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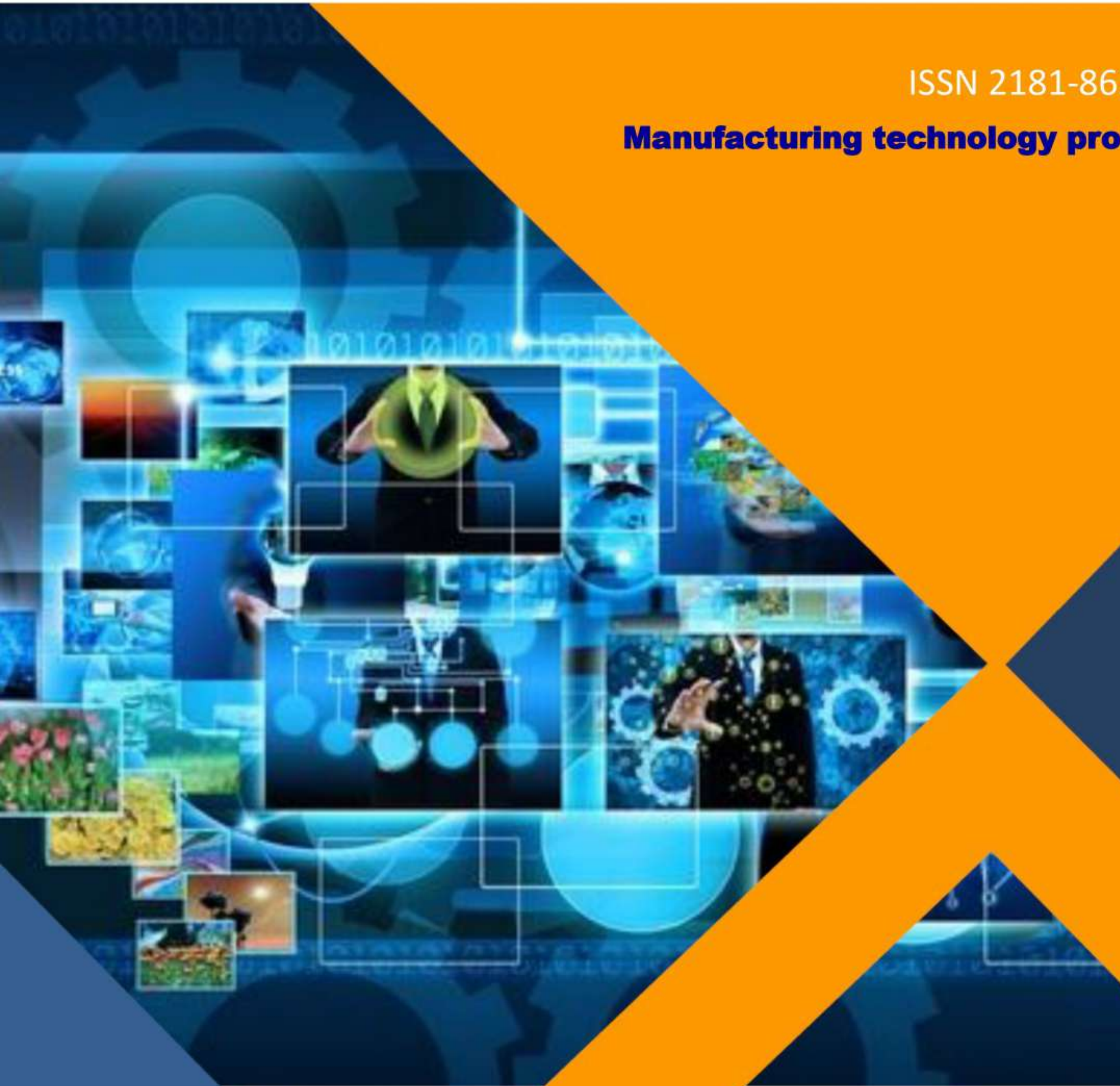

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STUDYING THE ALTERNATIVE TECHNOLOGICAL FACTORS OF THE LOOM IN THE PRODUCTION OF TEXTILES BASED ON BASALT YARN

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Abstract: This paper has studied the optimal conditions for the production of technical fabric based on basalt threads and also loom. In textile production, 11 samples of basalt thread weaves were obtained with a linear density of 300 tex with a composition of 100%. To determine the degree of influence of the factors on the optimization index, a rotatable central composition experiment has been conducted. Results showed that rotatable central composite experiment of the experimental methodology of tissue samples, and also the second-order regression multifactor mathematical model is produced. The Box-3 planning matrix is used to conduct experiments to obtain a mathematical model of the technological process. In the loom, the thread tension, the height of the shed, and the value of the average position were taken as input factors.

Keywords: shed, warp yarns, weft yarns, basalt, loom machine.

Introduction. Basalt is a natural material that is found in volcanic rocks originating from frozen lava, with a melting temperature comprised between 1500° and 1700 °C. Its state is strongly influenced by the temperature rate of the quenching process which leads to more or less complete crystallization [1], [2].

There is a range of factors that influence a loom in textile production. In particular, temperature and relative humidity play an important role. The properties of all textile materials, whether natural or synthetic, such as size, weight, elongation, elasticity, stiffness, etc., are affected by yarn moisture. Among them, yarn strength and elongation value at a given moisture directly affect the rate of loom breakage [3]. Weaving machine and fabric parameters, static and kinematic coefficient and index of friction between the warp and filling yams, total harness lift, shedding timing, backrest position, basic warp tension, and loom speed have been taken into account in predicting beat-up force and warp tension [4]. The yield production of the loom in the textiles based on basalt threads depends on many factors. These factors include the fiber content of the yarns, the filling ratio of the fabric with fibrous material, the loom parameters, and the loom adjustment parameters [5].

It is possible to rationally use raw materials to improve technology and develop scientifically based methods, to improve technological equipment, and to create an effective technology for the operation of looms in weaving enterprises is one of the important issues [6].

In turn, the performance and speed of the loom depend on the degree of thread breakage, and the degree of thread breakage depends on the type and tension of the threads on the body. The tension of the threads on the body is entered into the computer of the machine.

It was found that the deformation and tension of the warp thread increased by 30% on average with the increase in the weaving speed. Thread tension and deformation on the surface of tensioning mechanisms are reduced by 19%.

The production of the basalt fabric sample was carried out on a Somet Thema Super Excel-190 loom. 300 tex basalt (BT) yarns were used for the warp and weft yarns. In this sample, the number of threads in the weft yarn is 900, and the width of the raw fabric produced is 100 sm. The remaining parameters of the loom remained unchanged.

N=2K full factorial experiment was selected with N=20 experiments and a number of factors K=3 to study the effect of different factors on the loom [7].

According to the analysis of Aprior data and the results of preliminary experiments, the following factors have been identified that have a significant impact on the output index: X_1 tension of weft yarns, X_2 – height shed, X_3 – the amount of middle position.

The selected factors meet all the requirements of the theory of mathematical planning of the experiment, the factors are not interchangeable with each other, they can be measured using existing tools, in a wide range of minimum and maximum values, and they can be accepted with the necessary accuracy.

In the course of the experiment, such factors as the linear density of warp and weft yarns, the speed of the loom, the room temperature, the relative humidity of the room, and the moisture content of warp and weft yarns were kept constant.

In the process of weaving, the linear density of basalt yarns, the resistance of air, and the moisture of raw materials are the factors that have a small influence, and their instability in time, as well as the possibility of distortion of various processes and results in a large number of experiments, were taken into account, and their influence was mitigated by random ordering (randomization) of experiments.

With the help of a strain gauge, the tension of the warp threads during the weaving process and the breakage of the 300 tex basalt fiber thread were studied. The tension of the thread in the tissue formation was determined using a tension device and an oscillogram [8,9].

In the first stage, the initial factors of enthronement are established. To obtain an experimental-statistical mathematical model and determine the degree of influence of various factors on the optimization index, a rotatable central composite experiment was conducted, which allows not only to evaluate the influence of each factor on the optimization index but also their interaction [10,11].

Methodology & empirical analysis. Based on the analysis of a priori data, preliminary experimental results, and the technical capabilities of the weaving machine, the value, and intervals of the main factors were selected, and the level of factors and intervals are presented in Table 1.

Table 1. Factor level change and intervalsThe Box 3 planning matrix is used during the experiment to obtain a mathematical model of the technological process.

Factors	Level of change					Interval
	-1,682	-1	0	+1	+1,682	
X_1- weft yarn tension, sN	23	30	40	50	57	10
X_2 – shed height, mm	103	110	120	130	137	10
X_3 – amount of middle position, mm	33	40	50	60	67	10

Based on the results of the Rotatable central composite experiment, we apply a second-order regression, multifactorial mathematical model. As a result of the experiment, we can get the following second-order regression model.

$$Y_R = b_0 + \sum_{i=1}^{M} b_i x_i + \sum_{i=j=1}^{M} b_{ij} x_i x_j + \sum_{ij=1}^{M} b_{ij} x_i^2 \quad (1)$$

The values suspected to be significantly different in the experiments were checked according to the Smirnov-Grabs criterion. For this, the calculated values of the Smirnov-Grabs criterion were determined according to the formulas given below for the average value of the set $\overline{X}$, dispersion $S^2\{x\}$ and sharply different maximum X_{max} and minimum X_{min} values:

$$V_{Rmax} = \frac{X - \overline{X}_{max}}{S\{X\}} \sqrt{\frac{n}{n-1}},$$

Then, the table value of the Smirnov-Grabs criterion was found and compared with the calculated values, the values found to be sharply different were excluded from the set, and the opposite values were left in the account books. To obtain a mathematical model of the technological process, the Box 3 planning matrix is used for conducting experiments [12-14].

Table 2. Factors and the amount of thread breakage in iterations

12	Factors			Randomization			The amount of thread breaking in the repetition, break/meter			Average amount of thread breakage, break/meter
	X_1	X_2	X_3				Y_1	Y_2	Y_3	$\bar{Y}_u$
1.	+	+	+	1	16	7	0,61	0,62	0,60	0,61
2.	+	+	-	24	41	12	0,72	0,75	0,70	0,72
3.	+	-	+	49	4	37	0,66	0,62	0,62	0,63
4.	+	-	-	30	60	21	0,57	0,61	0,59	0,59
5.	-	+	+	46	19	28	0,51	0,48	0,47	0,48
6.	-	+	-	11	43	54	0,75	0,77	0,72	0,75

7.	-	-	+	58	25	2	0,59	0,57	0,60	0,59
8.	-	-	-	6	59	31	0,93	0,93	0,93	0,93
9.	+1,682	0	0	55	35	17	0,61	0,59	0,62	0,61
10.	-1,682	0	0	9	56	42	0,69	0,70	0,71	0,70
11.	0	+1,682	0	40	22	47	0,71	0,69	0,74	0,71
12.	0	-1,682	0	27	50	10	0,74	0,70	0,71	0,72
13.	0	0	+1,682	3	29	52	0,58	0,62	0,59	0,60
14.	0	0	-1,682	36	14	33	0,63	0,62	0,64	0,63
15.	0	0	0	53	44	5	0,51	0,54	0,52	0,52
16.	0	0	0	20	48	57	0,54	0,50	0,53	0,52
17.	0	0	0	32	51	15	0,55	0,58	0,56	0,56
18.	0	0	0	13	38	26	0,59	0,61	0,61	0,60
19.	0	0	0	18	8	45	0,60	0,63	0,62	0,62
20.	0	0	0	34	23	39	0,58	0,61	0,60	0,60

Processing of experimental results is carried out in the following sequence

1. Determination of the variance of the output indicator - the sum of the squared deviations is divided by the corresponding number of degrees of freedom.

$$S_u^2\{Y\} = \frac{m}{m-1}\sum_{i=1}^{m}(Y_i - \overline{Y})^2, \quad (4)$$

where $m = 3$ is the number of repetitions in the matrix experiment; $n = 20$ is the number of experiments in the matrix.

The number of degrees of freedom of reproduction variance is determined by the following formula:

Table 3. The calculation results are included in the table.

U	Y_u	$S_u^2\{Y\}$	$S_u\{Y\}$	V_{Rmax}	V_{Rmin}	Y_{RU}	$Y_U - Y_{RU}$	$(Y_U - Y_{RU})^2$
1	0,61	0,000265	0,01528	0,802	1,604	1,69051	-1,0838	1,17471
2	0,72	0,000633	0,02517	1,460	0,973	-0,204	0,92736	0,85999
3	0,63	0,000133	0,02309	1,591	0,530	1,62039	-0,9871	0,97427
4	0,59	0,000400	0,02000	1,225	1,225	-0,2741	0,86415	0,74675
5	0,48	0,000433	0,02082	1,765	0,588	-0,3541	0,84075	0,70686
6	0,75	0,000633	0,02517	0,973	1,460	1,75138	-1,0047	1,00945
7	0,59	0,000233	0,01528	0,802	1,604	-0,2292	0,81588	0,66565
8	0,93	0	0	0	0	1,87626	-0,9463	0,8954
9	0,61	0,000233	0,01528	0,802	1,604	0,68558	-0,0789	0,00623
10	0,70	0,000100	0,01000	1,225	1,225	0,77457	-0,0746	0,00556
11	0,71	0,000633	0,02517	1,460	0,973	0,75549	-0,0422	0,00178
12	0,72	0,000433	0,02082	1,177	1,177	0,80153	-0,0849	0,0072
13	0,60	0,000433	0,02082	1,177	1,177	0,58973	0,00693	4,8089
14	0,63	0,000100	0,01000	1,225	1,225	0,76713	-0,1371	0,0188
15	0,52	0,000233	0,01528	1,604	0,802	0,63583	-0,1125	0,01266
16	0,52	0,000433	0,02082	1,177	1,177	–	–	–
17	0,56	0,000233	0,01528	1,604	0,802	–	–	–
18	0,60	0,000133	0,01155	1,061	1,061	–	–	–
19	0,62	0,000233	0,01528	0,802	1,604	–	–	–
20	0,60	0,000233	0,01528	0,802	1,604	–	–	–
Σ	12,69	0,006533						7,1062

2. Exclusion of withdrawals.

We consider this operation in the analysis of the first experiment of the matrix when $= 1, Y_{max}, Y_{min}$

The calculation is carried out using the Smirnov-Grabs criterion according to the formulas (4.2, 4.3)

Here $S\{Y\} = \sqrt{S^2\{Y\}} = \sqrt{0{,}000233} = 0{,}0158.$

According to Appendix 1, [7] we find the tabular value of the Smirnov-Grabs criterion $V_{T[P_D=0{,}95;\ m=3]} = 1{,}412$. So $V_{Rmax} < V_T$ and $V_{Rmin} < V_T$ since the considered values $Y_{max} = 0{,}62$, $Y_{min} = 0{,}59$ are not significantly different and remain for further statistical processing.

3. Testing the hypothesis of homogeneity of variance in matrix experiments.

If the number of repetitions in the experiment is the same for all experiments in the matrix, the Cochrane test is used to check the homogeneity of variances, the calculation value of which is determined by the formula.

$$G_R = \frac{S^2_{umax}}{\sum_{u=1}^{N} S_u^2\{Y\}} \tag{5}$$

Here $S^2_{u\,\max}$ – emergence maximum dispersion of the indicator. N – number of experiments. $\sum_{u=1}^{N} S_u^2\{Y\} - the$ sum of all variances. $G_R = \frac{0{,}000633}{0{,}006165} = 0{,}127.$

The calculated value of the Cochran G_T criterion is the table value in $G_{T[P_D;N;f\{S_u^2\}=m-1]}$ was compared with (Appendix 7) [7]. If $G_R < G_T$, then the variances of $S_u^2\{Y\}$ are homogeneous, and the performed experiment is reproducible. $G_{T[P_D=0{,}95;\ N=20;\ f=m-1=2]} = 0{,}2705$. The tabular value of the Cochrane criterion $G_R = 0{,}1027$; $G_T = 0{,}2705$ So, since $G_R < G_T$ variances are considered homogeneous.

4. Mean square dispersion of the output indicator

The average variance describes the average spread of the output indicator values relative to the average values for the factors at each level, that is, the error of experiments in the experiment.

$$S^2_{(1)}\{Y\} = \frac{1}{N}\sum_{u=1}^{N} S_u^2\{Y\}. \tag{6}$$

The number of degrees of freedom of the reproduction variance is determined by the formula.

$$f\{S^2\{y\}\} = N \cdot (m-1) = 20(3-1) = 40$$

$$S^2\{y\} = \frac{1}{20} \cdot 0{,}006533 = 0{,}0003266$$

5. Determination of regression coefficients is carried out according to the following formulas:

The regression coefficients of the conducted rotatable central composite experiment and their variances were determined using the following formulas:

$$b_0 = g_1 \sum_{u=1}^{N} \overline{Y_u} - g_2 \sum_{i=1}^{M} \sum_{u=1}^{N} x_{iu}^2 \overline{Y_u}; \tag{7}$$

$$b_i = g_3 \sum_{u=1}^{N} x_{iu} \overline{Y_u}; \tag{8}$$

$$b_{ij} = g_4 \sum_{u=1}^{N} x_{iu} x_{ju} \overline{Y_u}; \tag{9}$$

$$b_{ii} = g_5 \sum_{u=1}^{N} x_{iu}^2 \overline{Y_u} + g_6 \sum_{i=1}^{M} \sum_{u=1}^{N} x_{iu}^2 \overline{Y_u} - g_7 \sum_{u=1}^{N} \overline{Y_u}. \tag{10}$$

here the free term of the b_0 −equation; b_i −linear coefficients; Coefficients of two-way interaction of b_{ii} −factors; Coefficients of the second degree of b_{ij} −variable.

Table 4. The values of constant coefficients

M	g_1	g_2	g_3	g_4	g_5	g_6	g_7	N	RCCE Core
3	0,1663	0,0568	0,0732	0,1250	0,0625	0,0069	0,0695	20	2^3

6. The experiment conducted on the given matrix allows us to obtain a second-order mathematical model describing the influence of the factors x_1, x_2, x_3 on the selected optimization indicator in the following form:

$$Y_R = 0{,}5704 - 0{,}0272x_1 - 0{,}0117x_2 - 0{,}0549x_3 + 0{,}0515x_{12} + 0{,}064x_{13} - 0{,}0068x_{23} - 0{,}1327{x_1}^2 - 0{,}2977{x_2}^2 - 0{,}3337{x_3}^2$$

7. Using the Student's test, we check the significance of the regression coefficients of the obtained model.

Approximate value of the student criterion:

$$t_R\{b_0\} = \frac{|b_0|}{S\{b_0\}}, \tag{11}$$

$$S^2\{b_0\} = g_1 S^2\{\overline{Y}\}, \tag{12}$$

$$S^2\{\overline{Y}\} = \frac{1}{mN}\sum_{u=1}^{N-N_{ts+1}} S_u^2\{Y\}, \tag{13}$$

$$t_J[P_D = 0{,}95;\ f\{S_u^2\} = N(m-1) = 20(3-1) = 40] = 2{,}021 \tag{14}$$

Since $t_R > t_J$, the coefficient b_0 is important and cannot be excluded from the mathematical model. The tabular value of the Student's criterion was taken from Appendix 3 [7] of the literature [8]:

$$S^2\{b_i\} = g_3 S^2\{Y\},$$

It can be shown that the variances of the regression coefficients depend on the diagonal elements of the matrix and are covariances describing the relationship between the coefficients.

$$COV\{b_0 b_{ii}\} = g_2 C\{\overline{Y}\} = 0{,}0568 \cdot 0{,}01044 = 0{,}000593$$

$$COV\{b_{ii} b_{ij}\} = g_6 \cdot C\{\overline{Y}\} = 0{,}0069 \cdot 0{,}01044 = 0{,}000072$$

Results and discussion

So we accept values greater than 2.021. Since b_{23} is insignificant, we will not take it into account, and the final form of the regression equation will be as follows:

$$Yr = 0{,}5704 - 0{,}0272x_1 - 0{,}0117x_2 - 0{,}0549x_3 + 0{,}0515x_{12} + 0{,}064x_{13} - 0{,}1327{x_1}^2 - 0{,}2977{x_2}^2 - 0{,}3337{x_3}^2$$

The resulting equation shows the relationship between the breaking of the body threads, the tension of the body thread, the height of the hummus, and the amount of the middle position. Change of output indicators according to the conditions of the 2nd order:

8. Testing the hypothesis about the adequacy of the obtained model. To determine the compatibility of the obtained equation, Fisher's criterion is used, and its calculated value is determined by the following formulas:

$$F_R = \frac{S_{ad}^2\{Y\}}{S^2\{Y\}} = \frac{S_{nad}^2\{Y\}}{S^2\{\overline{Y}\}}, \text{ unless } S_{nad}^2\{Y\} > S^2\{\overline{Y}\}, \quad (15)$$

$$F_R = \frac{S^2\{Y\}}{S_{ad}^2\{Y\}} = \frac{S^2\{\overline{Y}\}}{S_{nad}^2\{Y\}}, \text{ unless } S_{nad}^2\{Y\} > S^2\{\overline{Y}\}, \quad (16)$$

$$S_{nad}^2\{Y\} = \frac{\sum_{u=1}^{N}(Y_u - Y_{RU})^2}{N - N_k}, \quad (17)$$

where N_k the number of coefficients.

Y_{RU} values are calculated according to the obtained mathematical model and are summarized in Table 3.

$$Yr = 0{,}5704 - 0{,}0272x_1 - 0{,}0117x_2 - 0{,}0549x_3 + 0{,}0515x_1x_2 + 0{,}064x_1x_3 - 0{,}1327x_1^2 - 0{,}2977x_2^2 - 0{,}3337x_3^2$$

$$S_{nad}^2\{Y\} = \frac{7{,}10624}{20 - 9 + 1} = 0{,}7126.$$

So, since $S_{nad}^2\{Y\} > S^2\{\overline{Y}\}$ i.e. 0,4723>0,006533, the calculated value of Fisher's criterion is determined by the formula (15).

$$F_R = \frac{S_{ad}^2\{Y\}}{S^2\{Y\}} = \frac{S_{nad}^2\{Y\}}{S^2\{\overline{Y}\}} = \frac{0{,}004565}{0{,}006165} = 0{,}74.$$

The calculated value of Fisher's criterion F_R is compared with tabular F_j (Appendix 4) [7] at the confidence level $P_D = 0{,}95$ and $f\{S_{nad}^2\} = N - N_k$, $f\{S^2\}$ in the number of degrees of freedom. If $F_R < F_j$, then the hypothesis of the adequacy of model experimental data is not rejected.

Table value of Fisher's criterion for this example

$$F_{J[P_D=0{,}95;\ f\{S^2\}=20(3-1)=40;\ f\{S_{nad}^2\}=20-(6-1)=15]} = 1{,}92$$

Second-order planning ends by finding an adequate quadratic equation of the type (3.3):

We plot the values of the input factors based on the obtained formula (Y_R).

We analyze the graph of the dependence of the input factors, X_1-warp yarn tension and X_2 shed height (Fig. 1).

As can be seen from the graph, as the height of the shed increases, the tension of the warp yarns also increases, which leads to an increase in the number of breaks.

In the graph of the dependence of the height of the X_2-shed on the loom on the amount of the X_3-middle condition (Fig. 2), there are few interruptions when these values change (increase or decrease) relative to each other.

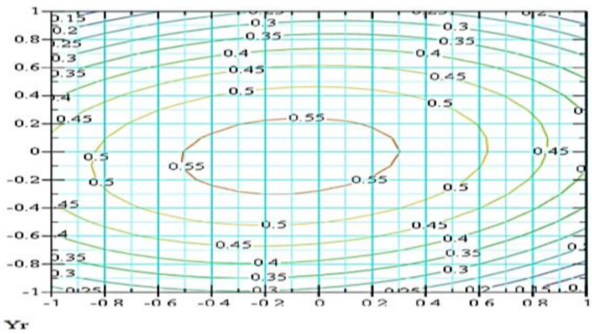

Figure 1. The dependence of warp yarn tension (X1) on shed height (X2) on the loom is isolines

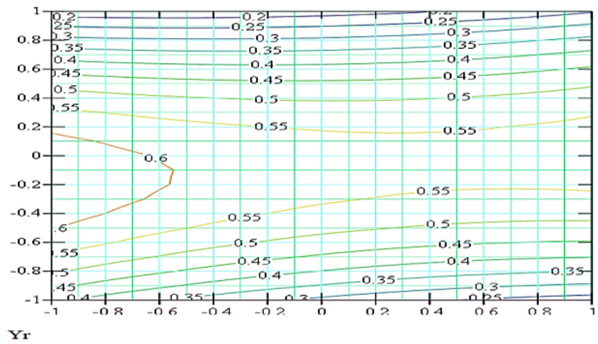

Figure 2. The dependence of the height of the shed (X2) on the amount of the middle position (X3) on the loom is isolines

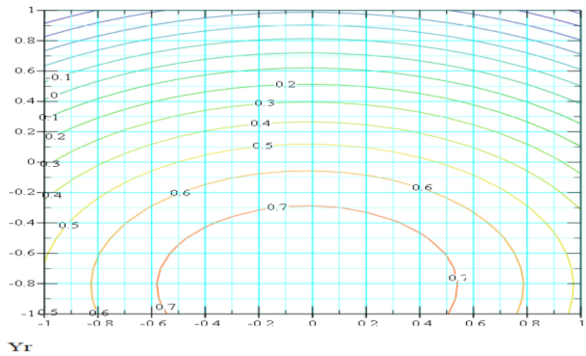

Figure 3. Dependence of the tension of warp yarns (X1) on the amount of the middle position (X3) on the loom is isolines

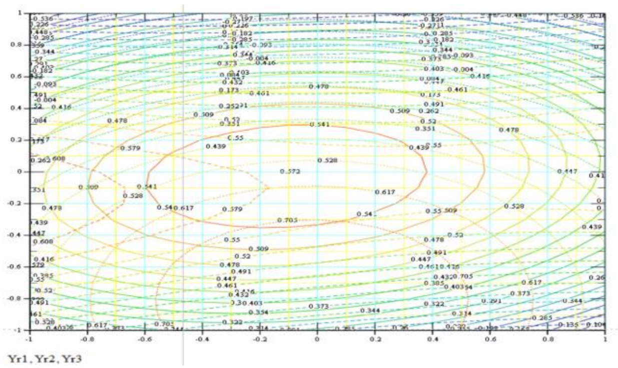

Figure 4. Yr1(x1, x2), Yr1(x2, x3), Yr1(x1, x3) intersection of graphs

Only as a result of the reduction in shed height, did the breaks increase due to the friction of rapier to warp yarns.

We can see from the graph of the dependence of X1-warp yarn tension on the amount of X3 middle position (Fig. 3), the warp tension decreases as the amount of middle position increases [1].

Conclusion

The breaking of warp yarns on the loom has been calculated with the following equations.

$$Y_{r1} = 0{,}5704 - 0{,}0272x_1 - 0{,}0117x_2 - 0{,}0549x_3 + 0{,}0515x_1x_2 + 0{,}064x_1x_3 - 0{,}1327x_1^2 - 0{,}2977x_2^2 - 0{,}3337x_3^2;$$

we determined the air permeability of the fabric based on the above formulas, namely Y_r2, the optimal option.

$$Y_{r2} = 6{,}80 + 0{,}62x_1 + 0{,}09x_2 + 0{,}11x_3 + 0{,}86x_1x_2 + 0{,}45x_1x_3 - 0{,}39\,x_2x_3 - 1{,}68x_1^2 - 3{,}56x_2^2 - 3{,}74x_3^2$$

Based on the intersection of the graphs of the input factors (Fig. 4), we can determine the values for the optimal operation of the loom. In this case, in the 5th option, i.e:

1. Warp yarns tension, $x_1 = 40$ sN;
2. Shed height, $x_2 = 130$ mm;
3. Average on the middle amount of when $x_3 = 60$ mm, the number of interruptions in the loom is the least.

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