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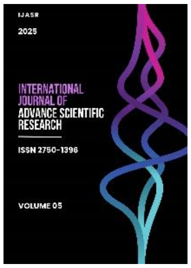

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Research Article

Experimental Study of The Power Consumption of The Saw Gin Electric Motor with A Shelling Chamber

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Abstract

This article presents the results of an experimental investigation into the power consumption characteristics of a saw gin equipped with a huller roller box. The study focuses on the influence of three primary parameters: the productivity of the saw gin, the vertical distance from the top of the grate to the horizontal axis of the saw cylinder, and the relative position of the comb. Through a series of controlled experiments, the optimal operational settings were determined that minimize electric motor power consumption while ensuring efficient seed separation and reduced fiber loss. The findings highlight specific configurations that promote energy efficiency, maintain raw roller density within an acceptable range, and significantly lower seed waste. These outcomes contribute to the design of more energy-efficient and productive cotton ginning systems.

Keywords

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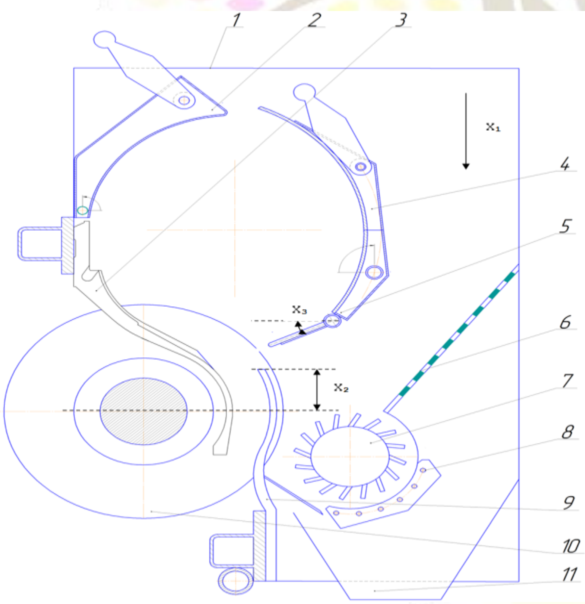
Saw gin, power consumption, huller roller box, energy efficiency, saw cylinder, raw roller density, cotton ginning, fiber separation, seed loss.

INTRODUCTION

Fiber separation machines are manufactured in machine-building plants in Uzbekistan, the USA, and in India and China under American patents [1-5]. It was stated that domestic saw gins are more efficient, cheaper to manufacture, and are equipped with simple design units and mechanisms.

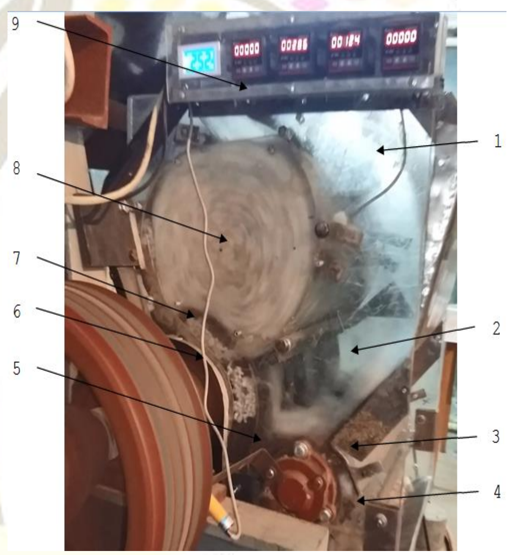
Saw blades with a diameter of ∅320 mm are widely used in the domestic cotton ginning industry. Therefore, developing a saw gin with a throwing drum on saw blades with a diameter of ∅320 mm is an urgent problem in this area.

Figure 1 shows a saw gin with a throwing drum [6]. To reduce wear of bars 3, saw blades (∅320 mm), and the power consumption of saw cylinder 10, raw cotton is fed directly to saw cylinder 10 through chute 6 using rotating throwing drum 7, under which lattice grate 8 is installed.



1- sidewall; 2- frontal beam; 3- working chamber bars; 4- upper apron; 5- lower apron with comb; 6- chute; 7- throwing drum; 8 – lattice grate of the shelling chamber; 9- bars of the shelling chamber; 10 - saw cylinder; 11- trash catcher.

Fig. 1 - Scheme of the working chamber of the saw gin with a throwing drum.



1 - neck; 2 - shelling chamber; 3 - throwing drum; 4 - lattice grate of the shelling chamber; 5 – bars of the shelling chamber; 6 - saw cylinder; 7 - bars of the working chamber; 8 - working chamber (raw cotton roller); 9 - sensor panel

Fig. 2 – Working chamber of the saw gin with a shelling chamber

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To evaluate the efficiency of the proposed saw gin with a throwing drum and a two-drum peg feeder (Figures 1 and 2), experimental studies were conducted using a full factorial experiment of type 2^3. The following values were adopted as input parameters: gin productivity (X_1 = 430, 645 kg/hour), distance from the top of bar 9 to the horizontal axis of saw cylinder 10 (X_2 = 58; 78 mm) and comb position (X_3 = 35°; 50°); these parameters affect the energy consumption of the saw gin, the density of the raw cotton roller, and the loss of seeds to waste through the shelling chamber.

The choice of these parameters is sufficient to evaluate the systems under consideration. The following were adopted as output parameters:

y_1 – power consumption of the saw cylinder electric motor, kW;

y_2 – density of the raw cotton roller, kg/m^3;

y_3 – loss of seeds to waste, %.

The experiments were conducted on cotton of the C 6524 variety, grade I, class 2, 8.19% of moisture content and 3.68% of impurity according to the scheme: Double-drum pin feeder $\rightarrow$ working chamber 30 of the saw gin with a throwing drum.

We study the power consumption of the electric motor of the saw gin with a throwing drum (response function y) depending on the gin productivity, kg/hour (z_1), the distance from the top of the grate to the horizontal axis of the saw cylinder, mm (z_2), and the position of the comb, degree (z_3), using the method proposed in [7].

Let us compose the design matrix PFE 2^3 (Table 1). FFE 2^3

$$z_1^0 = \frac{430+645}{2} = 537.5,\ z_2^0 = \frac{58+78}{2} = 68,\ z_3^0 = \frac{35+50}{2} = 42.5,$$

$$\Delta z_1 = \frac{645-430}{2} = 107.5,\ \Delta z_2 = \frac{78-58}{2} = 10,\ \Delta z_3 = \frac{50-35}{2} = 7.5$$

Table 1. Full factorial experiment for three factors with a dummy variable

Experiment number	Factors in natural scale			Factors in dimensionless coordinate system				Output parameter
	z_1	z_2	z_3	x_0	x_1	x_2	x_3	y_1
1	430	58	35	+1	-1	-1	-1	3.985
2	645	58	35	+1	+1	-1	-1	4.250
3	430	78	35	+1	-1	+1	-1	3.908
4	645	78	35	+1	+1	+1	-1	4.181
5	430	58	50	+1	-1	-1	+1	4.000

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6	645	58	50	+1	+1	-1	+1	4.371
7	430	78	50	+1	-1	+1	+1	3.886
8	645	78	50	+1	+1	+1	+1	4.277

The test showed that the experimental data are normally distributed and homogeneous.

Let us calculate the linear regression coefficients using the following formula:

$$b_0 = \frac{1}{8}\sum_{i=1}^{8} y_i = \frac{1}{8}(3.985 + 4.25 + 3.908 + 4.181 + 4.0 + 4.371 + 3.886 + 4.277) = 4.107$$

$$b_1 = \frac{1}{8}(-1\cdot 3.985 + 1\cdot 4.25 - 1\cdot 3.908 + 1\cdot 4.181 - 1\cdot 4.0 + 1\cdot 4.371 - 1\cdot 3.886 + 1\cdot 4.277 = 0.162$$

$$b_2 = \frac{1}{8}(-1\cdot 3.985 - 1\cdot 4.25 + 1\cdot 3.908 + 1\cdot 4.181 - 1\cdot 4.0 - 1\cdot 4.371 + 1\cdot 3.886 + 1\cdot 4.277 = 0.044$$

$$b_3 = \frac{1}{8}(-1\cdot 3.985 - 1\cdot 4.25 \text{-} 1\cdot 3.908 \text{-} 1\cdot 4.181 + 1\cdot 4.0 + 1\cdot 4.371 + 1\cdot 3.886 + 1\cdot 4.277 = 0.0262$$

We calculate the coefficients of pairwise interaction. For this, we will create an additional table (Table 2).

$$b_{12} = \frac{1}{8}\sum_{i=1}^{8} x_1 x_2 y_i = \frac{1}{8}(3.985 \text{-} 4.25 \text{-} 3.908 + 4.181 + 4.0 \text{ -} 4.371 \text{-} 3.886 + 4.277) = 0.00356$$

$$b_{13} = \frac{1}{8}\sum_{i=1}^{8} x_1 x_3 y_i = \frac{1}{8}(3.985 \text{-} 4.25 + 3.908 \text{-} 4.181 \text{-} 4.0 + 4.371 \text{-} 3.886 + 4.277) = 0.02815$$

$$b_{23} = \frac{1}{8}\sum_{i=1}^{8} x_2 x_3 y_i = \frac{1}{8}(3.985 + 4.25 \text{-} 3.908 \text{-} 4.181 \text{-} 4.0 \text{-} 4.371 + 3.886 + 4.277) = \text{-}0.00775$$

$$b_{123} = \frac{1}{8}\sum_{i=1}^{8} x_1 x_2 x_3 y_i = \frac{1}{8}(3.985 + 4.25 + 3.908 \text{-} 4.181 + 4.0 \text{-} 4.371 \text{-} 3.886 + 4.277) = 0.00147$$

Table 2. Extended design matrix for a full factorial experiment FFE 2^3

Experiment number	x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$	y_1
1	+1	-1	-1	-1	+1	+1	+1	-1	3.985
2	+1	+1	-1	-1	-1	-1	+1	+1	4.250
3	+1	-1	+1	-1	-1	+1	-1	+1	3.908
4	+1	+1	+1	-1	+1	-1	-1	-1	4.181

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5	+1	-1	-1	+1	+1	-1	-1	+1	4.000
6	+1	+1	-1	+1	-1	+1	-1	-1	4.371
7	+1	-1	+1	+1	-1	-1	+1	-1	3.886
8	+1	+1	+1	+1	+1	+1	+1	+1	4.277

Substituting the coefficients, we obtain the regression equations for the consumed power depending on the input parameters:

$$y_1 = 4.107 + 0.162 \cdot x_1 - 0{,}044 \cdot x_2 + 0.0262 \cdot x_3 + 0.00356 \cdot x_1 \cdot x_2 +$$

$$+ 0.02815 x_1 x_3 - 0.00775 \cdot x_2 x_3 + 0.00147 \cdot x_1 x_2 x_3 \qquad (1)$$

Analysis of the regression equation

Checking the significance of the coefficients of the regression equation (1), using the Student criterion and parallel experiments showed the significance of all the coefficients of the equation obtained.

We check the homogeneity of the series of adjusted variances (Table 3):

$$G = \frac{S^2_{j\max}}{\sum_{j=1}^{N} S_j^2} = \frac{0.005}{0.0229} = 0.218 < G_{0.05;8;2} = 0.5157$$

That is, the series is homogeneous. Then

$$S_в^2 = \frac{1}{N}\sum_{j=1}^{N} S_j^2 = \frac{0.0229}{8} = 0.0028; \qquad k_в = 8(3-1) = 16.$$

To determine the adequacy of model (1), it is necessary to determine the variance of adequacy

$$S_{ад}^2 = \frac{1}{N}\sum_{j=1}^{N} S_j^2 = \frac{0.0009}{8} = 0.0002; \qquad k_{ад} = 8 - 4 = 4.$$

The values of the Fisher criterion show that the model is adequate:

$$F = \frac{S_{ад}^2}{S_в^2} = \frac{0.0002}{0.0028} = 0.078 \ < \ F_{0.05;4;16} = 3.01$$

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Table 3 - Results of processing experimental data

Experiment number	f_N	Empirical variance		$\bar{y}$	$\hat{y}$	$\bar{y}-\hat{y}$	$(\bar{y}-\hat{y})^2$
		S_n^2	S_n				
1	3	0.001	0.0316	3.985	3.9851	0.00048	$2.34\cdot10^{-7}$
2	3	0.005	0.0707	4.250	4.2489	0.00114	$1.31\cdot10^{-6}$
3	2	0.0009	0.03	3.908	3.9089	-0.00057	$3.25\cdot10^{-7}$
4	3	0.002	0.0447	4.181	4.1811	0.00006	$3.36\cdot10^{-9}$
5	2	0.002	0.0447	4.000	3.9999	0.00023	$5.29\cdot10^{-8}$
6	3	0.004	0.0632	4.371	4.3701	0.00120	$1.45\cdot10^{-6}$
7	3	0.003	0.0547	3.886	3.8861	-0.00013	$1.56\cdot10^{-8}$
8	2	0.005	0.0707	4.277	4.2759	0.00139	$1.93\cdot10^{-6}$
Sum	21	0.0229	0.4105	32.860	32.856	0.00382	$5.32\cdot10^{-6}$

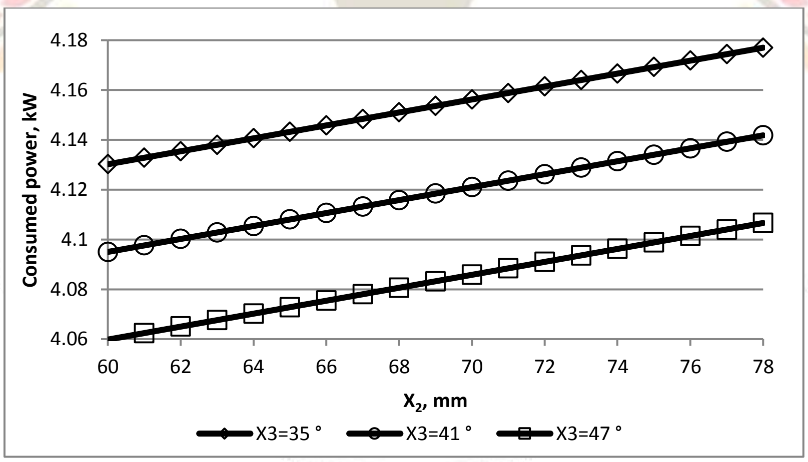

Fig. 3. Changes in the consumed power of the electric motor depending on the distance from the top of the grate to the horizontal axis of the saw cylinder (X_2) at different positions of the comb (X_3) for the gin productivity (X_1=537.5 kg/hour).

To determine the significance of the coefficients, we determine the standard deviation S_{bi} :

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$$S_{bi} = \sqrt{\frac{S_в^2}{nN}} = \sqrt{\frac{0.0028}{3 \cdot 8}} = 0.011, \ i=0, 1, 2, 3.$$

Then

$$t_0 = \frac{|b_0|}{S_{b0}} = 376.1 > t_{0.025;16} = 2.12 \quad t_1 = \frac{|b_1|}{S_{b1}} = 14.89 > t_{0.025;16} = 2.12 \quad t_2 = \frac{|b_2|}{S_{b2}} = 4.05 > t_{0.025;16} = 2.12$$

$$t_3 = \frac{|b_3|}{S_{b3}} = 2.4 > t_{0.025;16} = 2.12 \qquad t_{13} = \frac{|b_{13}|}{S_{b13}} = 2.58 > t_{0.025;16} = 2.12$$

The critical value of $t_{\alpha/2;k}$ is $t_{0.025;16} = 2.12$, i.e., except for t_{12}, t_{23}, t_{123}, all coefficients of the model are significant. Accounting for the dispersion, adequacy, and Student's criterion, the regression equation of the consumed power depending on factors x_1, x_2, x_3 has the following form:

$$y_1 = 4.107 + 0.162 \cdot x_1 - 0{,}044 \cdot x_2 + 0.026 \cdot x_3 + 0.028 \cdot x_1 \cdot x_3 \qquad (2)$$

In the same sequence, we construct the regression equations of factors x_1, x_2, x_3 depending on the density of the raw cotton roller during ginning.

Table 4 - Full factorial experiment for three factors with a dummy variable

Experiment number	Factors in natural scale			Factors in dimensionless coordinate system				Output parameter
	z_1	z_2	z_3	x_0	x_1	x_2	x_3	y
1	430	58	35	+1	-1	-1	-1	264.8
2	645	58	35	+1	+1	-1	-1	304.7
3	430	78	35	+1	-1	+1	-1	265.0
4	645	78	35	+1	+1	+1	-1	284.9
5	430	58	50	+1	-1	-1	+1	295.8
6	645	58	50	+1	+1	-1	+1	318.3
7	1.1	78	50	+1	-1	+1	+1	268.1
8	2.5	78	50	+1	+1	+1	+1	307.0

The regression equation of the density of the raw cotton roller during ginning is:

$$y_2 = 288.575 + 15.15 \cdot x_1 - 7.325 \cdot x_2 + 8.725 \cdot x_3 \qquad (3)$$

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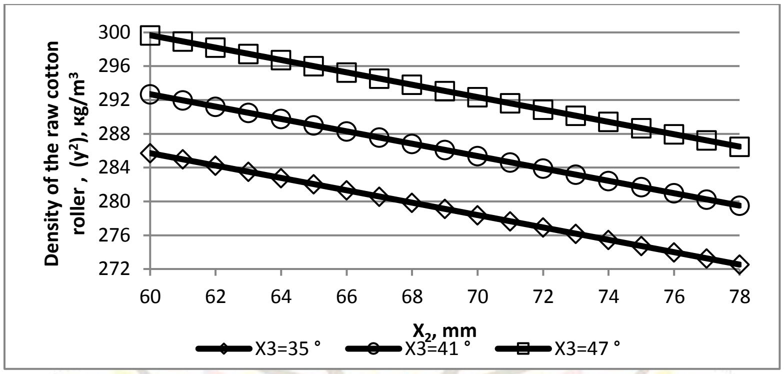

Fig. 4. Changes in the density of the raw cotton roller (y_2) depending on the distance from the top of the grate to the horizontal axis of the saw cylinder (X_2) at different positions of the comb (X_3) for the gin productivity (X_1=537.5 kg/hour).

We determine the significance of the coefficients of the regression equations (3):

$$t_0 = \frac{|b_0|}{S_{b0}} = 111.433 > t_{0.025;16} = 2.12 \quad t_1 = \frac{|b_1|}{S_{b1}} = 5.85 > t_{0.025;16} = 2.12 \quad t_2 = \frac{|b_2|}{S_{b2}} = 2.829 > t_{0.025;16} = 2.12$$

$$t_3 = \frac{|b_3|}{S_{b3}} = 3.369 > t_{0.025;16} = 2.12$$

The statistical significance of the regression coefficients b_0, b_1, b_2, b_3 is confirmed with a reliability of 95%.

As in the previous sequences, we construct the regression equations of factors x_1, x_2, x_3 depending on the seed loss during ginning.

Table 5 – Full factorial experiment for three factors with a dummy variable

Experiment number	Factors in natural scale			Factors in dimensionless coordinate system				Output parameter
	z_1	z_2	z_3	x_0	x_1	x_2	x_3	y
1	430	58	35	+1	-1	-1	-1	0.220
2	645	58	35	+1	+1	-1	-1	0.079
3	430	78	35	+1	-1	+1	-1	0.887
4	645	78	35	+1	+1	+1	-1	0.410
5	430	58	50	+1	-1	-1	+1	0.156
6	645	58	50	+1	+1	-1	+1	0.061
7	1.1	78	50	+1	-1	+1	+1	0.556
8	2.5	78	50	+1	+1	+1	+1	0.120

The regression equation for seed loss during ginning has the following form:

$$y_3 = 0.311 - 0.1436 \cdot x_1 + 0.18213 \cdot x_2 - 0.0879 \cdot x_3 - 0.0846 \cdot x_1 \cdot x_2 + 0.01088 \cdot x_1 \cdot x_3 - 0.0674 \cdot x_2 \cdot x_3 \quad (4)$$

We determine the significance of the coefficients of the regression equations (4):

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$$t_0 = \frac{|b_0|}{S_{b0}} = 77.43 > t_{0.025;16} = 2.12 \qquad t_1 = \frac{|b_1|}{S_{b1}} = 35.74 > t_{0.025;16} = 2.12$$

$$t_2 = \frac{|b_2|}{S_{b2}} = 45.32 > t_{0.025;16} = 2.12 \qquad t_3 = \frac{|b_3|}{S_{b3}} = 21.06 > t_{0.025;16} = 2.12$$

$$t_{12} = \frac{|b_{12}|}{S_{b12}} = 21.06 > t_{0.025;16} = 2.12 \qquad t_{13} = \frac{|b_{13}|}{S_{b13}} = 2.71 > t_{0.025;16} = 2.12$$

$$t_{23} = \frac{|b_{23}|}{S_{b23}} = 16.76 > t_{0.025;16} = 2.12 \qquad t_{123} = \frac{|b_{123}|}{S_{b123}} = 0.15 < t_{0.025;16} = 2.12$$

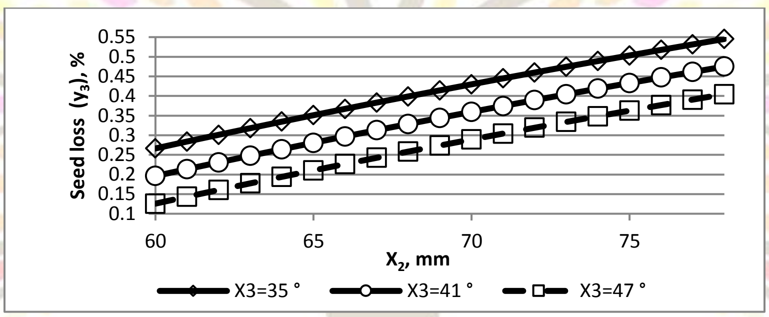

Fig. 5. Changes in seed loss (y_3) depending on the distance from the top of the grate to the horizontal axis of the saw cylinder (X_2) at different positions of the comb (X_3) for the gin productivity (X_1=537.5 kg/hour).

At critical value of $t_{0.025;16} = 2.12$, except for t_{123}, all coefficients of the model are significant.

The statistical significance of the regression coefficients b_0, b_1, b_2, b_3, b_{12}, b_{13}, b_{23} is confirmed with a reliability of 95%.

A generalized efficiency indicator of the machine under consideration is the cost of electricity; that is, ensuring the lowest power consumption under restrictions on the mass of the raw cotton roller.

Let us present a mathematical formalization of the problem of optimizing the power consumption of the saw cylinder electric motor (Table 6).

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Table 6. Optimization parameters

Input parameters			Output parameters of the system		
Gin efficiency, kg/hour	Distance from the top of the grate to the horizontal axis of the saw cylinder, mm	Comb positions, °	Power consumption of the saw cylinder, kW	Density of the raw cotton roller, kg/m^3	Seed loss, %
Parameter restrictions					
x_1=430; 645	x_2=58; 78	x_3=35; 50	$y_1 \leq 4.1$	$y_2 \leq 300$	$y_3 \leq 0.4$
Optimal values					
x_1=537.5	x_2=68	x_3=42.5	y_1 =4.107	y_2 =288.575	y_3 =0.311

Conclusions

As a result of using the full factorial design of the experiment, regression equations (2 - 4) were constructed depending on the input parameters: x_1 - gin productivity; x_2 - distance from the top of the grate to the horizontal axis of the saw cylinder; and x_3 - comb position.

Optimization of regression equations was conducted by the generally accepted program "Solution search for an optimized model using Newton's method". As a result of implementing the optimization, we obtained the productivity of the saw gin for cotton - x_1 = 537.5 kg/h, the distance from the top of the grate to the horizontal axis of the saw cylinder - x_2 = 68 mm, and the position of the comb - x_3 = 42.5° deg, at which the power consumption of the saw cylinder is y_1 = 4.107 kW, the density of the raw cotton roller is y_2 = 288.575 kg/m^3, and the seed loss is y_3 = 0.311%.

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