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METHODS FOR DEVELOPING A REGRESSION MODEL FOR FIBER SEPARATION IN WASTE AND DETERMINING MACHINE PRODUCTIVITY

Rashid Raxmonkulov*[1], Shavkat Ermatov[2]
[1.2]Termez State university of Engineering and Agricultural Technology, Termez, Uzbekistan
*Email: raxmonkulov.r.e@gmail.com

Abstract:

This work investigates the formulation of a regression model to assess fibre separation efficiency and machine productivity in textile waste processing. The experiment examined two primary variables: the distance between the grid and drum pins (x_1) and the drum rotation speed (x_2), with fibre cleaning efficiency (Y_1) as the result variable. A rotating centre composite design was used to develop the experimental plan. Regression coefficients were computed and confirmed using Student's t-test and Fisher's criteria to confirm model adequacy. The resultant model precisely forecasts cleaning efficiency at various operational tiers. The optimal efficiency was seen at a grid-to-drum spacing of 9 mm and a drum speed of 700–740 rpm. The experimental findings demonstrated a maximum divergence of 5% from theoretical predictions, therefore affirming the model's trustworthiness. The research establishes a solid foundation for enhancing fibre cleaning apparatus and aids in augmenting the efficiency of cotton waste recycling operations.

Keywords: Experimental Results, Stationary Level, Factors Under Study, Coefficient, Variance, Fisher's Criterion, RMKT

1. Introduction

In research work, special attention is paid to experimental research. Experimental and theoretical research is carried out to substantiate the correctness of the results or to solve the problems of their identification and optimization [1].

In theoretical-experimental scientific research, both theoretical and experimental results are taken into account, and currently, the type of theoretical-experimental research is more often used [2],[3].

Technological processes in the textile industry consist of a complex of physical and mechanical phenomena, which can be successfully studied only using modern achievements of science and technology. Therefore, it is advisable to conduct scientific research based on mathematical modeling [4].

2. Materials and Methods

The following parameters were taken as influencing factors: input factors x1 – distance between the 9-shaped grid and the drum pegs (mm), x2 – 625 drum speed (rpm). The Y1-cleaning efficiency property was selected as the output factor. The selection of the levels and ranges of change of the studied factors is presented in

The selection of the levels and ranges of change of the studied factors is presented in Table 1 – Experimental Factors and Their Variability Levels, see Table 1 below for details.

Table 1. Experimental Factors and Their Variability Levels.

Name and designation of factors		Change levels					Change interval
		-1,410	-1	0	1	1,410	
Distance between the shaped grid and the inclined pile drum, mm	x_1	6	7	9	11	12	2
Drum speed, rpm	x_2	450	560	690	800	850	110

The values of the constant coefficients in the formula are given in the table below;

The values of the constant coefficients in the central composite experiment with rototables (RCT) are given in the following table, see Table 2.

Table 2. Regression Model Constants for Rotatable Central Composite Design.

M	g_1	g_2	g_3	g_4	g_5	g_6	g_7	N	Yadro
2	0,2000	0,1000	0,1260	0,2560	0,1261	0,0197	0,1448	14	TOT 2^2
3	0,1673	0,0578	0,0742	0,1260	0,0625	0,0079	0,0695	31	TOT 2^3
4	0,1438	0,0367	0,0427	0,0635	0,0312	0,0047	0,0360	32	TOT 2^4
5	0,0591	0,0351	0,0427	0,0635	0,0322	0,0038	0,0351	33	TOT 2^5

The significance of the regression coefficients in the model is tested using the Student's t-test as in a full-factorial experiment (FTE).

Due to the non-orthogonality of the xi2 columns in the RCT (Rotate Central Composite Experiment) matrix, all other coefficients must be recalculated after the squared insignificant coefficients are removed from the model.

To obtain a regression model representing a stationary level, RCT is performed on the following matrix, see Table 3.

Table 3. Experimental Design Matrix for Regression Model Construction.

№	x_1	x_2	x_1^2	$x_1 x_2$	x_2^2	Y_n	Y_{Rn}	$(Y_n- Y_{Rn})$
1	-	-	+	+	+	64,60	71,46	48,30
2	+	-	+	-	+	51,30	63,00	141,66
3	-	+	+	-	+	96,90	90,68	36,30
4	+	+	+	+	+	83,30	82,04	1,15
5	-1,410	0	2	0	0	84,50	84,82	0,12
6	+1,410	0	2	0	0	79,50	73,01	44,77

7	0	-1,410	0	0	2	73,60	61,35	152,49
8	0	+1,410	0	0	2	82,50	88,28	35,78
9	0	0	0	0	0	83,78	85,22	2,71
10	0	0	0	0	0	86,30	85,42	1,19
11	0	0	0	0	0	84,80	85,42	0,18
12	0	0	0	0	0	86,50	85,22	1,19
13	0	0	0	0	0	85,30	85,22	0,012

We repeat each experiment 3 times according to this matrix, determine the loop strength and enter it in column 7 of the table above.

The hypothesis of the adequacy of the multivariate regression model is tested using the Fisher criterion. If repeated experiments are carried out only in the center of the experiments, then the calculated value of the Fisher criterion is determined as the ratio of the variance of the inadequacy;

$$F_R = \frac{S^2_{mod}\{Y\}}{S^2_M\{\bar{Y}\}} \qquad (1)$$

Here;

$$S^2_M\{Y\} = \frac{1}{N_M - 1}\sum_{u=1}^{N_M}(Y_{uM} - \bar{Y}_M)^2$$

$$S^2_{nad}\{Y\} = \frac{SS_0\{Y\} - SS_M\{Y\}}{N - N_{k.zi} - (N_m - 1)}$$

$$SS_0\{Y\} = \sum_{u=1}^{N}(Y_{uM} - Y_u)^2$$

$$SS_M\{Y\} = \sum_{u=1}^{NM}(Y_{uM} - \bar{Y}_M)^2$$

If the tests are conducted in all three groups of the matrix with the same repetition, the calculated value of the Fisher criterion is determined as in the full factorial experiment (TOT) [5].

Then the calculated and tabulated values of the criterion are compared. If FR<Fj, the obtained second-order model is considered adequate [6], [7], [8], [9].

In the central composite experiment with a rotatable based on the table, the regression coefficients and their variances are determined using the following formulas;

$$\sum x_{1u}\, Y_u = -64{,}4 + 51{,}3 - 96{,}9 + 83{,}3 - 119{,}524 + 112{,}654 = -33{,}87 \qquad (2)$$

$$\sum x_{2u}\, Y_u - 64{,}4 - 51{,}3 + 96{,}9 + 83{,}0 - 104{,}01 + 116{,}544 = 76{,}74$$

$$\sum x_{1u}\, x_{2u}\, Y_u = 64{,}1 - 51{,}3 - 96{,}9 + 83{,}3 = -0{,}3$$

$$\sum x^2_{1u} Y_u = 64{,}4 + 51{,}3 + 96{,}9 + 83{,}3 + 169{,}1 + 159{,}3 = 624{,}3$$

$$\sum x^2_{2u}\, Y_u = 64{,}4 + 51{,}3 + 96{,}9 + 83{,}3 + 147{,}1 + 164{,}9 = 607{,}9$$

$$\sum Y_u = 64{,}4 + 51{,}3 + 96{,}9 + 83{,}3 + 84{,}5 + 79{,}5 + 73{,}7 + 82{,}2 + 83{,}66 + 86{,}2 + 84{,}8 + 86{,}3 + 85{,}3 = 1043{,}7$$

$$\sum_{u=1}^{Nm} (Y_{uM} - \bar{Y}_M)^2 = 2{,}66 + 1{,}16 + 0{,}16 + 1{,}16 + 0{,}01 = 5{,}31$$

$$\sum_{u=1}^{Nm} (Y_u - \bar{Y}_{Ru})^2 = 48{,}2 + 141{,}61 + 36 + 26 + 1{,}13 + 0{,}1 + 44{,}75 + +152{,}52 + 35{,}74 + 2{,}68 + 1{,}18 + 0{,}17 + 0{,}01 = 465{,}54$$

$$\bar{Y}_{M=83{,}68+86{,}4+84{,}9+86{,}4+85{,}2=85{,}32}$$

Then we determine the regression coefficients:

$$b_0\text{=1042,5-0,1}\cdot (624{,}1 + 607{,}7)\text{=85,32}$$

$$b_1 = 0{,}125 \cdot (-33{,}7) = -4{,}25$$

$$b_2 = 0{,}125 \cdot 76{,}74 = 9{,}59$$

$$b_{12} = 0{,}25 \cdot (-0{,}3) = -0{,}07$$

$$b_{11} = 0{,}125 \cdot 624{,}1 + 0{,}0187 \cdot (624{,}1 + 607{,}7) - 0{,}1 \cdot 1042{,}5 = -3{,}2$$

$$b_{22} = 0{,}125 \cdot 607{,}1 + 0{,}0187 \cdot (624{,}1 + 607{,}7) - 0{,}1 \cdot 1042{,}5 = -5{,}25$$

$$Y_R = 85{,}32 - 4{,}25x_1 + 9{,}59x_2 - 0{,}07x_1x_2 - 3{,}2x_1^2 - 5{,}25x_2^2$$

We calculate the variance of the output parameter using the following formula:

$$S^2\{Y\} = S_M^2\{Y\} = \frac{5{,}21}{5-1} = 1{,}3 \qquad (3)$$

The variances of the regression coefficients are determined using the formula above:

$$S^2\{b_0\} = 0{,}2 \cdot 1{,}3 = 0{,}26 \qquad S^2\{b_0\} = 0{,}51$$

$$S^2\{b_i\} = 0{,}125 \cdot 1{,}3 = 0{,}16 \qquad S^2\{b_i\} = 0{,}4 \qquad (4)$$

$$S^2\{b_{ij}\} = 0{,}25 \cdot 1{,}3 = 0{,}04 \qquad S^2\{b_{ij}\} = 0{,}2$$

$$S^2\{b_{ii}\} = 0{,}1438 \cdot 1{,}3 = 0{,}01 \qquad S^2\{b_{ii}\} = 0{,}08$$

We find the calculated value of the Student's criterion:

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

$$t_R\{b_0\} = \frac{|85{,}32|}{0{,}51} = 167{,}11 \qquad t_R\{b_{12}\} = \frac{|-0{,}07|}{0{,}2} = 0{,}37$$

$$t_R\{b_1\} = \frac{|-4{,}25|}{0{,}4} = 10{,}52 \qquad t_R\{b_{11}\} = \frac{|-3{,}2|}{0{,}08} = \text{`}41{,}83 \qquad (5)$$

$$t_R\{b_2\} = \frac{|9{,}59|}{0{,}4} = 23{,}77 \qquad t_R\{b_{22}\} = \frac{|-5{,}25|}{0{,}08} = 68{,}61$$

t_R We take the tabular value of the criterion from Table 3:

$$t_j[R_D = 0{,}95; \qquad f\{S_M^2\} = 3 - 1 = 2] = 4.303 \qquad (6)$$

As can be seen from the comparisons, all coefficients except b_{12} are significant.

Therefore, there is the following relationship between the twist of a cotton thread and the density of the hair in the hair strand in a pile fabric, the capillary property of the fabric;

$$Y_R = 85{,}32 - 4{,}25x_1 + 9{,}59x_2 - 3{,}2x_1^2 - 5{,}25x_2^2 \qquad (7)$$

We test the hypothesis of the adequacy of the second-order regression multivariate model obtained by RMKT [10]. To do this, we determine the calculated value of the Fisher criterion according to the following formula [11].

$$S^2_{mod}\{Y\} = \frac{465.54 - 5.21}{13 - 5 - (3 - 1)} = 76{,}72 \qquad (8)$$

$$F_R = \frac{S_{mod}^2\{Y\}}{S_M^2\{\bar{Y}\}} = \frac{76{,}72}{5{,}21} = 14{,}72$$

We obtain the tabular value of Fisher's criterion from Appendix 4 under the following conditions;

$$F_J\left[R_D = 0{,}95; f\left\{S_{mod}^2\{Y\}\right\} = 13 - 6 - (3 - 1) = 5; f\{S_M^2\} = 3 - 1 = 2\right] = 19{,}35$$

(9)

Then we compare the calculated and tabulated values of the criterion;

$F_R = 14{,}72 < 19{,}35$

Therefore, the obtained regression model is considered adequate and can be used in future studies [12].

3. Results and Discussion

A regression method was developed using experimental findings to calculate the efficiency of cleaning cotton fibre. The regression formula was primarily used to visually depict the values of the input component at the principal levels, yielding the graph shown [13], [14]. The graph illustrates that cleaning efficiency is represented by the variables (x1) and (x2), with coded values ranging from -1 to 1 (Y1). The (x1) code value varies from 7 mm to 11 mm, corresponding to the -1 code value, which directly influences cleaning efficiency. The optimal values are attained when the cleaning efficiency is between 7 mm and 9 mm, with 9 mm being the most effective. The cleaning efficacy diminishes as the distance exceeds 10 mm, regarded as the crucial threshold. We evaluated the drum rotation speed at 510 and 740 RPM at 20 percent [15]. The cleaning efficiency was immediately influenced by the alteration in factor (x2), which was in turn directly influenced by the modification in the primary circles of 700 and 740. The optimal cleaning efficiency, exceeding 90 percent, was attained throughout the intervals.

4. Conclusion.

The separation component of the device was evaluated using a horizontally bar-grooved grid, a drum with an inclined tip, and a grid including a horizontal bar groove at dimensions of 12 mm, 9 mm, and 6 mm. The dimensions of the components of the fibre cleaning apparatus, designed for spinning from cotton fibre waste, were acquired and empirically evaluated. The experimental results of the cleaning apparatus were verified for correctness by mathematical approaches utilising the Fisher criteria and their concordance with the empirical findings. An inaccuracy of about 5% was identified when juxtaposing the experimental data with the theoretical results. This validates the dependability of the trials performed on the fibre cleaning apparatus.

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