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ANALYSIS OF THE RESULTS OF FULL-FACTOR EXPERIMENTS OF THE MODERNIZED SEWING MACHINE WITH THE RECOMMENDED THREAD TENSIONER WITH TWO ELASTIC ELEMENTS

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Abstract. The paper presents the results of full-factor experiments to optimize the parameters of an upgraded sewing machine with the recommended thread tensioners with two elastic elements. Optimal parameters of the system for sewing “Denim”, “Djin” and “Stretch” are determined. Ways of increasing productivity of a sewing machine have been substantiated.

Key words. Sewing machine, stitching materials, platter, shock absorber, elastic element, main shaft, speed, rigidity, tension, needle, shuttle, full-factor, parameter, optimization.

Experiment design. We have chosen the following parameters to compose the matrix of experiments [1]. Input parameters selected: the main shaft speed X_1, with a variation interval of 500 rpm machine, the stiffness of the rubber shock absorbing sleeve, X_2 0.50-104 n/m and the tension of the needle thread, X_3 - 100cN. The output parameter is the breaking force U.

Also, to compare the values, the experiments were conducted under the same conditions for the fabrics: denim material with a density of 14.5 oz/sq yd; gin denim material with a density of 12.0 oz/sq yd; stretch denim material with a density of 8.0 oz/sq yd;

Accordingly, for these materials, regression equations need to be formulated. Based on this, a planning matrix was prepared and is presented in Table 1.

Table 1.

Values of input factors in planning the experiment

Name of factor, dimensions	code designations	True values of the factor			Range of variation of the factor
		-1	0	+1	
Main shaft speed r/min.	X_1	4000	4500	5000	500
Rubber shock absorber stiffness, 104n/m	X_2	1,5	2,0	2,5	0,50
Needle thread tension, Sn	X_3	100	200	300	100

The true values of the factors were coded using the formula [2]:

X_1=(n-4500)/500; X_2=(E-1,50)/0,50; X_3=(T- 200)/100;

Here T is the thread tension , E is the stiffness of the rubber shock absorber, n is the number of revolutions per minute of the main shaft of the sewing machine.

Matrix for the full-factor experiment. The matrix for the full-factor experiment is shown in Table 2.

Table 2.

Matrix of planning, experiments

№ experiences	X_0	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3	$X_1 X_2 X_3$
1	+	-	-	-	+	+	+	-
2	+	+	-	-	-	-	+	+
3	+	-	+	-	-	+	-	+
4	+	+	+	-	+	-	-	-

5	+	-	-	+	+	-	-	+
6	+	+	-	+	-	+	-	-
7	+	-	+	+	-	-	+	-
8	+	+	+	+	+	+	+	+

Tables 3, 4 and 5 present the results of the conducted studies when using high, medium and low density denim as the materials to be sewn. The tables present the results of the experiments taking into account the variation of the values of the input factors.

Table 3.

The results of the research conducted on ginsy (high density) material.

№	X_1	X_2	X_3	$У_1$	$У_2$	$У_3$	$У_4$	$У_5$	$У_{mid}$.	S^2[У]
1	-	-	-	134,2	130,5	129,2	134,7	132,1	132,14	5,52
2	+	-	-	136,2	132,4	135,2	131,2	130,3	133,06	6,41
3	-	+	-	145,2	144,03	145,2	148,2	150,86	146,75	7,83
4	+	+	-	148,2	132,2	137,3	138,1	139,5	139,06	33,68
5	-	-	+	143,4	132,06	132,1	133,3	141,3	138,8	37,00
6	+	-	+	137,3	138,5	131,0	140,5	146,1	138,7	29,8
7	-	+	+	144,2	131,3	140,2	139,0	142,1	139,3	24,21
8	+	+	+	142,1	135,4	147,3	140,1	150,06	142,9	33,66
In general									1132,36	178,11
								middle	141,545	22,26

Table 4

Results of the conducted studies on ginsi material (with medium density).

№	X_1	X_2	X_3	$У_1$	$У_2$	$У_3$	$У_4$	$У_5$	Уср.	S^2[У]
1	-	-	-	95,1	93,2	88,3	96,9	98,9	94,48	65,59
2	+	-	-	90,2	95,86	93,2	91,2	98,3	93,7	44,57
3	-	+	-	92,2	97,03	90,2	91,2	90,86	92,29	30,04
4	+	+	-	87,2	97,2	88,3	95,1	91,5	91,86	73,5
5	-	-	+	89,4	97,06	91,1	90,3	90,4	91,65	38,00
6	+	-	+	93,3	95,5	92,0	90,5	95,1	93,28	28,17
7	-	+	+	90,2	97,3	90,2	89,0	90,1	91,36	45,1
8	+	+	+	94,1	90,4	92,3	88,1	98,06	92,59	57,19
In general									741,21	382,16
								middle	92,651	47,77

Table 5

Results of the conducted research on ginsi material (low density).

№	X_1	X_2	X_3	$У_1$	$У_2$	$У_3$	$У_4$	$У_5$	Уср.	S^2[У]
1	-	-	-	85,1	83,2	84,3	85,9	86,9	85,08	2,02
2	+	-	-	84,2	85,86	86,2	81,2	88,3	85,15	7,005
3	-	+	-	83,2	87,03	89,2	81,2	83,86	84,89	10,165
4	+	+	-	80,2	87,2	88,3	85,1	81,5	84,46	12,38
5	-	-	+	79,4	87,06	80,1	80,3	82,4	83,5	13,1
6	+	-	+	82,3	89,5	79,0	80,5	91,1	85,42	31,01
7	-	+	+	86,2	85,3	86,2	79,0	90,1	85,36	16,07

8	+	+	+	83,1	83,4	86,3	78,1	88,06	83,79	14,36
In general									677,83	106,11
								middle	84,728	13,26

Table 6

Experimental results

№	X_1	X_2	X_3	У Breaking force N. average of 5 repetitions.			Shaft speed. rpm.	Spring stiffness, 104 n/m	Needle thread tension, cn
				Denim	Streych	Djin	Code. X_1	Code.X_2	Code.X_3
1	-	-	-	132,14	94,48	85,08	4000	1,00	100
2	+	-	-	133,06	93,7	85,15	5000	1,00	100
3	-	+	-	146,75	92,29	84,49	4000	2,00	100
4	+	+	-	139,06	91,86	84,46	5000	2,00	100
5	-	-	+	138,8	91,65	83,5	4000	1,00	300
6	+	-	+	138,7	93,65	85,42	5000	1,00	300
7	-	+	+	139,3	91,36	85,36	4000	2,00	300
8	+	+	+	142,9	92,59	83,79	5000	2,00	300

The obtained values of the output factor are checked by criteria. In this case, according to [3], we determine the dispersion by the following formula

$$S^2[\bar{y}] = \frac{\sum_{1}^{8} y_u}{m-1} \quad (1)$$

m- number of experiments conducted under the same conditions.

The values are summarized in Tables 3, 4, and 5.

We calculate the Cochran criterion [7,8] using the formula:

$G_x = S^2[\text{У}] / \sum_{i-1}^{x} S_i^2(Y) = 37/178{,}11 = 0{,}207$; (Denim material with a density of 14.5 oz/sq yd); 73,5/382,16=0,1923; (12.0 oz/sq yd "Djin" denim material); 31,01/106,11=0,2922; (8.0 oz/sq yd stretch denim material).

For probability q=0.01 we choose the Cochran coefficient from the table T= 0,95, for N=8, m= 5, then $G_{\text{таб.}}$= 0.603 [9]. So in our case the dispersion is homogeneous, according to the data in Table 3.6 we calculate the regression coefficients and subtract the mean values.

$У_1$=141,54 (Denim denim material with a density of 14.5 oz/sq yd);

$У_2$=92,65 (12.0 oz/sq yd "Djin" denim material);

$У_3$=84,72 (8.0 oz/sq yd stretch denim material).

Determination of regression coefficients. We make calculations of regression coefficients at material denim with a density of 14.5 ounces/square yard [4]:

$$У = \frac{\sum_{1}^{8} y_u}{8} = 141{,}54 \qquad (2)$$

$$Б_1 = \frac{\sum_{1}^{8} X_1 y_u}{8} = (-132{,}14 + 133{,}06 - 146{,}75 + 139{,}06 - 138{,}8 + 138{,}7 - 139{,}3 + 142{,}9) = -0{,}7837,$$

$$Б_2 = \frac{\sum_{1}^{8} X_2 y_u}{8} = (-132{,}14 - 133{,}06 + 146{,}7 + 139{,}06 - 138{,}8 - 138{,}7 + 139{,}3 + 142{,}9) = 3{,}538,$$

$$Б_3 = \frac{\sum_{1}^{8} X_3 y_u}{8} = (-132{,}14 - 133{,}06 - 146{,}07 - 139{,}06 + 138{,}8 + 138{,}7 + 139{,}3 + 142{,}9 = 1{,}5462$$

$$Б_4 = \frac{\sum_{1}^{8} X_1 X_2 y_u}{8} = (132{,}14 - 133{,}06 - 146{,}07 + 139{,}06 + 138{,}8 - 138{,}7 - 139{,}3 + 142{,}9) = -0{,}528$$

$$Б_5=\frac{\sum_{1}^{8} X_1X_3У_u}{8}=(132{,}14-133{,}06+146{,}07-139{,}06-138{,}8+138{,}7-139{,}3+142{,}9)=-0{,}04$$

$$Б_6=\frac{\sum_{1}^{8} X_2X_3У_u}{8}=(+132{,}14+133{,}06-146{,}07-139{,}06-138{,}8-138{,}7+139{,}3+142{,}9)=-1{,}903$$

$$Б_7=\frac{\sum_{1}^{8} X_1X_2X_3У_u}{8}=(-132{,}14+133{,}06+146{,}07-139{,}06+138{,}8-138{,}7-139{,}3+142{,}9)=1{,}453$$

We calculate the regression coefficients when the material is “Jean” denim with a density of 12.0 ounces/square yard.

$$У=\frac{\sum_{1}^{8} У_u}{8}=92{,}65 \qquad (3)$$

$$Б_1=\frac{\sum_{1}^{8} X_1У_u}{8}=(-94{,}48+93{,}7-92{,}29+91{,}86-91{,}65+93{,}65-91{,}36+92{,}59)=0{,}2525,$$

$$Б_2=\frac{\sum_{1}^{8} X_2У_u}{8}=(-94{,}48-93{,}7+92{,}29+91{,}86-91{,}65-93{,}65+91{,}36+92{,}59)=-0{,}6725,$$

$$Б_3=\frac{\sum_{1}^{8} X_3У_u}{8}=(-94{,}48-93{,}7-92{,}29-91{,}86+91{,}65+93{,}65+91{,}36+92{,}59=-0{,}385$$

$$Б_4=\frac{\sum_{1}^{8} X_1X_2У_u}{8}=(94{,}48-93{,}7-92{,}29+91{,}86+91{,}65-93{,}65-91{,}36+92{,}59)=-0{,}0525$$

$$Б_5=\frac{\sum_{1}^{8} X_1X_3У_u}{8}=(94{,}48-93{,}7+92{,}29-91{,}86-91{,}65+93{,}65-91{,}36+92{,}59)=0{,}555$$

$$Б_6=\frac{\sum_{1}^{8} X_2X_3У_u}{8}=(94{,}48+93{,}7-92{,}29-91{,}86-91{,}65-93{,}65+91{,}36+92{,}59)=0{,}370$$

$$Б_7=\frac{\sum_{1}^{8} X_1X_2X_3У_u}{8}=(-94{,}48+93{,}7+92{,}29-91{,}86+91{,}65-93{,}65-91{,}36+92{,}29)=-0{,}1775$$

We calculate the regression coefficients when the material is stretch denim with a density of 8.0 ounces/square yard

$$У=\frac{\sum_{1}^{8} У_u}{8}=84{,}72 \qquad (4)$$

$$Б_1 = \frac{\sum_1^8 X_1 У_u}{8} = (-85{,}08 + 85{,}15 - 84{,}49 + 84{,}46 - 83{,}5 + 85{,}42 - 85{,}36 + 83{,}79) = 0{,}048,$$

$$Б_2 = \frac{\sum_1^8 X_2 У_u}{8} = (-85{,}08 - 85{,}15 + 84{,}49 + 84{,}46 - 83{,}5 - 85{,}42 + 85{,}36 + 83{,}79) = -0{,}131,$$

$$Б_3 = \frac{\sum_1^8 X_3 У_u}{8} = (-85{,}08 - 85{,}15 - 84{,}49 - 84{,}46 + 83{,}5 + 85{,}42 + 85{,}36 + 83{,}79 = -0{,}138$$

$$Б_4 = \frac{\sum_1^8 X_1 X_2 У_u}{8} = (85{,}08 - 85{,}15 - 84{,}49 + 84{,}46 + 83{,}5 - 85{,}42 - 85{,}36 + 83{,}79) = -0{,}448$$

$$Б_5 = \frac{\sum_1^8 X_1 X_3 У_u}{8} = (85{,}08 - 85{,}15 + 84{,}49 - 84{,}46 - 83{,}5 + 85{,}42 - 85{,}36 + 83{,}79) = 0{,}038$$

$$Б_6 = \frac{\sum_1^8 X_2 X_3 У_u}{8} = (85{,}08 + 85{,}15 - 84{,}49 - 84{,}46 - 83{,}5 - 85{,}42 + 85{,}36 + 83{,}79) = 0{,}188$$

$$Б_7 = \frac{\sum_1^8 X_1 X_2 X_3 У_u}{8} = (-85{,}08 + 85{,}15 + 84{,}49 - 84{,}46 + 83{,}5 - 85{,}42 - 85{,}36 + 83{,}79) = -0{,}423$$

The average U value of stitch breaking strength for each type of material is given in Table 7.

Table 7.

Average Y (breaking strength) values

“Denim” jeans with a lot of density.	“Stretch” jeans with a mid-rise fit.	“Jean” jeans with a low rise fit
Б= - 0,78	Б=0,25 X_1	Б= 0,048
Б= 3,53	Б=-0,67 X_2	Б= -0,131
Б= 1,54	Б=-0,38 X_3	Б= -0,138
Б=-0,52	Б=-0,05 X_1X_2	Б= -0,448
Б=-0,04	Б=0,5 X_1X3	Б= 0,038
Б=-1,9	Б=0,37 X_2X_3	Б= 0,188
Б=1,45	Б=-0,17 $X_1X_2X_3$	Б= -0,423
У=141,54.	У=92,6ср.	У=84,72 ср.

Regression equations and their adequacy. From the results obtained, we obtain the regression model. Regression equation for fabric Jeans with high density:

$У=141,5-0,78X_1 +3,53X_2 +1,54 X_3-0,52X1X2-0,04X_1X_3-1,9X_2X_3+1,45X_1X_2X_3$ (5)

Regression equation for a fabric with medium density:

$У= 92,6 -0,25X_1+0,67X2-0,38X_3-0,05X_1X_2 +0,5X_1X_3+0,37X_2X_3-0,17X_1X_2X_3$ (6)

Regression equation for low density fabric:

$У=84,72-0,048X_1+0,131X_2-0,138X_3-0,448X_1X_2+0,038X_1X_3+0,188X_2X_3-0,423X_1X_2X_3$ (7)

The adequacy of the obtained models was carried out according to Fisher's criterion [5]. Excel program was used for numerical solution of the problem on optimization of parameters, and the graphical dependences of the output factor on the change of input factors of the full-factor experiment were obtained.

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