibers move along the brush cylinder wires over a certain length, and after traveling a distance l_0, they transition to free motion. Using theoretical methods, the motion of the fibers and the time they remain on the surface of the brush cylinder wire (depending on their mass) are determined. At the same time, the angular velocity of the saw disk that ensures joint motion of the short fibers with the brush wire is also established.

The coordinate origin is placed at the center of the saw disk. The Ox axis is directed from right to left, and the Oy axis is perpendicular to it, directed upward from bottom to top (Figure 3). Let us assume that at an arbitrary moment t, a short fiber moves along the brush wire at a distance BM = r.

The angle between the radius of the saw disk and the direction of the metal brush cylinder wire (with the brush wires bent in the direction of cylinder rotation) is denoted by β. Let the coordinates of point M be denoted as (x, y).

In the chosen coordinate system, their expressions take the following form:

$$\begin{aligned} x &= (R + r\cos\beta)\cos(\omega t + \alpha_0). \\ y &= (R + r\cos\beta)\sin(\omega t + \alpha_0). \end{aligned} \tag{1}$$

where α_0 is the angle formed by the radius of the saw disk with the Ox axis at the initial moment.

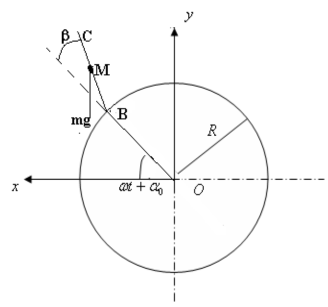

Figure 3. Schematic diagram of the motion of a short fiber with mass *m* along the brush wire

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Let us determine the forces acting on a short fiber scraped off by the combined saw–metal brush cylinder. These forces include the gravitational force, the friction force, and the force exerted by the suction air flow along the brush wire.

During the motion of the combined saw–metal brush cylinder, the directions of action of these forces continuously change. Therefore, whether the scraped short fiber remains on the brush wires or transitions into a state of free motion depends on the mass of the fiber, the rotational speed of the saw–metal brush cylinder, and the force exerted by the suction air flow. The gravitational and friction forces acting on the short fibers depend on the angle formed between the brush wire and the saw disk and on the velocity of the working cylinder. Using

Based on the calculation results, the time-dependent graphs of the fiber displacement r(t) on the combined saw–metal brush cylinder are shown in Figure 4. In the calculations $t_1 = 0.0125\,\text{sec}$ was assumed. Analysis of the graphs shows that short fibers with masses m=0.1 g and m=0.2 g do not remain on the combined saw–metal brush cylinder.

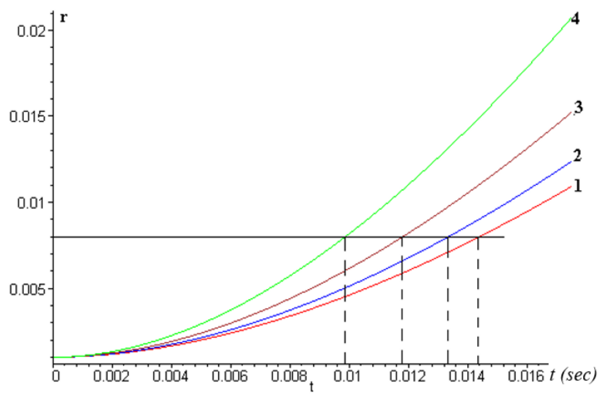

Figure 4. Time-dependent displacement curves r(m) of short fibers with different masses along the surface of the combined saw–metal brush cylinder:

1-in the graph 1-m=0.04 g; 2-in the graph. 1-m=0.04 g; 3-in the graph. 1-m=0.08; 4-in the graph. 1-m=0.1 g.

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If the condition for the displacement of the scraped short fibers along the surface of the combined saw–metal brush cylinder $r(t_1)<r_0$ is satisfied, fibers of such mass remain on the surface of the combined saw–metal brush cylinder. If $r(t_1)>r_0$, then the short fiber separates from the surface of the combined saw–metal brush cylinder and becomes a free fiber.

$$R=0.125\ m,\ L=0.05\ m,\ c=0.001\ kg.m^2/sec,\ v_0=10\ m/c,\ \omega=7.5 m/\sec,\ r_1=1mm,$$
$$r_0=2.0\ mm,\ f=0.2,\ \alpha_0=15^0,\ \beta=15^0.$$

Based on the results of the preliminary experimental studies [6, 7], the main factors influencing the increase in mechanical damage to delinted cottonseed were identified, and full factorial experiments were carried out (Table 1).

(Table 1).

Ranges of factors and their step sizes

№	Ranges of factors and their step sizes	Unit	Symbol	Factor level			Step size
				-1	0	+1	
1	Productivity of the improved delinter with respect to delinted cottonseed	kg/h	X_1	490	520	550	30
2	Air flow rate suctioned from the upper chamber of the improved delinter	m^3/s	X_2	0.9	1.2	1.5	0.3
3	Rotational speed of the combined saw–metal brush drum in the upper chamber of the improved delinter	rpm	X_3	750	850	950	100

A multifactorial experimental design based on the second-order PLANEXP-2 (B_3) methodology was employed to conduct the experimental trials. In the technological process, the increase in mechanical damage to delinted cottonseed was taken as the response variable Y_1.

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Based on the calculation results, taking into account the calculated value of the Cochran criterion [11] and applying the Fisher criterion, the adequacy of the regression model was confirmed.

According to the Student's t-test, for the criterion of increase in mechanical damage to delinted cottonseed (Y_1), the tabulated value was T(28) = 2.048.

For the Cochran criterion, the tabulated value was GT(2,14) = 0.3517, while the calculated Cochran value was G = 0.1347. The repeatability variance was $s^2 = 0.0003$.

Under these conditions, the following regression equation describing the increase in mechanical damage to delinted cottonseed was obtained:

$$Y_1 = 2.76 + 0.039X_1 - 0.053X_2 + 0.029X_3 + 0.03X_1^2 + 0.018X_1X_2 - 0.042X_2^2 + 0.042X_3^3 \quad (2)$$

To validate the results of the multifactorial experiment, an optimization problem was considered to determine the optimal parameters of the fiber cleaning equipment.

The boundary conditions [11]:

$$Y_1 \leq 2.65$$

The resulting optimization problem was solved using a random search method and modern computer-based application programs, and the following optimal solutions were obtained.

Results of the mathematical model optimization

Factors	X_1	X_2	X_3
Coded values	0	+1	-0,3756
Natural	520	1,5	813
Rounded values	520	1,5	810

Based on the results of the experiments, the following optimal parameters were obtained:

X_1 – productivity of the improved delinter with respect to delinted cottonseed: **520 kg/h**;

X_2 – air flow rate suctioned from the upper chamber of the delinter: **1.5 m³/s**;

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X_3 – rotational speed of the combined saw–metal brush drum in the upper chamber: **810 rpm**.

4. CONCLUSION

It was determined that if the movement of short fibers scraped off in the upper chamber of the delinter along the surface of the combined saw-metal brush cylinder satisfies the condition $r(t_1)<r_0$, then the fibers of such a mass will remain on the surface of the combined saw-metal brush cylinder, and if $r(t_1)<r_0$, then such short fibers will separate from the surface of the combined saw-metal brush cylinder and become free fibers.

Multifactorial experiments were conducted using mathematical planning of experiments. According to the results of the experiments, the following optimal parameters were obtained: the productivity of the improved delinter in terms of dehulled grain was 520 kg/h, the air consumption from the upper chamber of the delinter was 1.5 m^3/s, and the rotation speed of the combined saw-metal brush drum in the upper chamber of the delinter was 810 rpm.

By making the upper working chambers of the seed dehuller versatile and installing combined saw-metal brush cylinders in these chambers, it is possible to maintain the dehuller efficiency even at high working capacities of the dehuller. It has been proven that making the seed dehuller chambers versatile increases the efficiency of seed dehuller, and in addition, it has been determined that the use of combined saw-metal brush cylinders instead of the current metal brush cylinder has a positive effect on the dehuller's working capacity.

Due to the fact that the upper chamber of the improved delinter was changed to a multi-faceted one and high-performance combined saw-metal brush cylinders were used in its chambers, and the product from the upper chamber was separated using separate pneumatic pipes, it was possible to obtain up to 3-5% fluff instead of fluff.

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