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EVALUATION OF OPTIMAL PARAMETERS IN THE DEVELOPMENT OF DETECTED SEWING AND SEWING DEFECTS

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Abstract
In the proposed sewing and knitting production, when sewing and stitching products made of knitted fabrics to ensure high-quality and durable seams of materials with high elastic properties, the rotation speed of the main shaft of the sewing machine, (min. -1), the pitch of the sewing machine, (mm), the hardness of the seam, defects found in the seam and the role of the jumping needle are of great importance the value as a result of evaluating and applying the optimal one. The parameters of such sewing machines, the possibility of producing cheap and competitive knitted fabrics that can replace imports in our republic simultaneously in the sewing and knitting industries, will be a new step in sewing technologies.

Keywords: Regression equation, physical and mathematical model, Fisher criterion, needles, sewing machine, finished fabric.

Introduction

A mathematical model of a technological process (regression equation) is a relationship between the values of mathematical expectations of one process value and other values of the value.

It is known that the analytical expression of the function is expressed in the form of a regression equation for the connection of polynomials with an unknown variable and is written in the following form.

$$y = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \sum_{i<1}^{k} b_{ij} x_i x_j + \sum_{i<j<l} b_{ijl} x_i x_j x_l \qquad (1)$$

here,

Y is the calculated value of the optimization (alternative) parameter;

x_i - independent input parameters that change during the experiment;

$b_0, b_i, b_{ij}, b_{ijkb}$ - regression coefficients determined by the results of the experiment.

To construct a mathematical model in the form of an equation, the optimization (alternative) criterion "u" is selected; the independent variable x_i-factor is selected;

$b_0, b_i, b_{ij}, b_{ijkb}$ regression coefficients are determined, as a result, the type of plan function is determined.

It is enough to encode the factors, move the origin to the point of the main factor level of the factors (the central point of the experiment) and change the scale.

All coded coefficients are dimensionless and normalized values and take intermediate values during the experiment -1,414 -1, 0, +1 +1,414.

Such values are called factor levels. The coefficients of the estimated polynomial independent variables show the degree of influence of factors. If the coefficient is positive, then the output coefficient increases as the coefficient increases, and when the coefficient increases with a negative coefficient, its value decreases.

Regression coefficients show how much the size changes when the size is affected by a change in size [1..7].

Table 1 Experimental design and results

№	Number of components		The results of the experiment	
	X_1	X_2	seam hardness (Y_1)	seam defects, (Y_2)
1	-1	-1	**3,00**	**7,00**
2	1	-1	**7,00**	**5,00**
3	-1	1	**5,00**	**4,00**
4	1	1	**6,00**	**8,00**
5	-1,414	0	**1,00**	**1,00**
6	1,414	0	**7,00**	**7,50**
7	0	-1,414	**1,00**	**2,00**
8	0	1,414	**7,00**	**9,00**
9	0	0	**5,00**	**7,00**
10	0	0	**6,50**	**8**
11	0	0	**8,00**	**6**
12	0	0	**6,00**	**6,9**
13	0	0	**7,00**	**5**

Estimation of the parameters of the regression equation

The coefficients of the regression equation are calculated using the least squares method of mathematical statistics, software Mathcad, Excel, Matlab and Maple and expressed by the following mathematical models.

$$y = b_0 + \sum_{i=1}^{N} b_i x_i + \sum_{ii=1}^{N} b_{ii} x_i^2 + \sum_{ij=1}^{N} b_{ij} x_i x_j \qquad (2)$$

in which:

b_0, b_i, b_{ij} – parametric coefficients of the regression equation;

N – number of experiments; x_i, x_j — factors.

The parametric coefficients of the regression equation were determined using the following mathematical equations:

$$b_0 = g_1 \sum_{i=1}^{N} \bar{y}_u - g_2 \sum_{i=1}^{M} \times \sum_{i=1}^{N} x_{iu}^2 \bar{y}_u \quad b_i = q_3 \sum_{i=1}^{N} x_{iu} \cdot \bar{y}_{iu}$$

$$b_{ij} = q_4 \sum_{ij=1}^{N} x_{iu} \cdot x_{ju} \cdot \bar{y}_u \quad b_{ii} = q_4 \sum_{i=1}^{N} x_i^2 \cdot \bar{y}_i - q_1 \sum_{i=1}^{N} y_i \qquad (4)$$

We repeat each experiment 3 times according to the matrix of table (2), determine the hardness of the seam and the defects occurring in the seam and add them to the corresponding graph of the tables [1..7].

The hypothesis of the adequacy of the multifactorial regression model of the second order is checked using the Fisher criterion. If repeated experiments were carried out only in the experiment center, then the value of the Fisher criterion is equal to the ratio of the variance of inadequacy:

$$F_R = \frac{S_{mod}^2 \{Y\}}{S_M^2 \{\bar{Y}\}} \qquad (5)$$

here:

$$S_M^2 \{Y\} = \frac{1}{N_{M-1}} \sum_{u=1}^{N_M} (Y_{uM} - \bar{Y}_M)^2, \; S_{nod}^2 \{Y\} = \frac{SS_0\{Y\} - SS_M\{Y\}}{N - N_{kzi} - (N_m - 1)}$$

$$SS_0\{Y\} = \sum_{u=1}^{N} (Y_{uM} - Y_u)^2, \qquad SS_M\{Y\} = \sum_{u=1}^{NM} (Y_{uM} - \bar{Y}_u)^2 \qquad (6)$$

If all three groups of the matrix were tested with the same repeatability, then the calculated value of the Fisher criterion is determined in the same way as in the full-factor experiment. Then the calculated and tabular values of the criterion are compared. If $F_R<F_j$, the resulting second-order model is considered adequate.

Using the above formulas, based on the tables, we will determine the initial values for finding the regression coefficients of hardness along the seam and defects along the seam:

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Table 2 Summary table of experimental results on the rotation speed of the main shaft of the sewing machine and the pitch of the sewing thread.

№	X_1	X_2	X_1^2	$X_1 X_2$	X_2^2	Y_{n1}	Y_{Rn1}	Y_{n2}	Y_{Rn2}	$(Y_{n1}- Y_{Rn1})^2$	$(Y_{n2}- Y_{Rn2})$
1	-1	-1	1	1	1	3,00	1,00	7,00	4,29	4,014	7,330
2	1	-1	1	-1	1	7,00	5,87	5,00	4,09	1,282	0,827
3	-1	1	1	-1	1	5,00	4,87	4,00	3,77	0,018	0,054
4	1	1	1	1	1	6,00	6,74	8,00	9,56	0,546	2,449
5	-1,414	0	2	0	0	1,00	2,23	1,00	2,83	1,524	3,334
6	1,414	0	2	0	0	7,00	7,00	7,50	6,78	0,000	0,516
7	0	-1,414	0	0	2	1,00	2,94	2,00	4,30	3,769	5,310
8	0	1,414	0	0	2	7,00	6,29	9,00	7,80	0,499	1,432
9	0	0	0	0	0	5,00	6,50	7,00	6,58	2,250	0,176
10	0	0	0	0	0	6,50	6,50	8	6,58	0,000	2,016
11	0	0	0	0	0	8,00	6,50	6	6,58	2,250	0,336
12	0	0	0	0	0	6,00	6,50	6,9	6,58	0,250	0,102
13	0	0	0	0	0	7,00	6,50	5	6,58	0,250	2,496
∑ Total amount						6,5		6,58		16,650	26,380
The central arithmetic mean							6,50		6,58		

RESULTS AND ANALYSIS

$\sum X_{1u}Y_u = 13,48$, $\sum X_{2u}Y_u = 9,48$, $\sum X_{1u}X_{2u}Y_u = -3$, $\sum X_{1u}^2 Y_u = 37$, $\sum X_{2u}^2 Y_u = 37$

$\sum Y_u = 69,5$, $\sum Y_m = 6.5$, $\sum_{u=1}^{Nm}(Y_{uM} - \overline{Y}_M) = 5$, $\sum_{u=1}^{Nm}(Y_u - \overline{Y}_{Ru})^2 = 16.650$ $\overline{Y}_M = 6.5$

$$b_0 = g_1 \sum_{i=1}^{N} \bar{y}_u - g_2 \sum_{i=1}^{M} \sum_{i=1}^{N} x_{iy}^2 \overline{y}_u = 6.50, \quad b_1 = q_3 \sum_{i=1}^{N} x_i \cdot \bar{y}_i = 1.69, \quad b_2 = q_3 \sum_{ij=1}^{N} x_{2u} \cdot Y_{2u} = 1.19$$

$$b_{12} = q_4 \sum_{ij=1}^{N} x_{1u} \cdot x_{2u} \cdot Y_u = -0,75, \quad b_{11} = g_3 \sum_{ij=1}^{N} x_{1u}{}^2 Y_u + g_6 \cdot (\sum_{ij=1}^{N} x_{1u}{}^2 \cdot Y_{1u} + \sum_{ij}^{N} x_{2u}{}^2 \cdot Y_{2u}) + g_2 \cdot \sum_{ij}^{N} Y_u = -0.94$$

$$b_{22} = g_3 \sum_{ij=1}^{N} x_{2u}{}^2 Y_u + g_6 \cdot (\sum_{ij=1}^{N} x_{1u}{}^2 \cdot Y_{1u} + \sum_{ij}^{N} x_{2u}{}^2 \cdot Y_{2u}) + g_2 \cdot \sum_{ij}^{N} Y_u = -0.941$$

Regression coefficient and the equation of seam hardness:

$b_0 = 6.50$ $b_1 = 1.69$ $b_2 = 1.19$ $b_{12} = -0.75$ $b_1^2 = -0.94$ $b_2^2 = -0.941$

$$Y_{1R} = 6.50 + 1.69 \cdot x_1 + 1.19 \cdot x_2 - 0,75 \cdot x_1 \cdot x_2 - 0.94 \cdot x_1^2 - 0.941 \cdot x_2^2$$

Let's determine the regression coefficients of defects in the seam:

$\sum X_{1v}Y_v = 11.191$, $\sum X_{2v}Y_v = 9.898$, $\sum X_{1u}X_{2u}Y_u = 6$, $\sum X_{1u}^2 Y_u = 41$, $\sum X_{2u}^2 Y_u = 46$

$\sum Y_u = 76.4$, $\sum Y_m = 6.58$, $\sum_{u=1}^{Nm}(Y_{uM} - \overline{Y}_M) = 0.07$, $\sum_{u=1}^{Nm}(Y_u - \overline{Y}_{Ru})^2 = 26.38$, $\overline{Y}_M = 6.58$

$$b_0 = g_1 \sum_{i=1}^{N} \bar{y}_u - g_2 \sum_{i=1}^{M} \sum_{i=1}^{N} x_{iy}^2 \overline{y}_u = 6.58, \quad b_1 = q_3 \sum_{i=1}^{N} x_i \cdot \bar{y}_i = 1.40, \quad b_2 = q_3 \sum_{ij=1}^{N} x_{2u} \cdot Y_{2u} = 1.24$$

$$b_{12} = q_4 \sum_{ij=1}^{N} x_{1u} \cdot x_{2u} \cdot Y_u = 1.50 \quad b_{11} = g_3 \sum_{ij=1}^{N} x_{1u}{}^2 Y_u + g_6 \cdot (\sum_{ij=1}^{N} x_{1u}{}^2 \cdot Y_{1u} + \sum_{ij}^{N} x_{2u}{}^2 \cdot Y_{2u}) + g_2 \cdot \sum_{ij}^{N} Y_u = -0.89$$

$$b_{22} = g_3 \sum_{ij=1}^{N} x_{2u}{}^2 Y_u + g_6 \cdot (\sum_{ij=1}^{N} x_{1u}{}^2 \cdot Y_{1u} + \sum_{ij}^{N} x_{2u}{}^2 \cdot Y_{2u}) + g_2 \cdot \sum_{ij}^{N} Y_u = -0.26$$

Regression coefficient and the equation of seam hardness:

$b_0 = 6.50 \quad b_1 = 1.69 \quad b_2 = 1.19 \quad b_{12} = -0.75 \quad b_1^2 = -0.94 \quad b_2^2 = -0.941$

$$Y_{1R} = 6.50 + 1.69 \cdot x_1 + 1.19 \cdot x_2 - 0,75 \cdot x_1 \cdot x_2 - 0.94 \cdot x_1^2 - 0.941 \cdot x_2^2$$

Also, the regression equation in the mathematical model of defects occurring in the seam has the following form.

$b_0 = 6.58 \quad b_1 = 1.40 \quad b_2 = 1.24 \quad b_{12} = -1.50 \quad b_1^2 = -0.89 \quad b_2^2 = -0.26$

$$Y_{2R} = 6.58 + 1.40 \cdot x_1 + 1.24 \cdot x_2 + 1.50 \cdot x_1 \cdot x_2 - 0.89 \cdot x_1^2 - 0.26 \cdot x_2^2$$

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

$$S^2\{Y\} = S_M^2\{Y\} = \frac{\sum_{u=1}^{Nm}(Y_{uM} - \bar{Y}_M)}{n-1} = \frac{5}{4} = 1.25, \quad S^2\{Y\} = S_{vM}^2\{Y\} = \frac{\sum_{v=1}^{Nm}(Y_{uv} - \bar{Y}_M)}{n-1} = \frac{5,128}{4} = 1,282$$

According to the formula $S^2\{b_0\} = g_1 S^2\{\bar{Y}\}$, $S^2\{b_i\} = g_3 S^2\{\bar{Y}\}$, $S^2\{b_{ij}\} = g_4 S^2\{\bar{Y}\}$, $S^2\{b_{ii}\} = g_7 S^2\{\bar{Y}\}$ the variance of the regression coefficients for the hardness of the seam is determined:

Values of the dispersion of the seam hardness

$s^2\{b_0\} = 0.25 \quad s\{b_0\} = \sqrt{0.25} = 0.5, \quad s^2\{b_1\} = 0.15625 \quad s\{b_1\} = 0.4$

$s^2\{b_2\} = 0.0915 \quad s\{b_2\} = 0.40, s^2\{b_{11}\} = 0.17975 \quad s\{b_{11}\} = 0,42, s^2\{b_{12}\} = 0.3125$

$s\{b_{12}\} = 0,55$

The values of the dispersion of defects occurring in the seam:

$S^2\{b_{0v}\} = 0,2 \cdot 1,282 = 0,3205 \qquad S\{b_{0v}\} = \sqrt{0,2 \cdot 1,282} = \sqrt{0,3205} = 0,5661$

$S^2\{b_{1v}\} = 0,125 \cdot 1,282 = 0,16025 \qquad S\{b_{1v}\} = \sqrt{0,125 \cdot 1,282} = \sqrt{0,16025} = 0,40$

$S^2\{b_{12v}\} = 0,25 \cdot 0,16025 = 0,040063 \quad S\{b_{12v}\} = \sqrt{0,25 \cdot 0,16025} = 0,200157$

$S^2\{b_{11v}\} = 0,1438 \cdot 0,040063 = 0,0058$

$$S\{b_{11v}\} = \sqrt{0,1438 \cdot 0,040063} = \sqrt{0,0058} = 0,076$$

Let's determine the value of the Student's criterion: $t_R = \frac{|b_i|}{s\{b_i\}}$

We determine the hardness of the seam:

$t_R\{b_0\} = \frac{|b_0|}{s\{b_0\}} = \frac{6.50}{0.5} = 13 \qquad t_R\{b_{12}\} = \frac{|b_{12}|}{s\{b_{12}\}} = \frac{|-0.75|}{0.55} = 1,363636$

$t_R\{b_1\} = \frac{|b_1|}{s\{b_1\}} = \frac{|1.69|}{0.395285} = 4,225 \qquad t_R\{b_{11}\} = \frac{|b_1|}{s\{b_{11}\}} = \frac{|1,69|}{0.42} = 4,02381$

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$$t_R\{b_2\} = \frac{|b_2|}{s\{b_2\}} = \frac{|1,19|}{0.40} = 2,98 \qquad t_R\{b_{22}\} = \frac{|b_{22}|}{s\{b_2\}} = \frac{|-0,941|}{0.40} = 2,3525$$

Values determined by seam defects:

$$:t_R\{b_{0v}\} = \frac{|b_{0v}|}{S\{b_{0v}\}} = \frac{|6,58|}{0,5661} = 11,62339 \qquad t_R\{b_{12v}\} = \frac{|b_{12v}|}{S\{b_{12v}\}} = \frac{|-1,50|}{0,200157} = 74,94$$

$$t_R\{b_{1v}\} = \frac{|b_{1v}|}{S\{b_{1v}\}} = \frac{|1,40|}{0,40} = 3,5 \qquad t_R\{b_{11v}\} = \frac{|b_{11v}|}{S\{b_{11}\}} = \frac{|-0,89|}{0,0058} = 153,4483$$

$$t_R\{b_{2v}\} = \frac{|b_{2v}|}{S\{b_2\}} = \frac{|1,24|}{0,40} = 3,1 \qquad t_R\{b_{22v}\} = \frac{|b_{22v}|}{S\{b_2\}} = \frac{|1,14|}{0,0198} = 57,77$$

The tabular value of the t_R criterion is obtained from [8,465-467.pp] Appendix 7:

$$t_j\left[P_d = 0.95;\ f\left\{S_M^2\right\} = 3-1 = 2\right] = 4.303$$

It can be seen from the comparisons that all the coefficients of the regression coefficients on the seam hardness are significant.So, there is the following relationship between the hardness of the weld and the defects of the weld:

$$Y_{1R} = 6.50 + 1.69\cdot x_1 + 1.19\cdot x_2 - 0,75\cdot x_1\cdot x_2 - 0.94\cdot x_1^2 - 0.941\cdot x_2^2$$

$$Y_{2R} = 6.58 + 1.40\cdot x_1 + 1.24\cdot x_2 + 1.50\cdot x_1\cdot x_2 - 0.89\cdot x_1^2 - 0.26\cdot x_2^2$$

We are testing the hypothesis of the adequacy of the second-order multivariate regression model obtained in the central Rotatabelli composite experiment. To do this, we determine the calculated value of the Fisher criterion using the formula (4).

$$S_{\text{mod}}^2\{Y\} = \frac{\sum_{u=1}^{Nm}(Y_u - \bar{Y}_{Ru})^2 - \sum_{u=1}^{Nm}(Y_{uM} - \bar{Y}_M)^2}{13-5-(3-1)} = \frac{16.650-5}{6} = 1.942$$

$$F_R = \frac{S_{\text{mod}}^2\{Y_u\}}{S_{Mu}^2\{\bar{Y}_u\}} = \frac{1.942}{0,5} = 3.8833$$

$$S_{\text{mod}}^2\{Y_v\} = \frac{\sum_{v=1}^{Nm}(Y_v - \bar{Y}_{Rv})^2 - \sum_{v=1}^{Nm}(Y_{vM} - \bar{Y}_M)^2}{13-5-(3-1)} = \frac{26.380-6.58}{6} = 3.300$$

$$F_{Rv} = \frac{S_{\text{mod}}^2\{Y_v\}}{S_{Mv}^2\{\bar{Y}_v\}} = \frac{3.300}{1.282} = 2.574042$$

The tabular value of the Fisher criterion is obtained from Appendix 4 under the following conditions:

$$F_j = \left[P_D = 0.95;\ f\left\{S_{\text{mod}}^2\{Y\}\right\} = 13-5-(3-1) = 6;\ f\left\{S_M^2\right\} = 3-1 = 19.35\right]$$

We compare the calculated value of the Fisher criterion and the tabular values:

F_{Ru}=3.8833<19,35, F_{2Rv}=2.574<19,35

Based on the results of the comparison, the obtained regression model is adequate and can be used in further studies.

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Based on the experimental results obtained on the main indicators of seam hardness and defects occurring in the weld, graphs were constructed showing the relationship of the main indicators. Below are the graphs illustrated using the Matlab software.

Based on the regression coefficient and the seam hardness equation, we can see the graph drawing in Figure 2.9 using the Matlab program:

$$Y_{1R} = 6.50 + 1.69 \cdot x_1 + 1.19 \cdot x_2 - 0,75 \cdot x_1 \cdot x_2 - 0.94 \cdot x_1^2 - 0.941 \cdot x_2^2$$

Matlab Support Program

```
[x1,x2]=meshgrid (-1:0.1:1, -1:0.1:1);
Y1R=6.50+1.69*x1+1.19*x2 -0.75*x1.*x2-0.941*x2^2;
Contour (x1,x2,Y1R,'ShowText','on')
```

We will also consider the regression coefficient and the equation of defects found in the seam using the Matlab program:

$$Y_{2R} = 6.58 + 1.40 \cdot x_1 + 1.24 \cdot x_2 + 1.50 \cdot x_1 \cdot x_2 - 0.89 \cdot x_1^2 - 0.26 \cdot x_2^2$$

Matlab Support Program

```
[x1,x2]=meshgrid (-1:0.1:1, -1:0.1:1);
Y2R=6.58+1.40*x1+1.24*x2+1.50*x1.*x2-0.89*x1^2-0.23*x2^2;
contour (x1,x2,Y1R,'ShowText','on')
```

Graphs of the regression coefficient and equations of weld hardness and weld defects are shown below (see Figures 1-2.).

Conclusion

In Figure 1. As can be seen from the graph, the rotation speed of the main shaft of the input sewing machine, min-1 (X1) and the pitch of the sewing machine, mm, (X2) coefficients have changed from the accepted minimum (-1) value to the permissible one. the maximum (1) value. When switching and using the average value of the coefficients (Y1), the values of the change in the hardness of the weld are described. Using the diagram, X1 is the rotation speed of the main shaft of the sewing machine (0÷1) in encoded values in the range (3000; 4500 min -1) and X2 is the step of the sewing machine in encoded values in the range -0.4÷0.6 (4; 8 mm), the hardness of the seam is of the greatest importance.

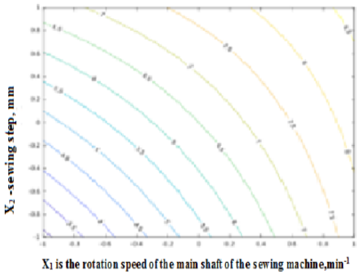

Figure 1. Graph of the relationship of the seam hardness (R_1) with the rotation speed of the main shaft of the sewing machine (X_1) and the pitch of the sewing machine,mm (X_2)

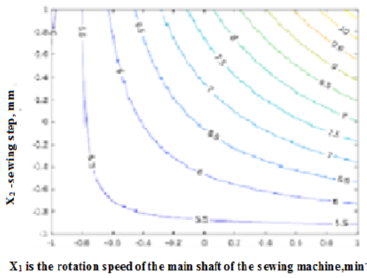

Figure 2. Graph of the dependence of seam defects (Y_{2R}) on the spindle speed of the sewing machine, min^{-1} (X_1) and the pitch of the sewing thread, mm (X_2).

In Figure 2. From the graph of the dependence of defects occurring in the seam, it can be seen that the rotation speed of the main shaft of the sewing machine (X_1) and the pitch of the sewing machine in mm, (X_2) from the accepted minimum value (-1) to the maximum value (1) when changing and using the average value of the coefficients (Y_2) Weld defects, the values are described. Using the diagram, X_1 is the rotation speed of the main shaft of the sewing machine (-1÷1) in coded values in the range (1500; 4500 min $^{-1}$) and X_2 is the pitch of the sewing machine, and in coded values in the range -0.8÷-0.2 (5.5;7 mm)). The rotation speed of the main shaft of the sewing machine, min-1, had the highest value in the range 0-1 on the X_1 axis and 0-1 on the X_2 axis. Consequently, the rotation speed of the main shaft of the sewing machine (3000; 4500 min^{-1}) increases as a result of increasing the seam pitch. by 0.5 mm . When the rotation speed of the main shaft of the sewing machine changes to (1500; 4500), it is found that the pitch of the sewing machine also changes with an interval of 0.5 mm. It is determined that the sewing machine can be normalized and manufactured at a rotational speed of the main shaft of the sewing machine 3000 min^{-1}.

It is possible to determine that the quality of the sewn product is high at the rotation speed of the main shaft of the sewing machine 3000 rpm.

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