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MATHEMATICAL ANALYSIS OF THE DEPENDENCE OF THE OPTIMIZATION PARAMETER ON THE FACTORS AFFECTING THE STRENGTH OF THE THREAD CONNECTION OF WORKWEAR PARTS

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ABSTRACT. In this article, a study is carried out based on mathematical methods of experiment planning. The seam seams of a shuttle stitch made on a JK-6588BD sewing machine were examined. Stitch samples were made on gabardine with 100% cotton fabric ref. 3232 with weights of 210 g / m^2, 220 g / m^2 and 230 g / m^2 twill weave. The studied factors were the sewing frequency, linear density of sewing threads and seam width. The strength of the seam was chosen as an optimization criterion. When solving the problem, a mathematical model of the research object was used, i.e. an equation that connects the optimization parameter with factors. The significance of the coefficients was checked using the Student's t-test. It was found that for the accepted level of significance and the corresponding number of degrees of freedom, the mathematical model is considered adequate.

Keywords: mathematics, sewing threads, workwear

I. INTRODUCTION:

Stitches and seams are two important components of a garment's structure. Stitches are used to join pieces of clothing together, and seams shape the clothing to be worn. These two factors, together with their performance characteristics, improve the quality of the garment. The seam will interact with the fabric components to ensure better product stability [1].
The seam enhances usability and durability while maintaining the functional characteristics of the fabric. Both the functional and the aesthetic characteristics of the garment in terms of durability and stability depend on the strength of the seam.

II. LITERATURE REVIEW.

The aim of the research is to study the influence of types of sewing threads and types of stitches on the seam strength of cotton garments. Seam strength was measured and analyzed in both warp and weft directions. Statistical analysis has shown that the types of stitches and types of thread have a significant and positive influence on the strength and efficiency of the seam.
In works [2-3] fabrics of different proportions are considered, ie, polyester / cotton were prepared with different fabric structures, such as linen, twill, satin. Plain weave samples were found to have better seam performance than twill and satin. Various other factors affecting joint strength are also discussed in detail.
Seam compatibility with functional and aesthetic requirements is very important for the usability and durability of the garment. The choice of thread type, fabric and seam are the main elements of a garment's durability, in terms of cost and quality.
This research paper [4] focuses on the effect of seam type, stitch type and stitch density on the seam strength of a fabric. The results showed that these factors influence the overall seam performance of the garment.

To obtain thread seams of garments, there is a known method [6], in which, when grinding layers of material, a polymer based on acrylate latex is applied to the surface of the thread seam. The main disadvantage of this method is rigidity, seam thickness and the complexity of the technological process of garments.
The quality indicators of thread connections depend on various factors. The strength of the seam depends on the type and properties of the material, threads, structure of the stitch and seam, technological sewing modes. The appearance of the joints depends on the dimensional parameters and the structure of the stitches in the stitches, the evenness of the stitches, the degree of tightening of the stitches, the integrity of the stitch, etc. Each quality indicator of the thread joints is determined by a set of factors due to the

properties of materials, threads, the type of weaving and the structure of the stitches, sewing modes, parameters seams.

III. EXPERIMENTAL STUDY.

When studying the overalls of workers in fat and oil production, it was found that they did not meet the requirements for protective properties, i.e. their early failure is observed. At the same time, it was revealed that the types of seams and the threads used for sewing seams, the frequency of seams were selected incorrectly and did not meet the requirements. This was observed, in most cases, when stitching the shoulder and side seams of the jacket, sleeves, back, step and side seams of trousers [7].

In this regard, the work investigated the strength of the connection of workwear parts made of cotton fabric using a polymer composite material (PCM) based on a collagen derivative - a protein hydrolyzate [8-9]. Domestic cotton fabrics with a surface density of 210 g / m2, 220 g / m2 and 230 g / m2 were selected as objects of research; needles 90-100, with a material thickness of 0.4-0.5 mm.

To analyze the results of experimental studies, a mathematical model of the dependence of the optimization parameter on factors has been built.

Determination of optimal quality indicators is a complex multifactorial task associated with the optimization of the parameters of their formation. Modern mathematical methods of experiment planning allow: 1) to carry out multifactorial studies while reducing the number of experiments; 2) to obtain quantitative estimates of the influence of factors; 3) find the optimum of the investigated parameter [10].

The influence of the technological modes of sewing on the strength of the shuttle stitch seam is shown in [11]. It is known that shuttle stitches are widespread for connecting seams of workwear parts.

Research results. At the Department of Design and Technology of Garments at the Tashkent Institute of Textile and Light Industry, the seams of a shuttle stitch made on a sewing machine JK-6588BD were investigated. Stitch samples were made on gabardine with 100% cotton fabric ref. 3232 with weights of 210 g / m2, 220 g / m2 and 230 g / m2 twill weave.

The strength of the weld in the longitudinal and transverse directions was chosen as an optimization criterion.

When solving the problem, a mathematical model of the research object was used, i.e. the equation connecting the optimization parameter with the factors [12]:

$y= f(x_1, x_2, \ldots, x_k)$(1)

where y = optimization parameter; (x1, x2,..., xk) - factors.

Initially, a full factorial experiment was performed. The studied factors were the sewing frequency, linear density of sewing threads and seam width. The factors are unambiguous, compatible and independent.

The levels of variation of factors are taken on the basis of a priori information (Table 1). Type 23 experiment planning matrix and working matrix for welds are given in table. 2 and 3.

Table 1
Levels and intervals of variation of factors

Factor	Factor designation	Variation level			Variation interval
		-1	0	+1	
Joint width, mm	X_1	0,4	0,7	1,0	0,3
Number of stitches, st / cm	X_2	3	4	5	1
Surface density of fabric,%	X_3	210	220	230	10

Table 2
Matrix of a full factorial experiment of type 23 and experimental results

	Planning matrix								Experiment Results			
									Seam strength, N			
	X_0	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3	$X_1X_2X_3$	y_1	y_2	y_3	$y_в$
1	+	-	-	+	+	-	-	+	120	76	92	96

2	+	+	-	+	-	+	-	-	80	60	79	73
3	+	-	+	+	-	-	+	-	112	65	69	82
4	+	+	+	+	+	+	+	+	80	68	77	75
5	+	-	-	-	+	+	+	-	100	100	82	94
6	+	+	-	-	-	-	+	+	95	90	70	85
7	+	-	+	-	-	+	-	+	92	93	73	86
8	+	+	+	-	+	-	-	-	78	73	74	75

For each row of the planning matrix, based on the results of n parallel experiments, the $\bar{y}_j$-arithmetic mean of the optimization parameter is found:

$$\bar{y}_j=\frac{1}{n}\sum_{u=1}^{n} y_{ju}, \qquad (1)$$

where u is the number of the parallel experiment;
yju-value of the optimization parameter of the lu-th parallel experiment of the j-th row of the matrix.
In order to assess the deviations of the optimization parameter from its average value, for each row of the planning matrix, the variance S_j ^ 2 of the experiment is calculated from the data of n parallel experiments. The statistical variance of experience is determined as the mean of the square of the deviations of a random variable from its mean value:

$$S_j^2=\frac{1}{n-1}\sum_{u=1}^{n}(y_{ju}-\bar{y}_j)^2 \ , \qquad (2)$$

Then the error of experience is found from the expression

$$S_j=\sqrt{\frac{1}{n-1}\sum_{u=1}^{n}(y_{ju}-\bar{y}_j)^2} \ . \qquad (3)$$

The variances of the experiments calculated by the formula (2) correspond to the following values (according to the numbers of the experiments):
S_j^2=496; 127; 679; 39; 108; 175; 127; 7.

With uniform duplication of experiments (n = 3), the homogeneity of a number of variances is checked using the Cochran G-test, which is the ratio of the maximum variance to the sum of all variances:

$$G_p=\frac{S_{max}^2}{S_1^2+S_2^2+\cdots+S_N^2}=\frac{S_{max}^2}{\sum_{j=1}^{N}S_j^2} \qquad (4)$$

The calculated value of the Gp criterion is

$$G_p=\frac{679}{1758}=0{,}3862$$

According to the table [12], depending on the number N of the compared variances and the n-number of parallel experiments, we select the tabular value of the Gt-criterion, which is equal to 0.5157.
Thus, having the values Gp = 0.3862 and Gp = 0.5157, we can conclude that the variances are homogeneous, since the necessary and sufficient condition for homogeneity is satisfied:

$G_p \leq G_т$(6)

If the variances S_j ^ 2 of the experiments are homogeneous, then the variance of the reproducibility of the experiment is calculated by the expression:

$$S_y^2=\frac{1}{N}\sum_{j=1}^{N}S_j^2, \qquad (7)$$

which was $S_y^2=219{,}75$.

According to the results of the experiment, the coefficients of the model are calculated. The free term bo is determined by the formula:

$b_o = \frac{1}{N}\sum_{j=1}^{N} \bar{y}_j$ (8)

Regression coefficients characterizing linear effects are calculated by the expression

$b_i = \frac{1}{N}\sum_{j=1}^{N} X_{ij}\, \bar{y}_j,$ (9)

The regression coefficients characterizing the interaction effects are determined by the formula

$b_{il} = \frac{1}{N}\sum_{j=1}^{N} X_{ij}\, X_{lj} \bar{y}_j,$ (10)

where ȳ_j is the arithmetic mean of the optimization parameter;
i, l- factor numbers;
X_ij 〖, X〗 _lj- coded values of factors i and l in bj-m experiment.
Regression equation coefficients calculated by formulas (8), (9) and (10) gave the following results:

$b_0 = 83{,}25;\ \ b_1 = -6{,}25; b_2 = 3{,}75\ ;\ \ b_{12} = -1{,}25\ ;$

$b_{13} = -1{,}75; b_{23} = -0{,}75;\ b_{123} = -2{,}25.$

In accordance with the obtained data of the coefficients, the regression equation takes the form:
$y=83{,}25-6{,}25x_1-1{,}75x_2+3{,}75x_3-1{,}25x_1x_2-1{,}75x_1x_3-0{,}75x_2x_3-2{,}25x_1x_2x_3.$ (11)

The significance of the model coefficients is checked in two ways: 1) by comparing the absolute value of the coefficient with a confidence interval; 2) using the Student's t-test.
We will check the significance of the coefficients in the second way. For this, the calculated value of the tp-criterion was calculated by the expression

$t_p = \frac{|b_i|}{S\{b_i\}},$ (12)

where S {b_i} is an error in determining the i-th regression coefficient, calculated by the formula

$S\{b_i\} = \sqrt{S^2\{b_i\}}\,.$ (13)

In formula (13), the variance S ^ 2 {b_i} of the i-th coefficient calculated is determined by the expression

$S^2\{b_i\} = \frac{1}{nN} S_y^2\ .$ (14)

Thus, we get the following values of variance and error: S ^ 2 {b_i} = 1.445, S {b_i} = 1.0698. The calculated value of the tp-criterion, calculated by the formula (12), is compared with the tabular tt - criterion (tt = 2.12) [99]. This value of the Student's criterion tt corresponds to the number of degrees of freedom ƒ = (n-1) N = 16 with uniform duplication of experiments.
Taking into account the values of the tp-criterion for each regression coefficient and the ratio tp> tt, we determine the significance of these coefficients. We exclude statistically insignificant coefficients from equation (11) and finally get:
$y=83{,}25-6{,}25x_1+3{,}75x_3-2{,}25x_1x_2x_3.$ (15)

The variance of the adequacy of the model is determined by the formula

$S_{ад}^2 = \frac{n\sum_{j=1}^{N}(\bar{y}_j-\hat{y}_j)^2}{f} = \frac{n\sum_{j=1}^{N}(\bar{y}_j-\hat{y}_j)^2}{N-(k+1)},$ (16)

where ȳ_j is the arithmetic mean of the optimization parameter of the lj experience;

$\hat{y}_j$-value of the optimization parameter, calculated by the model for conditions j-20 experience;
ƒ-number of degrees of freedom equal to N- (k + 1);
k-number of factors.

Table 3
Data for calculating the variance of model adequacy

Experience number, No.	$\bar{y}_j$	$\hat{y}_j$	$(\bar{y}_j - \hat{y}_j)^2$	Degree of freedom	
				f_1	f_2
1	94	91	9	16	4
2	85	83	4		
3	96	95,5	0,25		
4	73	78,5	30,25		
5	86	88	4		
6	75	71	16		
7	82	83,5	2,25		
8	75	75,5	0,25		

The variance of adequacy, calculated by formula (15) in accordance with the data in Table 3, was

$$S^2_{ад} = \frac{3 * 96}{8 - (3 + 1)} = 72$$

At the completed stage of processing the experimental results, we check the hypothesis of the adequacy of the resulting model according to Fisher's F-criterion

$$F_p = \frac{S^2_{ад}}{S^2_y} . \qquad (17)$$

IV. CONCLUSION.

If the value F_p <F_t (tabular) for the accepted level of significance and the corresponding numbers of degrees of freedom, then the mathematical model is considered adequate. For ƒ1 = 16 (ƒ1 = (n-1) N) is the number of degrees of freedom for a larger variance and ƒ2 = 4 (N- (k + 1)) is the number of degrees of freedom for a smaller variance. The tabular value of Fisher's F-test at a 5% significance level is Ft = 5.9 [11].
Since Fp = 72 / 219.25 = 0.3276, the condition F_p <F_t is fulfilled and therefore the model is adequate.

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