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Determining the Optimal Parameters of an Advanced Linter Machine

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Abstract

In this article, research was conducted to improve Linter machines that remove short fibers remaining in ginned cotton seeds at cotton ginneries. The study examined the effect of changing the dimensions of the brush drum, guide and mesh surface in the cleaning device proposed for the linting machine on the movement of the peg and the cleaning efficiency, and the highest level of efficiency in separating impurities from the peg was determined. During the study, the main factors influencing the effective operation of the improved linting machine were identified, the limits of their values were determined, and studies were carried out using the mathematical modeling method. As a result, at the values of the given coefficients, efficient operation of the improved linting machine was observed, that is, the lint cleaning efficiency reached 55.1%.

Keywords

Linter Machine, Fluff, Impurities, Cleaning Efficiency, Lint, Brush Drum, Guide, Mesh Surface, Input Factors, Output Parameters, Working Element, Tilt Angle, Speed

1. Introduction

Seed linting technology is one of the most labor-intensive and expensive stages of the technological process of raw cotton processing. When linting, equipment and energy costs amount to up to 30%, and production areas account for more than 40% of the cotton area. In addition, the purchase price of lint is lower than the production costs of obtaining it, which makes the production of lint unprofitable [1] [2] [3].

The introduction of new engineering and technical developments into production is of great importance in the development of industry and is the main factor in economic growth.

According to the technical regulations, after ginning cotton raw materials at cotton ginning enterprises, the seeds of cotton linters are linted to produce linters, which are widely used in the textile, chemical and pulp and paper industries. The practice of using 5LP series linters shows that 5LP linters provide only 50% - 60% of the efficiency indicated in the passport. In addition, due to the low percentage of linter removal (2% - 2.5%), it is difficult for the seeds to leave the working chamber, which leads to their prolonged presence in the linting zone, increased mechanical damage to the seeds and a decrease in the quality of the linter. The main reason for this is the imperfection of the main working body of the linter, which mixes the seeds. Many scientists have made important contributions to the development of linting technology [4] [5] [6].

At the same time, the problem of creating a linter machine of a new design, equipped with additional devices and intensively effective cleaning of lint impurities, has not yet been fully resolved in Uzbekistan [7] [8] [9].

An improved linter device was developed by studying the cotton seed linting process and its disadvantages in a cotton gin plant.

In order to increase the cleaning efficiency of the linting machine, a new design technological scheme was chosen (**Figure 1**). This design works like regular 5LP linters, but features a brush drum and a mesh surface system for additional cleaning of small impurities in the pile. When this linter machine operates, the seeds that have passed through the feeding section are crushed in a stacking drum 1 and, after being cleaned from some impurities, enter the chamber where the purifier 2 is located to form raw materials. In the roll of the resulting raw

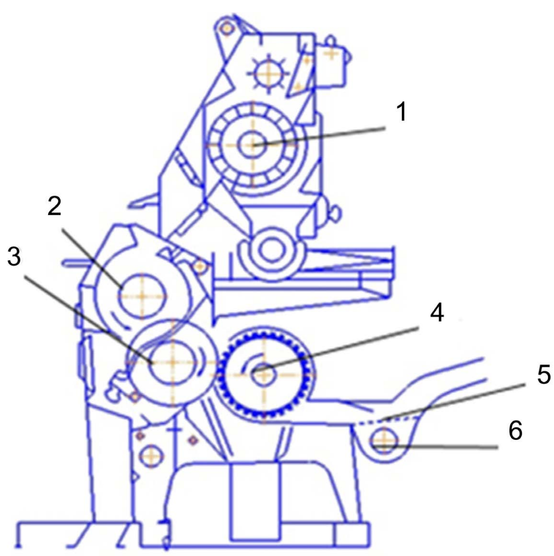


Figure 1. Flow diagram of the newly improved liter machine. 1—pining drum, 2—agitator, 3—saw drum, 4—brush drum, 5—mesh surface, 6—screw for impurities.

material, fibers are removed from the surface of the seeds by a saw drum 3, and the fibers adhered to the saw teeth are separated by a brush drum 4 and thrown onto the mesh surface 5. As a result of the emerging lint sliding along the surface of the mesh 5, small impurities of the lint pass through narrow slots and enter the impurity auger 6, and the cleaned lint exits through the outlet pipe and is separated from the air using a separator and sent to the pressing process. Changes were made to the design of the unit by installing a cleaning device on a 5LP type linting machine in picture 1 [8].

2. Determination of Technological Parameters by Experimental

Based on the results of theoretical and practical experiments, the main factors influencing the quality operation of the linter machine were identified, and multifactorial experiments were carried out. The main objective of optimization is to determine the important factors affecting the operation of the linter, in which "the lint from the saw tooth is separated by the brush drum and transferred to the cleaning process. The linters coming from the brush drum are sent to the brush drum. the surface of the mesh through a specially installed guide, which serves for maximum purification of impurities from the lint contents due to the movement of the lint along the surface of the mesh, based on the above, the optimization parameters are as follows [10] [11].

Taking into account the results of literature reviews of theoretical and research works regarding the design of the lint equipped with a new cleaning device, and in the original single-factor experiment, the following were selected as factors influencing the optimization parameters (**Table 1**):

Outgoing parameter:

Y_1—Pollutants were selected based on their separation efficiency, in %

Incoming parameters:

x_1—Brush drum rotation speed, rpm

x_2—Guide inclination angle, degrees

x_3—Mesh surface length, mm

In order to simplify the processing of research results, we will move from natural values of factors to coded values.

$$x_i = \frac{x_i - x_{ai}}{I}$$

Here x_{ai}—is the simplified value of the coefficient;

x_i—natural value of the nth factor;

I—variation range.

The coding results are presented in **Table 2**.

Thus, after encoding, all higher levels are designated +1 or simply (+), lower levels are designated −1 or simply (−).

A working planning matrix is created, that is, a matrix on which the experiment is carried out. For this, a standard planning matrix is used.

Table 1. The factors studied are the choice of levels and intervals of change.

Name of factors and measurement	Designation	Changing levels			Change interval Δx
		−1	0	+1	
Brush drum rotation speed, rpm	x_1	1100	1200	1300	100
Guide inclination angle, degree	x_2	30	45	60	15
Mesh surface length, mm	x_3	200	400	600	200

Table 2. Central non-composite matrix of experience.

No	Factors			x_1x_2	x_1x_3	x_2x_3	x_1^2	x_2^2	x_3^2	$\bar{Y}_1$	$S_u^2\{Y_1\}$
	x_1	x_2	x_3								
1	+	+	0	+	0	0	+	+	0	42.5	2.2
2	+	−	0	−	0	0	+	+	0	46.1	1.3
3	−	+	0	−	0	0	+	+	0	48.6	1.2
4	−	−	0	+	0	0	+	+	0	55.1	1.3
5	+	0	+	0	+	0	+	0	+	48.8	1.1
6	+	0	−	0	−	0	+	0	+	46.2	1.4
7	−	0	+	0	−	0	+	0	+	53.2	1.2
8	−	0	−	0	+	0	+	0	+	44.1	1.2
9	0	+	+	0	0	+	0	+	+	49.9	1.6
10	0	+	−	0	0	−	0	+	+	43.2	1.9
11	0	−	+	0	0	−	0	+	+	47.2	1.5
12	0	−	−	0	0	+	0	+	+	49.2	0.8
13	0	0	0	0	0	0	0	0	0	52.9	0.8
14	0	0	0	0	0	0	0	0	0	52.6	0.9
15	0	0	0	0	0	0	0	0	0	53.1	0.76

This matrix is filled in with the calculated upper and lower levels of factors.

The working matrix of CNCT and the experimental results are presented in Table 2.

Based on the TOT results, it became clear that the process under study is represented by a higher order equation. Therefore, to obtain a mathematical model of second-order regression, a central non-composite experiment (CNCT) was selected and implemented, which is somewhat simpler and more convenient than other methods and is widely used in the study of technological processes.

Based on the experimental results, we are looking for a multifactor mathematical second-order regression model. As a result of this experiment, we can obtain the following general regression model:

$$Y_R = b_0 + \sum_{i=1}^{M} b_i x_i + \sum_{\substack{i=j=1 \\ j\neq 1}}^{M} b_{ij} x_i x_j + \sum_{i=1}^{M} b_{ii} x_i^2$$

or, since there are three factors involved in our experience, it looks like this:

$$Y_R = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2$$

$b_0, b_1, \cdots$ are regression coefficients in the equation,

x_1, x_2, x_3—coded value of coefficients.

Calculations for optimization (Y_1) on the efficiency of dirt separation of the brush drum:

Let's calculate the regression coefficients:

$$b_0 = \frac{1}{N_u}\sum_{u=1}^{N_u}\overline{Y}_u = \frac{1}{3}(52.9 + 52.6 + 53.1) = 52.87$$

$$b_i = g_3\sum_{u-1}^{N} x_{iu}\overline{Y}_u$$

$g_2 = 0.166$ $\quad g_5 = 0.125$

$g_3 = 0.125$ $\quad g_6 = 0.0625$

$g_4 = 0.25$ $\quad g_7 = 0.3125$

$$b_1 = 0.125(42.5 + 46.1 + (-48.6) + (-55.1) + 48.8 + 46.2 + (-53.2) + (-44.1)) = -2.18$$

$$b_2 = 0.125(42.5 + (-46.1) + 48.6 + (-55.1) + 49.9 + 43.2 + (-47.2) + (-49.2)) = 1.68$$

$$b_3 = 0.125(48.8 + (-46.2) + 53.2 + (-44.1) + 49.9 + (-43.2) + 47.2 + (-49.2)) = 2.05$$

$$b_{12} = 0.25(42.5 + (-46.1) + (-48.6) + 55.1) = 0.73$$

$$b_{13} = 0.25(48.8 + (-46.2) + (-53.2) + 44.1) = -1.63$$

$$b_{23} = 0.25(49.9 + (-43.2) + (-47.2) + 49.2) = 2.18$$

$$b_{ii} = g_5\sum_{u=1}^{N} x_{iu}^2\overline{Y}_u + g_6\sum_{i=1}^{M}\sum_{u=1}^{N} x_{iu}^2\overline{Y}_u - g_2\sum_{u-1}^{N}\overline{Y}_u$$

$$\sum x_1^2\overline{Y}_u = 42.5 + 46.1 + 48.6 + 55.1 + 48.8 + 46.2 + 53.2 + 44.1 = 384.6$$

$$\sum x_2^2\overline{Y}_u = 42.5 + 46.1 + 48.6 + 55.1 + 49.9 + 43.2 + 47.2 + 49.2 = 381.8$$

$$\sum x_3^2\overline{Y}_u = 48.8 + 46.2 + 53.2 + 44.1 + 49.9 + 43.2 + 47.2 + 49.2 = 381.8$$

$$\sum \overline{Y}_u = 42.5 + 46.1 + 48.6 + 55.1 + 48.8 + 46.2 + 53.2 + 44.1 + 49.9 + 43.2 + 47.2 + 49.2 + 52.9 + 52.6 + 53.1 = 732.7$$

$$\sum_{i=1}^{M}\sum x_i^2\overline{Y}_u = 384.6 + 381.8 + 381.8 = 1148.20$$

$$b_{11} = 0.125 * 384.6 + 0.0625 * 1148.2 - 0.166 * 732.7 = -1.79$$

$$b_{22} = 0.125 * 381.8 + 0.0625 * 1148.2 - 0.166 * 732.7 = -2.14$$

$$b_{33} = 0.125 * 381.8 + 0.0625 * 1148.2 - 0.166 * 732.7 = -2.14$$

Let's write the equation taking into account the found regression coefficients:

$$Y_R = 52.87 - 2.18X_1 + 1.68X_2 + 2.05X_3 + 0.73X_1X_2 - 1.63X_1X_3 + 2.18X_2X_3 - 1.79X_1^2 - 2.14X_2^2 - 2.14X_3^2$$

Let us determine the significance of the regression coefficients.

To do this, we determine the dispersion of the output parameter.

$$S^2\{Y\} = S_m^2\{Y\} = \frac{1}{N_u - 1}\sum_{u=1}^{N_u} S^2\{\overline{Y}\}$$

$$S^2\{\overline{Y}\} = \frac{1}{3-1}2.5 = 1.23$$

and on this basis we calculate the variance when determining the regression coefficients:

$$S^2\{b_0\} = g_1 S^2\{\overline{Y}\} = 0.2 * 1.23 = 0.25$$

$$S^2\{b_i\} = g_3 S^2\{\overline{Y}\} = 0.125 * 1.23 = 0.15$$

$$S^2\{b_{ij}\} = g_4 S^2\{\overline{Y}\} = 0.25 * 1.23 = 0.308$$

$$S^2\{b_{ij}\} = g_7 S^2\{\overline{Y}\} = 0.3125 * 1.23 = 0.38$$

Finding the standard deviation when determining regression coefficients:

$$S\{b_0\} = 0.5 \quad S\{b_i\} = 0.39 \quad S\{b_{ij}\} = 0.55 \quad S\{b_{ii}\} = 0.62$$

After this, we determine the calculated value of the Student's test using the following equation:

$$t_R\{b_i\} = \frac{|b_i|}{S\{b_i\}}$$

$$t_R\{b_0\} = \frac{|52.87|}{0.5} = 105.74 \qquad t_R\{b_{13}\} = \frac{|1.63|}{0.55} = 2.96$$

$$t_R\{b_1\} = \frac{|-2.18|}{0.39} = 5.59 \qquad t_R\{b_{23}\} = \frac{|2.18|}{0.55} = 3.96$$

$$t_R\{b_2\} = \frac{|1.68|}{0.39} = 4.31 \qquad t_R\{b_{11}\} = \frac{|1.79|}{0.62} = 2.89$$

$$t_R\{b_3\} = \frac{|2.05|}{0.39} = 5.26 \qquad t_R\{b_{22}\} = \frac{|2.14|}{0.62} = 3.45$$

$$t_R\{b_{12}\} = \frac{|0.73|}{0.55} = 1.33 \qquad t_R\{b_{33}\} = \frac{|2.14|}{0.62} = 3.45$$

The table value of the Student's test is obtained from the literature [11].

$$t_{ж}\left[R_{д} = 0.95; f\{S_u^2\} = 3 - 1 = 2\right] = 2.77$$

It is known that if the calculated value of the criterion is less than the value of the table, then this coefficient is not significant and we remove it from the equation. During the research, it was found that the coefficient b_{12} is insignificant for the studied parameters [12] [13].

Let's rewrite the equation with significant coefficients:

$$Y_R = 52.87 - 2.18X_1 + 1.68X_2 + 2.05X_3 - 1.63X_1X_3 + 2.18X_2X_3 - 1.79X_1^2 - 2.14X_2^2 - 2.14X_3^2$$

To check the adequacy or inadequacy of the above mathematical regression model, we determine using the calculated value of the Fisher criterion.

$$F_R = \frac{S^2_{\text{над}}\{Y\}}{S^2\{Y\}}$$

Here:

$$S^2\{\bar{Y}\} = \frac{\sum_{u=1}^{N} S^2\{Y\}}{N_u - 1} = \frac{2.5}{2} = 1.23$$

$$S^2_{\text{над}}\{Y\} = \frac{\sum_{u=1}^{N-N_{n+1}} \left(Y_{Ru} - \bar{Y}_u\right)^2}{N - N_{\text{к.эн}} - \left(N_u - 1\right)^2}$$

$$N - N_{\text{к.эн}} - \left(N_u - 1\right)^2 = 15 - 7 - (3-1)^2 = 4$$

$$N - N_u + 1 = 15 - 3 + 1 = 13$$

$$Y_R = 52.87 - 2.18X_1 + 1.68X_2 + 2.05X_3 - 1.63X_1X_3 + 2.18X_2X_3 - 1.79X_1^2 - 2.14X_2^2 - 2.14X_3^2$$

$$Y_{R1} = 52.87 + (-2.18) + (-1.68) + (-1.79) + (-2.14) = 43.58$$

$$Y_{R2} = 52.87 + (-2.18) + 1.68 + (-1.79) + (-2.14) = 46.44$$

$$Y_{R3} = 52.87 + 2.18 + (-1.68) + (-1.79) + (-2.14) = 49.44$$

$$Y_{R4} = 52.87 + 2.18 + 1.68 + (-1.79) + (-2.14) = 52.80$$

$$Y_{R5} = 52.87 + (-2.18) + 2.05 + (-1.63) + (-1.79) + (-2.14) = 47.18$$

$$Y_{R6} = 52.87 + (-2.18) + (-2.05) + 1.63 + (-1.79) + (-2.14) = 46.34$$

$$Y_{R7} = 52.87 + 2.18 + 2.05 + 1.63 + (-1.79) + (-2.14) = 54.80$$

$$Y_{R8} = 52.87 + 2.18 + (-2.05) + (-1.63) + (-1.79) + (-2.14) = 43.44$$

$$Y_{R9} = 52.87 + (-1.68) + 2.05 + 2.18 + (-2.14) + (-2.14) = 51.14$$

$$Y_{R10} = 52.87 + (-1.68) + (-2.05) + (-2.18) + (-2.14) + (-2.14) = 42.68$$

$$Y_{R11} = 52.87 + 1.68 + 2.05 + (-2.18) + (-2.14) + (-2.14) = 47.14$$

$$Y_{R12} = 52.87 + 1.68 + (-2.05) + 2.18 + (-2.14) + (-2.14) = 50.40$$

$$\sum_{u=1}^{N-N_n+1} \left(Y_{Ru} - \bar{Y}_u\right)^2 = 16.2 \quad S^2_{\text{над}}\{Y\} = \frac{16.2}{4} = 4.04$$

It is known that if the calculated value of the criterion is less than the tabulated one, then this coefficient is adequate and indicates the correctness of the calculations.

To simplify the calculations, let's create the following **Table 3**:

Table 3. Comparison table between calculated and experimental results.

No	$\overline{Y}_u$	Y_{Ru}	$Y_{Ru} - \overline{Y}_u$	$\left(Y_{Ru} - \overline{Y}_u\right)^2$
1	42.5	43.58	1.08	1.17
2	46.1	46.44	0.34	0.12
3	48.6	49.44	0.84	0.71
4	55.1	52.8	−2.30	5.29
5	48.8	47.18	−1.62	2.62
6	46.2	46.34	0.14	0.02
7	53.2	54.8	1.60	2.56
8	44.1	43.44	−0.66	0.44
9	49.9	51.14	1.24	1.54
10	43.2	42.68	−0.52	0.27
11	47.2	47.14	−0.06	0.00
12	49.2	50.4	1.20	1.44
jami				16.2

$$F_R = \frac{S^2_{\text{над}}\{Y\}}{S^2\{\overline{Y}\}} = \frac{4.04}{1.23} = 3.28$$

$$F_{\text{ж}}\left[P_{\text{д}} = 0.95; f\,S^2_{\text{над}}\{Y\} = 15 - 6 - (3-1) = 5; f\left\{S^2_u\right\} = 3 - 1 = 2\right] = 4.74$$

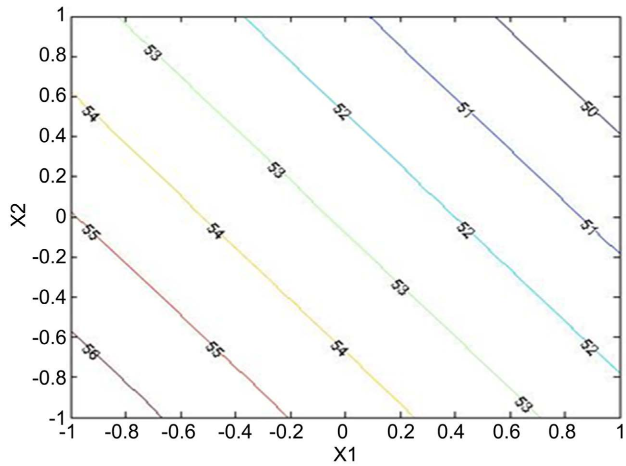
$$F_R = 3.28 < 4.74 = F_{\text{ж}}$$

$$\begin{aligned} Y_R = {} & 52.87 - 2.18X_1 - 1.68X_2 + 2.05X_3 - 1.63X_1X_3 \\ & + 2.18X_2X_3 - 1.79X_1^2 - 2.14X_2^2 - 2.14X_3^2 \end{aligned}$$

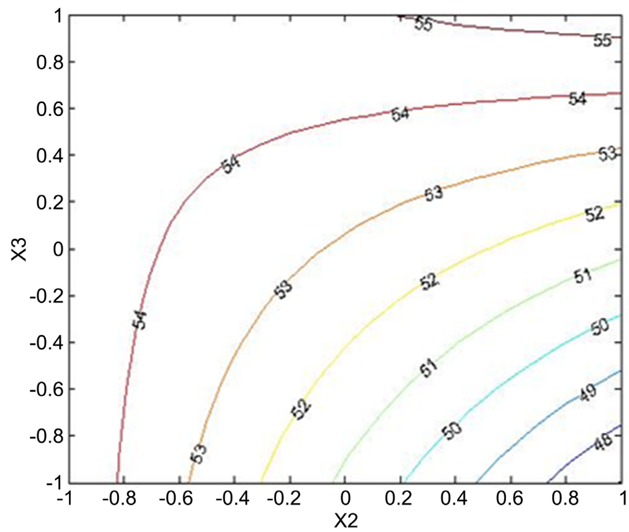
3. Results

Graphs are plotted to show the effect of processing each input factor into a regression equation that adequately describes the lint separation efficiency of Y_1, forming a combined cleaning device with a brush drum, guide and mesh surface (**Figure 2**).

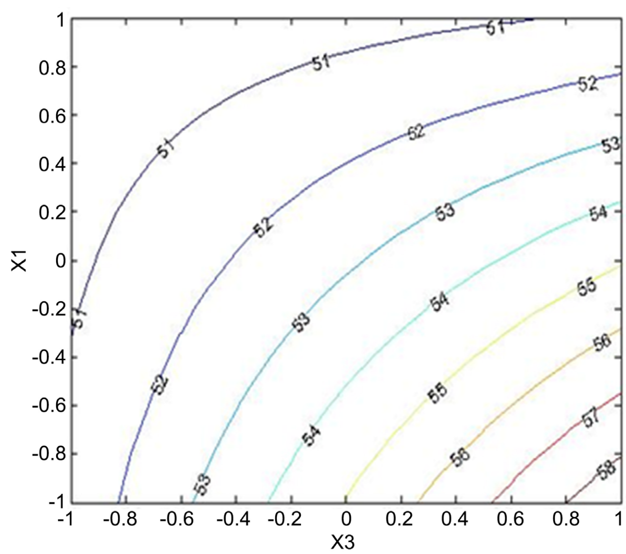
Based on the analytical work carried out, it was possible to use a linting machine with a device for separating impurities in fluff, to separate the fluff scraped from the ginned seeds from the saw tooth through a drum with a brush. In this device, the main working element is the brush drum, and since the rotation speed of the brush drum is 0.5 times higher than the rotation speed of the saw cylinder, the transmission process is carried out due to effective separation. In addition, the diameter of this drum, its length and the distance between the saw teeth have a significant effect on the lint separation process. The brush drum separates the lint from the saw tooth, simultaneously shredding it and throwing the lint into the path of the exhaust air condenser. The brush drum is surrounded by a special working chamber, which is connected to an air condenser channel that draws out the lint. The working chamber of the brush drum



(a)



(b)



(c)

Figure 2. Graphs of dependence of 3 factors.

is equipped with a mesh surface at the bottom and a guide at the top. As the brush drum separates the linter from the saw tooth, the guide guides the linter toward the mesh surface and allows it to pass through the mesh surface. As a result, small impurities fall off the surface of the mesh, and by separating small impurities from the composition of the linter, the quality of the linter (fluff) improves.

4. Conclusion

The results obtained showed that the rotation speed of the brush drum installed on the linting machine, the change in the angle of inclination of the guide located in its working chamber, the length of the mesh surface and the size of the slots in it lead to an increase in cleaning efficiency. Optimal values of factors influencing the cleaning surface of a linting machine: Rotation speed of the brush drum—1100 rpm; Guide inclination angle, 30 (α), degrees; With a mesh surface length of 400 mm, we achieved a cleaning efficiency of 55.1%.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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