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MODELING OF TECHNOLOGICAL PARAMETERS OF FILAMENT JOINTS OF CLOTHING PARTS FOR PROFESSIONAL SPORTS FENCING

Об'єктом поданого дослідження є технологічний процес виготовлення одягу для професійного спортивного фехтування. Предметом дослідження є якість ниткових з'єднувань, які регламентуються технічними вимогами та вимагають особливої уваги під час проектування асортименту одягу для спортсменів-фехтувальників.

Методологія дослідження спирається на аналіз наукової літератури, вимірювання механічних властивостей та моделювання технологічних параметрів ниткових з'єднувань деталей фехтувального одягу. З метою визначення впливу кількості стібків на розривальне зусилля та повздовжню деформацію ниткових з'єднувань одягу для фехтування застосовано математичне моделювання технологічного процесу виготовлення з використанням методу планування експерименту. Вибір плану експерименту пов'язаний з визначенням числа експериментальних точок і такого розміщення їх у факторному просторі, який дозволить при порівняно невеликій кількості дослідів отримати необхідну інформацію для прийняття рішення. У ході дослідження застосовано методи визначення розривального зусилля та повздовжної деформації швів. Особливістю дослідження є визначення раціональних технологічних параметрів ниткових з'єднувань за умови збереження необхідної межі міцності та визначеного рівня повздовжньої деформації. Раціональними параметрами кількості стібків в зшивально-обметувальній та оздоблювальній строчках настрочного шва для досліджуваних матеріалів фехтувального одягу пропонуються такі, за яких розривальне зусилля шва ≥970 Н, а повздовжня деформація не перевищує ±2,0 %, а саме: t–(5,0÷6,5) стібків/10 мм, h–(3,0÷3,5) стібків/10 мм.

Отримані результати доводять можливість застосування методів математичного моделювання для прогнозування якості ниткових з'єднувань деталей одягу для професійного спортивного фехтування. Даний підхід має практичну значущість та може бути застосований як на етапі проектування технології виготовлення одягу під час вибору режимів обробки нових матеріалів, так і на етапі виготовлення та контролю якості виконаних операцій.

Ключові слова: *фехтувальний одяг, якість ниткових з'єднувань, міцність швів, деформація швів, контроль якості.*

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1. Introduction

Competitive activity and the motor structure of the technical and tactical actions of fencing athletes require certain physical, psychological and intellectual abilities and skills [1, 2]. Training speed and endurance is the basis of the physical training of the fencer [3, 4]. The main means of individual protection of fencing athletes from the possible traumatic effects of weapons during fights is clothing [5]. With strict observance and implementation of safety and control measures provided by the rules [6, 7] for weapons, equipment and clothing, fencers are practically exempt from the danger of severe pain and power confrontation. However, the mismatch of the linear dimensions of the clothes to the dimensions of the surface of the fencer's body during sports movements leads to stresses in individual sections of the clothing and contributes to the seam breaking.

The issue of the quality of the thread connected during the design of the range of fencing clothes becomes especially relevant when choosing structural and technological solutions, depending on the properties of the materials used and the characteristics of the equipment. After choosing the processing modes and adjusting the corresponding equipment, strict quality control of operations is necessary for the maximum deviations from the nominal dimensions of the finished products. Differences in size with a satisfactory quality of processing should not exceed the range of permissible deviations or tolerances, it is a condition to ensure that the clothes correspond to the size and age-specific group, as well as the so-called «protective zones».

It is known that the main functions of fencing clothes are facilitated by the use of knitted fabrics, the essence of which is aimed at improving (except for protective) operational and technological indicators [8, 9]. However, when stitching parts made of synthetic materials, which include knitted fabrics for the manufacture of fencing clothes, deformation of the material along the seam line is observed, especially when connecting parts with curved contours. Therefore, *the object of this research* is the technological process of manufacturing clothes for professional sports fencing.

The aim of research is to develop recommendations on the selection of rational technological parameters of the filament joints of fencing clothing to be connected while maintaining the achieved tensile strength and a certain level of longitudinal deformation, which does not exceed the permissible deviations of the main measurements according to the time sheet.

2. Methods of research

An analysis of scientific publications shows that the requirements for filament joints ones depend primarily on the type and purpose of clothes, and their quality is a comprehensive indicator that covers aesthetic, operational, mechanical and economic groups of properties [10, 11].

Typically, to obtain filament joints with predetermined properties, researchers solved complex multifactor problems in order to establish optimal technological modes for their implementation [12].

The factors that affect the quality of the filament joints are considered in more detail in [13, 14] and divided into groups:

– by type of weaving and stitch structure;
– by type and properties of the joined materials;
– by type and properties of sewing threads;
– according to the manufacturing technological conditions (number of stitches, tension of sewing threads, stitching speed, diameter of the sewing needle, pressure of the foot on the material);
– according to the seam parameters (the number of joined layers of material, the width of the seam, the number of thread lines, the seam thickness).

To assess the quality indicators of the filament joints, organoleptic, measuring, registration and calculation methods are usually used [15]. When predicting the quality level of the filament joints by an overwhelming majority of scientists, the influence of one factor or another on the breaking strength and elongation at the time of breaking is studied [12–14]. A number of authors in [12, 14] found that the strength of joints is affected by:

– damage caused by improperly selected modes of operation of the transport mechanism;
– tension of sewing threads by wet-heat treatment or by the location of the seams relative to the warp and weft threads of the applied materials of the connected parts of the product.

The possibility of improving the previously known calculation methods appeared on the basis of the strength loops made by the authors in depth studies [16–18]. The geometric models obtained by the authors of [19, 20] for the dependence of optimizing factors on the parameters of the filament joints allow one to choose modes that provide the expected weld properties and can be used as operational cards. As it is known, modeling the process of joining parts of garments using classical methods of mathematical modeling is quite complicated due to the need to take into account a large number of factors and establishing quantitative relationships that will determine the expected quality of the products as a whole [21, 22].

In order to determine the effect of the number of stitches per 10 mm of stitch on the breaking strength and the longitudinal deformation of the filament joints of the clothes for fencing, the authors use mathematical modeling of the technological process of making step-by-step seams of trouser stitches using the experimental design method. To achieve the stated aim, methods are used to determine the breaking strength and extended deformation of the joints.

3. Research results and discussion

Considering the fact that for a mathematical description of the object of research with the required accuracy of linear approximation is not enough, the authors apply rotatable second-order planning (Box plan) [23]. The breaking strength of the thread connection (y_1) is chosen as the optimization criteria, the factors are the number of stitches per 10 mm of stitching-sewn stitches (x_1 – stitch code 401.504) and the number of stitches per 10 mm of finishing stitch (x_2 – stitch code 301). Using the algorithm of actions according to Box plan, a working matrix is constructed (Table 1, 2), after the implementation of which the necessary experimental data are established.

Table 1

Values of factor levels and variation steps

Factors	Variation levels					Variation steps
	–1.414	–1	0	+1	+1.414	
x_1	3.5	4.1	5.5	6.9	7.5	1.4
x_2	2.7	2.8	3.3	3.8	4.0	0.5

Table 2

Planning matrix and experiment results

No. of experiment	Planning matrix		Working matrix		Breaking strength of the seam *P*, N	Longitudinal deformation of joints *D*, %
	x_1	x_2	*t*	*h*		
1	+	+	6.9	3.8	1052.0	4.5
2	–	+	4.1	3.8	1001.5	–0.5
3	+	–	6.9	2.8	948.0	3.0
4	–	–	4.1	2.8	929.2	–1.0
5	–1.414	0	3.5	3.3	956.7	–1.5
6	+1.414	0	7.5	3.3	987.5	6.0
7	0	–1.414	5.5	2.7	937.2	0.1
8	0	+1.414	5.5	4.0	1068.0	1.0
9	0	0	5.5	3.3	982.5	0.5
10	0	0	5.5	3.3	982.5	0.6
11	0	0	5.5	3.3	983.5	0.6
12	0	0	5.5	3.3	983.0	0.5
13	0	0	5.5	3.3	980.2	0.5

To determine the breaking strength and longitudinal deformation, samples of the knitted fabric of the StM trademark (Kyiv, Ukraine) are prepared, which is used for the manufacture of fencing clothing of the 2nd level of protection. The samples are prepared taking into account the direction of the position of the looped posts and rows in the joined parts of the step seam of the trousers and using the same sewing equipment. The number of parallel experiments $m=4$.

For a full factorial experiment, the selected type of regression equation corresponds to the dependence:

$$y(x_1,x_2)=b_0+b_1\cdot x_1+b_2\cdot x_2+b_{12}\cdot x_1\cdot x_2+$$
$$+b_{11}\cdot x_1^2+b_{22}\cdot x_2^2, \quad (1)$$

where $b_0, b_1, b_2, b_{12}, b_{11}, b_{22}$ – coefficients of the regression equation.

The experimental results are processed using the Mathcad software and the dispersion homogeneity is checked using the Cochran's criterion (with significance level $q=0.05$). In this case, the condition $G_T>G_P$ is satisfied (0.2880>0.2453). So, the process is reproducible.

Based on the calculation results, a mathematical model is developed for the dependence of the breaking strength on the number of stitches in the seam-sewn and finishing stitches, which is described by the regression equation in encoded form:

$$y_1(x_1,x_2)=982.588+14.091\cdot x_1+45.141\cdot x_2+ \\ +7.938\cdot x_1\cdot x_2-7.265\cdot x_1^2+7.982\cdot x_2^2. \quad (2)$$

The regression equation for natural factors takes the form:

$$f_1(t,h)=1070.68+13.412\cdot t-182.798\cdot h+ \\ +11.339\cdot h\cdot t-3.706\cdot t^2+31.926\cdot h^2, \quad (3)$$

where f_1 – breaking strength of the seam P, N; t – the number of stitches in the seam-sewn stitch; h – the number of stitches in the finishing line.

The regression equations, which are obtained by approximating the data, adequately describe the dependence that is given above (verified using the Fisher criterion). The table value of the Fisher test $F_T=2.34$. The calculated value does not exceed the tabular $F_T>F_P$, i. e. 2.34>1.58 – the model is adequate.

A similar approach is used to obtain equations describing the dependence of the longitudinal deformation of the seams y_2 on the number of stitches in the seam-sewn and finishing stitches with the same parameters:

– for coded factor values:

$$y_2(x_1,x_2)=0.550+2.467\cdot x_1+ \\ +0.405\cdot x_2+0.263\cdot x_1\cdot x_2+0.887\cdot x_1^2, \quad (4)$$

– for the natural values of the factors:

$$f_2(t,h)=8.684-4.458\cdot t-1.253\cdot h+ \\ +0.375\cdot ht+0.453\cdot t^2, \quad (5)$$

where f_2 – longitudinal deformation of the joints, %; t – the number of stitches in the suture-sewn stitch; h – the number of stitches in the finishing line.

At the same time, the process is reproducible: $G_T>G_P$ (0.2880>0.1142) and is confirmed by the adequacy of the $F_T>F_{model}$, i. e. 2.34>2.31.

Using the obtained regression equations, let's build the response surfaces of the developed models of the dependence of the breaking strength and longitudinal deformation of the seam on the number of stitches in the lines forming the step seam of the trousers (Fig. 1, 2).

The obtained mathematical models clearly demonstrate that an increase in the number of stitches, both in the seam-sewn stitch (t) and in the finishing (h), leads to an increase in the breaking strength of the seam. But this tendency to improve strength is accompanied by an increase in the longitudinal deformation of the seams, and at a certain stage – cutting of knitted fabrics, which ultimately leads to a loss of strength.

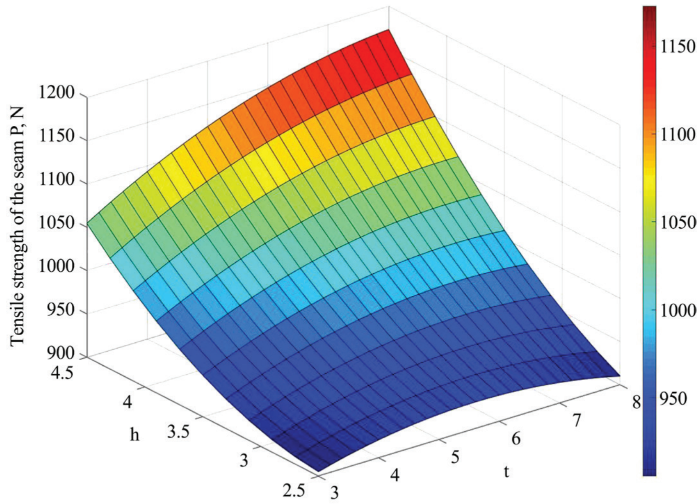

Fig. 1. The diagram of the tensile strength of the seam from the number of stitches in the lines

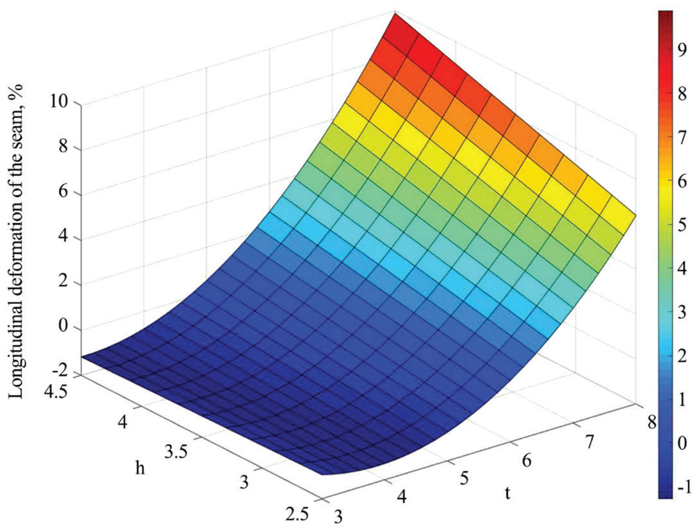

Fig. 2. The diagram of the dependence of the longitudinal deformation of the seam on the number of stitches in the lines

It is established that the number of stitches in the finishing stitch is a significant factor influencing the breaking strength of the studied seams, while the longitudinal deformation of the seams with the same seam parameters is more affected by the number of stitches in the sewing-sewn stitch.

To select the optimal parameters, the main optimization criterion remains the breaking strength of the knitted joints, the normative level of which is ≥970 N.

Since the frequency of the stitch in the finishing stitch is regulated by technical documentation and is within (3.0÷3.5) stitches per 10 mm, it is advisable to determine the values of the stitch parameters (t, h) at which the longitudinal deformation (5) will correspond to zero.

For h=const=3.3, two values of the number of stitches t_0 are determined at which the longitudinal deformation (5) is zero: $t_{01}=1.9$ and $t_{02}=5.2$.

By substituting the parameters t_{01} and t_{02} in the equation for the dependence of the breaking strength on the number of stitches (4), let's obtain:

1) h=const=3.3; $t_{01}=1.9$: $f_1(t, h)=900$ N;
2) h=const=3.3; $t_{02}=5.2$: $f_1(t, h)=979$ N.

Since the ultimate strength value is ≥970 N, the stitch parameters according to the first embodiment do not satisfy a certain condition of the weld strength.

At h=3.3 and t_{02}=5.2, the seam strength meets the requirements and such parameters can be recommended as optimal.

However, it is practically impossible to achieve exact observance of the indicated line parameters at the technological level of modern equipment. It is advisable to establish rational parameters of the seams that would satisfy the conditions of the seam strength and the permissible deviation of the main measurements according to the time sheet. Rational parameters of the number of se in the seams for the materials under study are those in which the tensile strength of the seam corresponds to ≥970 N, and the longitudinal deformation does not exceed ±2.0 %.

Using the above algorithm for determining the parameters of the seam, according to equation (5), let's determine the number of stitches t at h=const=3.3 and a strain level of 2.0 %: t_1=0.9 and t_2=6.2.

4. Conclusions

In the course of the study, rational parameters for the number of stitches in the suture-sewing and finishing stitching lines for the studied materials of fencing clothes are proposed for which the tensile strength of the seam is ≥970 N and the longitudinal deformation does not exceed ±2.0 %, namely: t–(5.0÷6.5) stitches/10 mm, h–(3.0÷3.5) stitches/10 mm.

The obtained results prove the possibility of using mathematical modeling methods to predict the quality of knitted joints of clothing parts for professional sports fencing. This approach is of practical importance and can be applied both at the stage of designing the technology of manufacturing clothes for professional sports fencing when choosing processing modes for new materials, and at the stage of manufacturing and quality control of performed operations.

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