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Improvement of a Device for Cleaning Cotton from Small Impurities

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Abstract

The article describes the work being carried out to improve the equipment for cleaning raw materials of the cotton ginning industry from small impurities. Through mathematical planning research, the limits of the values of the main factors affecting the efficiency of the cleaning device were determined, and the optimal values of the factors were determined based on regression equation calculations.

Keywords

Cotton, Fine Dirt, Efficiency, Cleaning, Technology, Device, Drum, Plank, Pile, Continuous Slot, Mesh Surface, Factor, Parameter, Wire, Regression, Fisher, Coefficient

1. Introduction

The process of separating small impurities from cotton is one of the most important processes in the initial processing of cotton, which has a significant impact on the subsequent stages, *i.e.*, ginning and fiber cleaning. If small impurities are not sufficiently cleaned, they pass from passive impurities to active impurities, and it becomes difficult to separate these impurities in the fiber cleaner. All cleaners that separate small impurities from cotton work in the same way, that is, cotton is shaken in pile drums and moved through mesh surfaces. This process is repeated several times, and small impurities are removed from the cotton. The cleaning efficiency depends on the number of rotations of the pile drums, the mesh surface, and the moisture content of the cotton, etc. The number of rotations of the pile-slat drums is limited by the increase in mechanical damage to the cotton seed, and the area of the mesh surface is limited by the passage of cotton into the composition of impurities [1] [2].

Cotton raw materials may contain cotton leaves, boll residues, broken and broken seeds, and mineral impurities. If the impurities in the cotton are not removed to the maximum extent during cleaning (usually the cleaning efficiency is 70% - 75%), the quality of the fiber produced after subsequent processes may decrease [3] [4]. Taking this into account, the newly improved fine impurities cleaning device prevents fine impurities from the cotton raw materials from being released into the air and passing into subsequent technological processes. The advantage of the newly proposed cleaning device is to increase efficiency and reduce mechanical effects on the raw materials due to cleaning on a continuous mesh surface and with the help of belt piles.

The main working elements of the improved fine dirt removal device are a mesh surface with continuous slots [5] (the slots do not have any obstacles along the total area of the surface, the rings that ensure the strength of the wires are located at the bottom of the mesh surface and do not interfere with the dirt falling through the rings) and a drum with pegs mounted on a belt element (**Figure 1**).

The improved fines cleaning device provides significant economic efficiency to the enterprise due to the improvement of fiber quality by 12% - 14%. The improved cleaning device consists of the following main parts (**Figure 1**): 1-feed rollers, 2-squeezing drum, 3-pile drums, 4-pile, 5-belt base of the pile, 6-continuous slotted mesh surface.

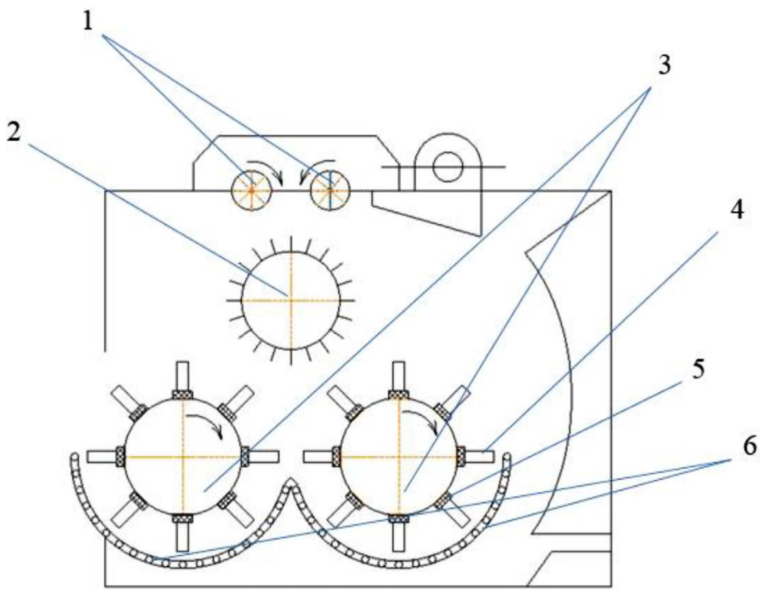

Figure 1. Technological scheme of the improved fine impurities cleaning zone. (1-supply rollers, 2-suction drum, 3-drums with piles, 4-piles, 5-belt base of piles, 6-continuous slotted mesh surface.)

The device works as follows: From the supply rollers 1, through the cleaning drum 2, the cotton raw material meets the pile drums 3 mounted on the belt base

5. The pile drums carry the mass of cotton raw material and bring it onto the mesh surfaces 6, and the cotton is thoroughly cleaned under the influence of the piles and as a result of dragging it over the mesh surface. As a result of the cleaning, small impurities contained in the cotton raw material pass through the slots of the mesh surface.

The main technological difference of the device from other cleaners is that the mesh surface is made of smooth steel wires and, due to the fact that the wires form continuous slots, the useful area of the mesh surface increases by almost 2 times (54.2%) compared to the existing one, which significantly increases the cleaning efficiency. In addition, due to the increased smoothness of the surface, it is possible to work freely without jamming at a given maximum performance, and since the pegs are mounted on a flexible base, the intensity of the cleaning increases, while the risk of damage from mechanical impact is also reduced.

2. Determination of Technological Parameters of an Improved Cleaning Device Using the Method of Mathematical Planning

It is known that the mathematical planning method is used to simplify experiments and determine the influence of the main factors affecting the device on the output parameters [6]. These studies serve to reveal the most important aspects of the issue.

The main goal of creating an improved fine impurities cleaning device is to remove the fine impurities from the cotton content to the maximum extent. Therefore, during optimization, it is necessary to pay attention to the maximization of the output parameter value [7].

First of all, it is necessary to identify the main factors affecting the operation of the cleaning device based on previous studies and existing methodology [8] [9]. They are:

x_1: distance between drum pegs and mesh surface, mm.

x_2: productivity, kg/hour.

x_3: Distance between wires, mm.

The output parameter, the cleaning efficiency, is denoted by Y. The range of values of the input factors is given in **Table 1**.

Table 1. Selecting the levels of change and ranges of the studied factors.

Name and unit of measurement of factors	Marking	Change levels			Change interval Δx
		−1	0	+1	
Distance between drum pins and mesh surface, mm	x_1	14	16	18	2
Productivity, kg/hour	x_2	6000	7000	8000	1000
Distance between wires, mm	x_3	5	7	9	2

Based on previous studies, the limits of the values of the input factors were determined [10].

x_1, the distance between the drum piles and the mesh surface is considered one of the quantities affecting the cleaning efficiency, and the distance should have an optimal value for cleaning the cotton passing between them from impurities, since this quantity also depends on the performance of the device. Therefore, its value was taken in the range of 14 - 18 mm.

x_2, it is no secret that the performance of the device also largely affects the cleaning efficiency, based on previous studies, it was taken as 6000 - 8000 (on average 7000 at enterprises) kg/h.

x_3, the distance between the wires is considered the most important factor, and changing the distance directly affects the process and the strength of the mesh surface. This distance was determined in the range of 5 - 9 mm using small experiments. Because if the distance exceeds 9 mm, the chances of clogging on the surface and cotton passing to the waste side increase.

In order to simplify the processing of the research results, we will switch from the natural values of the factors to their coded values. $x_i = \frac{x_i - x_{ai}}{I}$.

Here x_{ai}, simplified value of the factor;

x_i, i the natural value of the nth factor;

I, variation range.

The results of the coding are presented in Table 2.

Thus, after coding, all higher levels are marked with +1 or simply (+), and lower levels are marked with −1 or simply (−).

The working planning matrix, that is, the matrix structure according to which the experiment is conducted. For this, the standard planning matrix is used.

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

Table 2. Calculated upper and lower levels of factors.

№	Varied factors	Low-level coding	High-level coding
1	Distance between drum pins and mesh surface, mm	$x_i = \frac{1100-1200}{100} = -1$	$x_i = \frac{1300-1200}{100} = 1$
2	Productivity, kg/hour	$x_i = \frac{30-45}{15} = -1$	$x_i = \frac{60-45}{15} = 1$
3	Distance between wires, mm	$x_i = \frac{200-400}{200} = -1$	$x_i = \frac{600-400}{200} = 1$

The experiments are carried out strictly in the sequence given in column 4, with the values of the input parameters in column set. The results obtained are recorded in column 5. The order of column 4 is based on a random table, the task of which is to conduct the tests in this order and eliminate the influence of random factors on the process under study.

The working matrix of the MNKT and the results of the experiments are given in Table 3.

Table 3. Central non-compositional experimental matrix.

№	Factors			x_1x_2	x_1x_3	x_2x_3	x_1^2	x_2^2	x_3^2	$\bar{Y}$	$S_u^2\{Y\}$
	x_1	x_2	x_3								
1	+	+	0	+	0	0	+	+	0	87.6	0.86
2	+	-	0	-	0	0	+	+	0	82.1	0.65
3	-	+	0	-	0	0	+	+	0	88.8	0.48
4	-	-	0	+	0	0	+	+	0	84.9	0.09
5	+	0	+	0	+	0	+	0	+	84.9	0.6
6	+	0	-	0	-	0	+	0	+	89.4	0.07
7	-	0	+	0	-	0	+	0	+	90.9	0.5
8	-	0	-	0	+	0	+	0	+	91.7	0.48
9	0	+	+	0	0	+	0	+	+	86.1	0.09
10	0	+	-	0	0	-	0	+	+	87.2	0.6
11	0	-	+	0	0	-	0	+	+	83.7	0.07
12	0	-	-	0	0	+	0	+	+	87.3	0.19
13	0	0	0	0	0	0	0	0	0	88.9	0.1
14	0	0	0	0	0	0	0	0	0	89.9	0.8
15	0	0	0	0	0	0	0	0	0	89.9	0.9

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

Based on the results of the experiments, we search for a second-order regression multifactorial mathematical model. As a result of this experiment, we can obtain the following general form of a 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 three factors are involved in our experiment, it takes the following form:

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

In the equation $b_0, b_1, \cdots$, regression coefficients, x_1, x_2, x_3, coded value of factors.

Optimization calculations to determine the efficiency of the purification device (Y).

We calculate the regression coefficients:

$$b_0 = \frac{1}{N_u} \sum_{u=1}^{N_u} \bar{Y}_u = \frac{1}{3}(88.9 + 89.9 + 89.9) = 89.57$$

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

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

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

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

$$b_1 = 0.125(87.6 + 82.1 - 88.8 - 84.9 + 84.9 + 89.4 - 90.9 - 91.7) = -1.54$$

$$b_2 = 0.125(87.6 - 82.1 + 88.8 - 84.9 + 86.1 + 87.2 - 83.7 - 87.3) = 1.46$$

$$b_3 = 0.125(84.9 - 89.4 + 90.9 - 91.7 + 86.1 - 87.2 + 83.7 - 87.3) = -1.25$$

$$b_{12} = 0.25(87.6 - 82.1 - 88.8 + 84.9) = 0.40$$

$$b_{13} = 0.25(84.9 - 89.4 - 90.9 + 91.7) = -0.93$$

$$b_{23} = 0.25(86.1 - 87.2 - 83.7 + 87.3) = 0.62$$

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

$$\sum x_1^2 \overline{Y}_u = 87.6 + 82.1 + 88.8 + 84.9 + 84.9 + 89.4 + 90.9 + 91.7 = 700.3$$

$$\sum x_2^2 \overline{Y}_u = 87.6 + 82.1 + 88.8 + 84.9 + 86.1 + 87.2 + 83.7 + 87.3 = 687.7$$

$$\sum x_3^2 \overline{Y}_u = 84.9 + 89.4 + 90.9 + 91.7 + 86.1 + 87.2 + 83.7 + 87.3 = 701.2$$

$$\begin{aligned} \sum \overline{Y}_u &= 87.6 + 82.1 + 88.8 + 84.9 + 84.9 + 89.4 + 90.9 + 91.7 + 86.1 \\ &\quad + 87.2 + 83.7 + 87.3 + 88.9 + 89.9 + 89.9 \\ &= 1313.3 \end{aligned}$$

$$\sum_{i=1}^{M} \sum x_i^2 \overline{Y}_u = 700.3 + 687.7 + 701.2 = 2089.2$$

$$b_{11} = 0.125 \times 700.3 + 0.0625 \times 2089.2 - 0.166 \times 1313.3 = 0.10$$

$$b_{22} = 0.125 \times 687.7 + 0.0625 \times 2089.2 - 0.166 \times 1313.3 = -1.47$$

$$b_{33} = 0.125 \times 701.2 + 0.0625 \times 2089.2 - 0.166 \times 1313.3 = 0.22$$

Taking into account the determined regression coefficients, we write the equation:

$$\begin{aligned} Y_R = 89.57 + (-1.54) X_1 + 1.46 X_2 + (-1.25) X_3 + 0.4 X_1 X_2 + (-0.92) X_1 X_3 \\ + 0.62 X_2 X_3 + 0.10 X_1^2 + (-1.47) X_2^2 + 0.22 X_3^2 \end{aligned} \quad (1)$$

We determine the significance of the regression coefficients.

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

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

$$S_m^2\{Y\} = 1.8 \quad S^2\{\overline{Y}\} = \frac{1}{3-1} \times 1.8 = 0.9$$

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

$$S^2\{b_0\} = g_1 S^2\{\overline{Y}\} = 0.2 \times 0.9 = 0.18$$

$$S^2\{b_i\} = g_3 S^2\{\overline{Y}\} = 0.125 \times 0.9 = 0.11$$

$$S^2\{b_{ij}\} = g_4 S^2\{\overline{Y}\} = 0.25 \times 0.9 = 0.225$$

$$S^2\{b_{ij}\} = g_7 S^2\{\overline{Y}\} = 0.3125 \times 0.9 = 0.28$$

We narrow down the mean square deviation in determining the regression coefficients:

$$S\{b_0\} = 0.42 \quad S\{b_i\} = 0.34 \quad S\{b_{ij}\} = 0.47 \quad S\{b_{ii}\} = 0.53$$

Then, we determine the calculated value of the Student's t-test using the following equation:

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

$$t_R\{b_0\} = \frac{|89.57|}{0.42} = 213.26 \quad t_R\{b_{13}\} = \frac{|0.93|}{0.47} = 1.98$$

$$t_R\{b_1\} = \frac{|-1.54|}{0.34} = 4.53 \quad t_R\{b_{23}\} = \frac{|0.62|}{0.47} = 1.32$$

$$t_R\{b_2\} = \frac{|1.46|}{0.34} = 4.29 \quad t_R\{b_{11}\} = \frac{|0.10|}{0.53} = 0.19$$

$$t_R\{b_3\} = \frac{|-1.25|}{0.34} = 3.68 \quad t_R\{b_{22}\} = \frac{|-1.47|}{0.53} = 2.77$$

$$t_R\{b_{12}\} = \frac{|0.4|}{0.47} = 0.85 \quad t_R\{b_{33}\} = \frac{|0.22|}{0.53} = 0.42$$

We take the tabular value of the Student criterion from **Appendix 3**:

$$t_j\left[P_d = 0{,}95;\ f\{S_u^2\} = 3-1 = 2\right] = 2.77$$

It is known that if the calculated value of the criterion is less than the table value, then that coefficient is not significant and we remove it from the equation. In the studies, it was found that the coefficients $b_2, b_3, b_{11}, b_{12}, b_{33}$ are insignificant for the parameters under study:

We rewrite the equation with significant coefficients:

$$Y_R = 89.57 + (-1.54)X_1 + 1.46X_2 + (-1.25)X_3 + (-1.47)X_2^2 \quad (3)$$

In order to check whether the above-mentioned regression mathematical model is adequate or not, we will use the calculated value of Fisher's criterion to determine.

$$F_R = \frac{S_{nad}^2\{Y\}}{S^2\{Y\}}$$

Here:

$$S^2\{\bar{Y}\} = \frac{\sum_{u=1}^{N} S^2\{Y\}}{N_u - 1} = \frac{2}{2} = 0.9 \quad S_{nad}^2\{Y\} = \frac{\sum_{u=1}^{N-N_{n+1}}\left(Y_{Ru} - \bar{Y}_u\right)^2}{N - N_{k.en} - (N_u - 1)^2}$$

$$N - N_{k.en} - (N_u - 1)^2 = 15 - 7 - (3-1)^2 = 4$$

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

$$Y_R = 89.57 + (-1.54)X_1 + 1.46X_2 + (-1.25)X_3 + (-1.47)X_2^2$$

$$Y_{R1} = 89.57 + (-1.54) + 1.46 + (-1.47) = 85.02$$

$$Y_{R2} = 89.57 + (-1.54) + (-1.46) + (-1.47) = 83.60$$

$$Y_{R3} = 89.57 + 1.54 + 1.46 + (-1.47) = 90.00$$

$$Y_{R4} = 89.57 + 1.54 + (-1.46) + (-1.47) = 88.18$$

$$Y_{R5} = 89.57 + (-1.54) + (-1.25) = 86.78$$

$$Y_{R6} = 89.57 + (-1.54) + 1.25 = 89.28$$

$$Y_{R7} = 89.57 + 1.54 + (-1.25) = 87.86$$

$$Y_{R8} = 89.57 + 1.54 + 1.25 = 92.36$$

$$Y_{R9} = 89.57 + 1.46 + (-1.25) + (-1.47) = 88.31$$

$$Y_{R10} = 89.57 + 1.46 + 1.25 + (-1.47) = 90.81$$

$$Y_{R11} = 89.57 + (-1.46) + (-1.25) + (-1.47) = 85$$

$$Y_{R12} = 89.57 + (-1.46) + 1.25 + (-1.47) = 86$$

$$\sum_{u=1}^{N-N_n+1} \left(Y_{Ru} - \overline{Y}_u\right)^2 = 57 \quad S_{nad}^2\{Y\} = \frac{74}{4} = 14$$

It is known that if the calculated value of the criterion is less than the table value, then this coefficient is adequate and proves that the calculations were carried out correctly.

In order to simplify the calculations, we will compile **Table 4**:

Table 4. Comparison table of computational and experimental results.

№	$\overline{Y}_u$	Y_{Ru}	$Y_{Ru} - \overline{Y}_u$	$\left(Y_{Ru} - \overline{Y}_u\right)^2$
1	87.6	85.02	−2.58	6.66
2	82.1	83.6	1.50	2.25
3	88.8	90	1.20	1.44
4	84.9	88.18	3.28	10.76
5	84.9	86.78	1.88	3.53
6	89.4	89.28	−0.12	0.01
7	90.9	87.86	−3.04	9.24
8	91.7	92.36	0.66	0.44
9	86.1	88.31	2.21	4.88
10	87.2	90.81	3.61	13.03
11	83.7	85.39	1.69	2.86
12	87.3	85.89	−1.41	1.99
total				57.1

$$F_R = \frac{S_{nad}^2\{Y\}}{S^2\{\overline{Y}\}} = \frac{14.27}{0.9} = 15.9$$

$$F_j\left[P_d = 0.95;\ f\,S_{nad}^2\{Y\} = 15 - 6 - (3-1) = 5;\ f\left\{S_u^2\right\} = 3 - 1 = 2\right] = 4.74$$

$$F_R = 3.28 < 4.74 = F_j$$

From Figures 2-4, it can be seen that the optimal values of the device for cleaning cotton from small impurities had a significant impact on the efficient operation of the machine. In this case, the rational solutions are as follows: the distance between the drum pegs and the mesh surface is 14 mm, the device's productivity is 7000 kg/h, and the distance between the wires is 5 mm.

X1	X2		
	-1	0	1
-1	88	91	91
-0,5	87	90	90
0	87	90	90
0,5	86	89	89
1	85	88	88

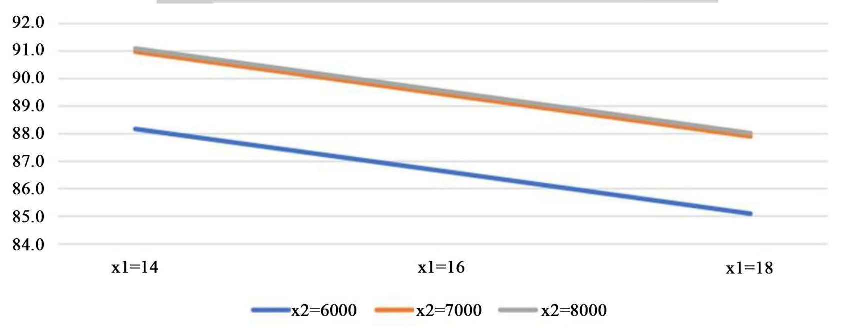

Figure 2. Graph of the relationship between the distance between the drum pins and the mesh surface and the productivity.

X2	X3		
	−1	0	1
−1	88	87	85
−0.5	90	88	87
0	91	90	88
0.5	91	90	89
1	91	90	88

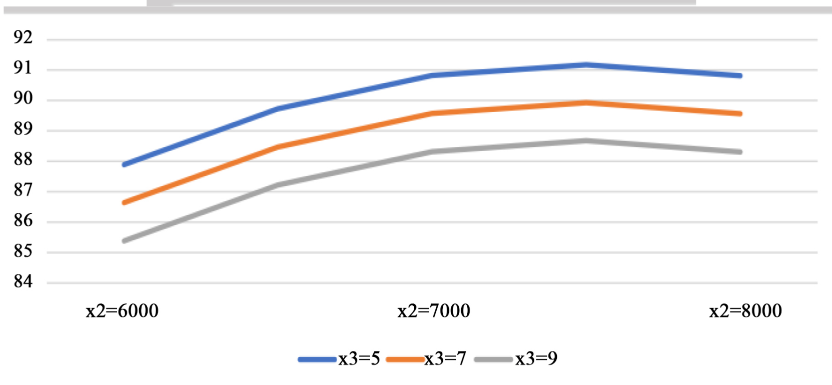

Figure 3. Graph of performance versus distance between wires.

X3	X1		
	−1	0	1
−1	92	91	89
−1	92	90	89
0	91	90	88
1	90	89	87
1	90	88	87

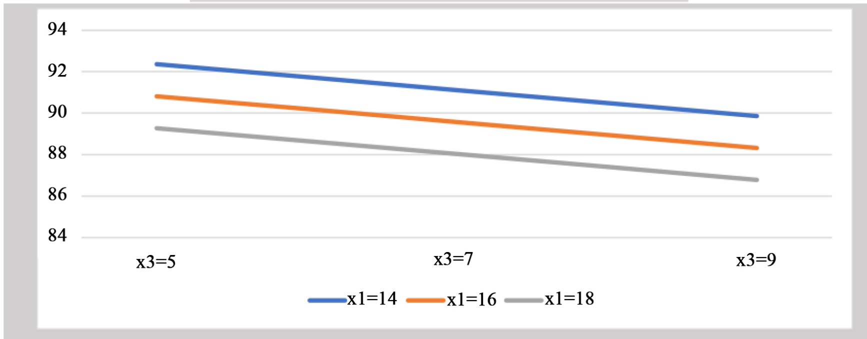

Figure 4. Graph of the distance between the wires and the distance between the drum pegs and the mesh surface.

3. Conclusion

Through a mathematical planning study, the limits of the values of the main factors affecting the efficiency of the cleaning device were determined, and based on regression equation calculations, the optimal values of the factors were determined: x_1, the distance between the drum pegs and the mesh surface was 14 mm, x_2, the device's productivity was 7000 kg/h, and x_3, the distance between the wires was 5 mm.

Conflicts of Interest

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

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