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THEORETICAL STUDY OF THE QUALITY INDICATORS OF NEWLY STRUCTURED KNITTED FABRICS BASED ON A MATHEMATICAL MODEL

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Abstract: Mathematical modeling of the physical-mechanical properties and technological indicators of knitted fabrics, along with their theoretical study through practical experiments, creates opportunities to improve the quality indicators of the resulting knitted products and to make preliminary forecasts during the production process. In turn, this leads to an increase in the parameters of achieving economic efficiency through scientific research.

Keywords: Technique and technology, theoretical, experimental, and theoretical-experimental approaches, loop pitch, indicators, breaking force and elastic recovery, adequacy, Fisher's criterion, and regression coefficients.

Introduction. The importance of scientific research is steadily increasing in the development of all sectors of Uzbekistan's national economy, and production enterprises are being improved on the basis of global scientific achievements. This improvement is being carried out through automation and mechanization, as well as the application of new techniques and technologies. [1; 5-10b].

Methodology & empirical analysis. Scientific research activities, depending on the methods of implementation, are divided into the following types: theoretical, experimental, and theoretical-experimental. Theoretical research is carried out by analyzing based on an already known law, studying the interdependence of technological processes or object parameters from a theoretical perspective, while experimental research is conducted through practical experimentation. At present, the introduction of new techniques and modern computer technologies into the production process requires the conduct of scientific research to be more comprehensive and of higher quality. Economic efficiency represents the useful result obtained through the use of production means and living labor. Under market economy conditions, since each enterprise possesses complete economic and legal independence, its main objective is directed towards the full and efficient utilization of the resources assigned to it. The greater the income and profit obtained from each unit of these resources, the stronger the enterprise's competitive advantage becomes [2].

In theoretical-experimental research, both theoretical and experimental results are taken into account, and at present, this type of research is being used more frequently. The technological processes in the textile industry consist of a combination of physical and chemical phenomena, which can only be successfully studied by applying modern achievements of science and technology. Therefore, conducting scientific research on the basis of mathematical modeling is considered appropriate.

Results. In studying the input parameters that determine the structure of knitted fabrics, it is advisable to make effective use of multifactor mathematical modeling. As influencing factors, the following input variables were selected: x_1 – loop pitch A (mm), x_2 – loop course height B (mm), and x_3 – horizontal density P_g. As output variables, Y_1 – breaking force R (N) along the length and width, and Y_2 – elastic recovery ε_0 (%) along the length and width [3] were chosen. In studying the influence of fabric structure on the production of knitted textiles, the levels and intervals of factor variation were determined (see Table 1).

Table 1. Selection of factor variation levels and intervals under study

Name and designation of factors	Levels of variation -1	0	+1	Range of variation of factors
x_1 – loop pitch, A (mm)	0,39	0,405	0,42	0,015
x_2 – loop course height, B (mm)	0,43	0,445	0,46	0,015
x_3 – horizontal density, P_g (units)	120	122	124	2

To determine the significance of the regression coefficients, Student's criterion was applied, while Fisher's criterion was used to test whether the mathematical model was adequate or not.

In the research, the main objective of mathematical modeling was to identify the breaking force and elastic recovery of knitted fabrics under the influence of certain factors. For this purpose, computational models were developed in the Pascal programming language, and deviation diagrams of isolines were obtained. Through these isolines, it is possible to determine the breaking force and elastic recovery indicators of knitted fabrics based on influencing factors.

The results of the TOT experiments showed that the studied process is expressed by a higher-order equation. Therefore, in order to obtain a second-order regression mathematical model, the central composite design (CCD), which is simpler and more convenient compared to other methods and is widely used in studies of technological processes in the textile industry, was selected and implemented.

Based on the experimental results, we seek a second-order multivariable regression mathematical model. As a result of this experiment, a regression model of the following general form can be obtained

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

Or, since three factors are involved in our experiment, the above expression takes the following form:

$$Y_R = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2 \quad (2)$$

In the equation:

b_0, b_1, … – regression coefficients,

x_1, x_2, x_3 – coded values of the factors.

Using the standard working matrix of the central composite design (CCD), the regression coefficients of the second-order regression mathematical model were determined. As a result of testing their significance and confirming the adequacy of the index, the following outcomes were obtained.

Central Non-Composite Design (CCD) Matrix

№	factors			x_1x_2	x_1x_3	x_2x_3	x_1^2	x_2^2	x_3^2	Y_1 (along length and width))		Y_2 (along length and width)		$S_u^2(Y_1)$		$S_u^2(Y_2)$	
	x_1	x_2	x_3														
1	+	+	0	+	0	0	+	+	0	702	236	92	94	11	7,8	1	1,25
2	+	-	0	-	0	0	+	+	0	420	216	93	96	12	8,2	1,13	0,9
3	-	+	0	-	0	0	+	+	0	303	94	76	82	14	10,1	1,2	1,14
4	-	-	0	+	0	0	+	+	0	478	147	93	96	15	8,2	1,9	1,4
5	+	0	+	0	+	0	+	0	+	732	258	82	94	16	8	1,04	1,8
6	+	0	-	0	-	0	+	0	+	742	228	82	94	11	6,7	1,03	1,2
7	-	0	+	0	-	0	+	0	+	300	96	76	96	9	9,5	1,12	1,5
8	-	0	-	0	+	0	+	0	+	416	112	85	96	12	11,4	1,5	1,5
9	0	+	+	0	0	+	0	+	+	478	174	85	96	13	9,4	1,76	1,8
10	0	+	-	0	0	-	0	+	+	475	170	75	95	8	9,1	1,21	1,5
11	0	-	+	0	0	-	0	+	+	474	164	82	90	7	7	1,8	1,34
12	0	-	-	0	0	+	0	+	+	480	152	84	96	14	11,5	1,6	1,4
13	0	0	0	0	0	0	0	0	0	475	138	85	96	13	7,2	1,5	1,2
14	0	0	0	0	0	0	0	0	0	478	174	88	93	14	10,2	1,3	1,9
15	0	0	0	0	0	0	0	0	0	450	182	86	84	11	10,7	1,4	2

The matrix should use the values (+), (−), and 0.

Regression models for optimizing the breaking force of knitted fabric (Y_1 – along the length) [4; 5]:

Experiments were conducted using the central non-composite design matrix presented in Table 2, and based on the results, the regression coefficients of the second-order regression mathematical model for studying the breaking force of the knitted fabric along the Y_1-axis were determined.

$$Y_R = 467{,}7 + 137{,}4x_1 + 42{,}5x_2 - 16{,}1x_3 + 114{,}3x_1x_2 + 26{,}5x_1x_3 + 2{,}25x_2x_3 + 32{,}7x_1^2 - 2{,}6x_2^2 + 33{,}2x_3^2$$

It is known that if the calculated value of a criterion is smaller than the tabulated value, the corresponding coefficient is not significant and is excluded from the equation. In the study, it was found that the coefficients b_{23} and b_{22} are insignificant for the parameters under investigation. The equation is then rewritten with only the significant coefficients as follows:

$$Y_R = 467{,}7 + 137{,}4x_1 + 42{,}5x_2 - 16{,}1x_3 + 114{,}3x_1x_2 + 26{,}5x_1x_3 + 32{,}7x_1^2 + 33{,}2x_3^2$$

To verify whether the regression mathematical model obtained above is adequate or not, the calculated value of the Fisher criterion was used. Based on this, it can be concluded that the resulting regression mathematical model represents the studied process with sufficient accuracy.

From the graph above, it can be seen that when the first factor x_1=0, and the second (x_2) and third (x_3) influencing factors vary from the accepted minimum value (−1) to the maximum value (1), the breaking force along the length (Y_1), calculated using the average value, shows its minimum and maximum values.

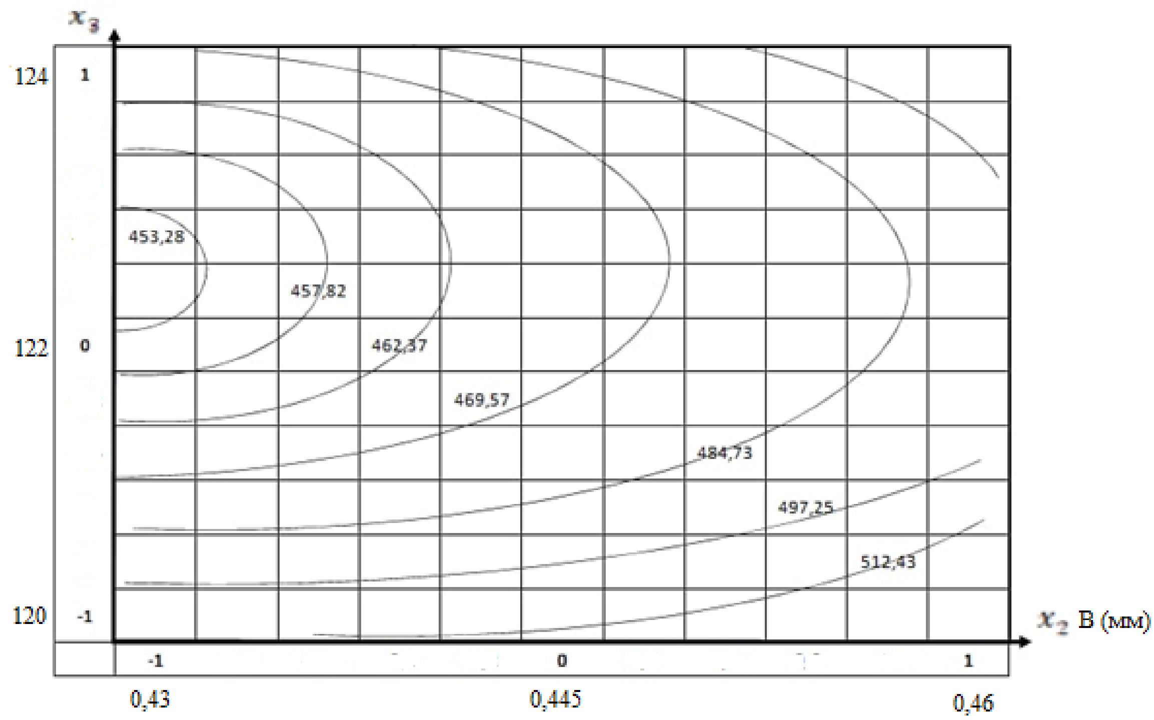

Figure 1. a. x_1=0

Using the diagram, it can be observed that the knitted fabric achieves the highest breaking force (Y_R = 512.43 N) when the loop course height x_2 B(mm) is in the range of 0.445–0.46 mm and the horizontal density x_3 Pg is in the range of 120–122 units. Conversely, the lowest breaking force (Y_1 = 453.28 N) is reached when x_2 is in the range of 0.43–0.445 mm and x_3 Pg is in the range of 122–124 units (Figure 1a).)

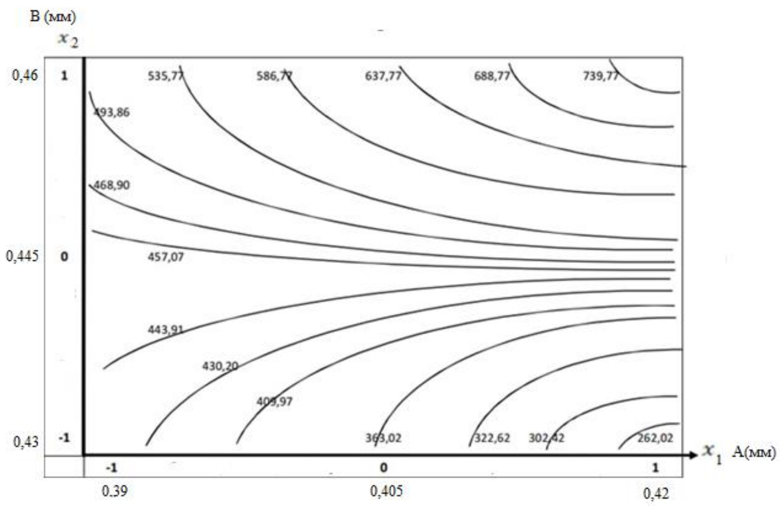

Figure 1b. Regression equation for breaking force along the length (Y_1) when x_3=0

In Figure 1b, when the third influencing factor x_3=0, the values of the first (x_1) and second (x_2) factors vary from the accepted minimum (−1) to the maximum (1), and the corresponding breaking force along the length (Y_1) is shown. The knitted fabric achieves the lowest breaking force (Y_1 = 262.02 N) at x_1– loop pitch A = 0.405–0.42 mm and x_2 – loop course height B = 0.43–0.445 mm. The highest breaking force (Y_1 = 739.77 N) is reached at x_1 – loop pitch A = 0.405–0.42 mm and x_2–loop course height B=0.445–0.46 mm (Figure 1b).

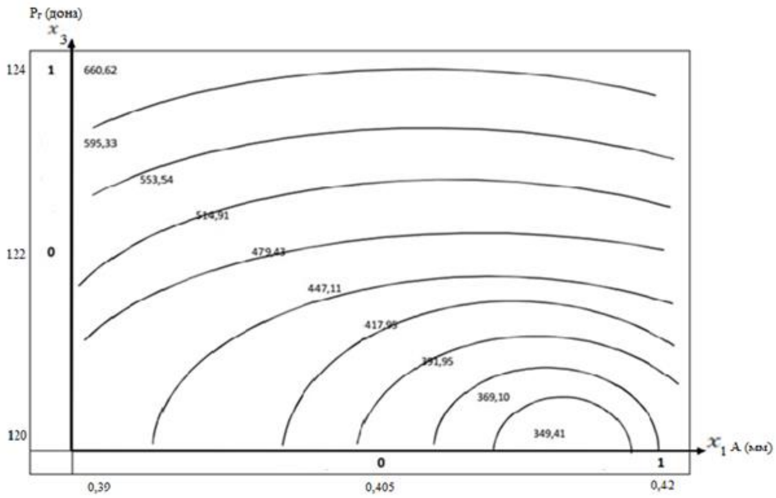

Figure 1. c. x_2=0

Here's the English translation in academic style:

When the first (x_1) and third (x_3) factors vary from the accepted minimum (−1) to the maximum (1) and x_2=0, the knitted fabric achieves the lowest breaking force (Y_1 = 349.01 N) at x_1 – loop pitch A = 0.405–0.42 mm and x_3 – horizontal density P_g = 120–122 units. The highest breaking force (Y_1 = 660.02 N) is reached at x_1 – loop pitch A = 0.39–0.405 mm and x_3– horizontal density P_g= 122–124 units (Figure 1c).

Conclusions. Summarizing the research results for the three cases, when the first factor (x_1) – loop pitch A (mm) = 0, the second factor (x_2) – loop course height B (mm) = 1, and the third factor (x_3) = 0, the breaking force (Y_1) reaches its maximum value.

$$Y_R = 467,7 + 137,4 * 0 + 42,5 * 1 - 16,1 * 0 + 114,3 * 0 * 1 + 26,5 * 0 * 0 + 32,7 * 0 + 33,2 * 1 = 533,4$$

Thus, the obtained regression mathematical model adequately represents the studied process.

Based on the analysis of the regression equations, it was determined that variations in the loop pitch, loop course height, and horizontal density of the knitted fabric are significantly related to its technological and physical-mechanical properties.

Using the central non-composite design, a regression equation was derived linking the breaking force and elastic recovery characteristics of double-layer knitted fabrics. Based on the analysis of this equation, the rational structure and parameters of the knitted fabric that ensure optimal consumer properties were identified.

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