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Forecasting of Integrated Knitted Fabric Quality Metrics

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Abstract

The production of integrated double-layer knitted fabric with specified functional properties requires a comprehensive analysis of interaction between the parameters of a knitting process and fabric quality metrics. The problems, which consider multiple interconnected quality indicators, are solved by means of mathematical optimization and involve the use of modern computer technology.

On the basis of regression dependencies, set up experimentally, we developed a specialized computer program. It allows finding knitting parameters, which provide optimal balance between all the quality indicators of a readymade knitted fabric. The Simplex method of linear programming set up the basis for the algorithm of solution of the multi criterion optimal control problem.

Keywords

Integrated knit; Double-layer knitted fabric; Quality metrics designing; Knockover depth; Knitting parameters; Linear programming; Computer software; Mathematical optimization

Introduction

Integrated knit belongs to the class of multifunctional textile materials which are widely used in manufacturing of clothes for special purposes, in particular for sports and tourism. Thus, clothes created on the basis of integrated knitwear absorb moisture released by human body and provide its transfer to the outer layer. As a result the human body remains dry [1].

The use of means and methods of mathematical optimization for the research and mathematical description of the process makes it possible to predict the functional properties of knitwear and manage the process of knitting. In terms of manufacturing the knitted structure parameters, that provide specified quality properties, are determined by the selection of knitting parameters. Very often optimization index of one parameter leads to deterioration of another one. It is a long and laborious process. Today the problem solution of integrated knitwear quality metrics designing by means of mathematical modeling of the parameters of its structure and properties is an urgent task for knitting companies [2,3].

The ultimate goal of such kind of designing consists in solving the problem of development of recommended technological modes of knitwear manufacture taking into account a set of structure parameters and consumer characteristics. The use of mathematical optimizing means and methods for the research and mathematical description of the process allows to predict the functional properties of knitwear and to manage the knitting process.

The aim of the research is to develop the mathematical algorithm of the structure of engineering parameters and functional properties of knitted fabric. The simplex method of linear programming is used to solve the optimization problem. The knitting process optimization is realized on the basis of established multivariate regression models [4,5].

Experimental

For the functional underwear manufacturing we have proposed a double-layer weft knitting structure with the press layers connected by basic yarns [6]. The connecting elements between the layers are arranged in the fabric chequer-wise (Figure 1).

The experimental knitted fabrics were knitted on a circular rib machine 20 gauge with interlock needles arrangement listed in Table 1. The initial knitting process data are presented on Table 1. Linear density is selected in accordance with the knitting equipment gauge and knitted fabric designation. One layer of a knitted fabric is formed by means of a hydrophilic raw material, and the other one and connecting elements – by means of a hydrophobic material.

The knitwear designing process with specified quality metrics presupposes a preliminary study and determination of knitting parameters influence on the structure parameters and properties. A comprehensive full three-factor experiment was planned and realized for this purpose. As the factors are selected the following ones: x_1 – a knock over depth for loops forming on the cylinder needles, x_2 – a knock over depth for loops forming on the dial needles, x_3 – a knock over depth for connecting tuck stitch on dial needles. The knock over depth - knitting equipment parameter, the distance, that is determined by the depth setting of the stich cam, which can be adjusted by adjusting screw [7]. The main level of factors, the interval of variation, the upper and lower factors levels were set up on the basis of a preliminarily - conducted experiment (Table 2). Experimental fabrics were produced by different raw materials in knitting system in accordance with full three-factor experiment planning matrix (Table 3) [8,9].

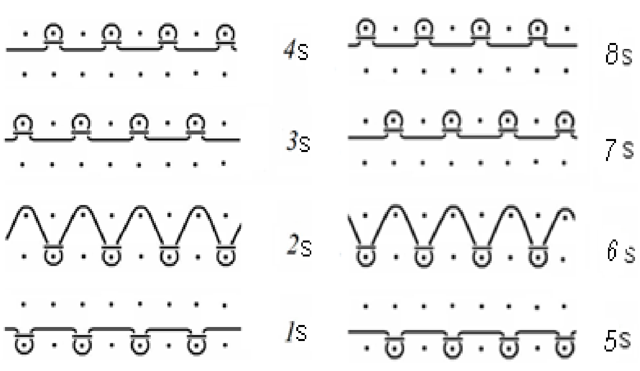

Figure 1: Notation of double-layer weft knitted fabrics.

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The integrated weft knitted fabrics quality is proposed to estimate the following metrics:

y_1 – full tensile deformation along the wale, %

y_2 - full tensile deformation along the course, %

y_3 - elastic deformation along the wale, %

y_4 - elastic deformation along the course, %

y_5 - plastic deformation along the wale, %

y_6 - plastic deformation along the course, %

y_7 – permanent deformation along the wale, %

y_8 - permanent deformation along the course, %

y_9 - height of liquid raising along a wale on the cotton yarns side, mm

y_{10} - height of liquid raising along a course on the cotton yarns side, mm

y_{11} - height of liquid raising along a wale on the synthetic threads side, mm

y_{12} - height of liquid raising along a course on the synthetic threads side, mm

y_{13} - hygroscopic property, %

y_{14} - shrinkage in length,%

y_{15} - shrinkage in width, %

y_{16} – breathability, dm^3/m^2c

y_{17} – wales per 100 mm of fabric

y_{18} - courses per 100 mm of fabric

y_{19} - fabric weight, g/m^2

y_{20} – loop length formed by the cylinder needle from synthetic threads, mm

y_{21} - loop length formed by the dial needle from cotton yarns, mm

y_{22} - loop length with connecting tuck loop formed by the dial needle from synthetic threads, mm.

As a result of experimental data, statistical processing are derived mathematical regression of quality metrics y_1-y_{22}. Tables 3 and 4 present the obtained regressive mathematical dependence (models).

The solution of the problem of optimization requires the definition of compromise properties of technological knitting parameters (x_i) by set restrictions on quality metrics (y_i). Restrictions on the quality metrics are established on the basis of obtained regression models using experimental ranges of values x_i (Table 5).

Results and Discussions

Optimization of one of the parameters may lead to a different parameter that would cause an invalid value. It is therefore necessary to consider changing of all parameters simultaneously. The solution of this problem is a compromise: such a combination of the factors x_1, x_2, x_3 when parameters y_1 - y_{22} possibly do not reach their optimal values, but remain within the framework of their existence and provide possibly the best quality metrics.

As the factors x_1, x_2, x_3 are limited by possibilities of a knitting equipment and established on the basis of normal conditions of the knitting process without disturbances and faults, they cannot change (increase or decrease) in an unlimited way. In addition, the controlled variables cannot be negative, namely: $x_1 \geq 0$, $x_2 \geq 0$, $x_3 \geq 0$. The properties of admitted factors are determined by experimental investigations carried out by means of the above mentioned knitting equipment for a certain raw material and structure. The problem is to find such x_i which satisfies the condition of non-negativity and quality metrics limitation (y_i) [10,11].

In this case one or more functions, selected in the course of stating the problem, are maximized or minimized. The objective function, which is to be minimized or maximized, is a linear function of its variables. The restrictions on these variables are linear too.

On the basis of objective functions y_i, selected controlled variables x_1, x_2, x_3 and formalized restrictions, obtained in the course of conducting an experiment, a special programming product was created, that might be used in technological sphere. It allows to design the whole process of developed double-layer knitted fabrics production starting since the knitting parameters (x_i) to the parameters of its structure and properties (y_i) by computer means. As the indicators of rational technological parameters of a knitting process we consider the complex of integrated knitted fabrics quality metrics.

The newly-created program allows the user to perform calculations of technological knitting parameters in two modes: "design mode" and "optimization mode" automatically.

To make calculations in the "optimization mode" (Figure 2) the user selects the optimization criterion and specifies the optimization direction: maximum or minimum. Besides choosing the objective function, the technologist may also impose limitation on any of the quality metrics provided in calculations by moving the sliders. In the automatic mode there is a calculation of the best combinations

Table 1: Initial knitting process data for knitted fabric production.

Fabric number	Raw materials in knitting system	Linear density, tex	Fabric weight, g/m²	Wales/ 100 mm	Courses/ 100 mm
1	3s, 4s, 7s, 8s – cotton 1s, 2s, 5s, 6s – polyester	20 × 2 16,7	474,55	119	154
2	3s, 4s, 7s, 8s – cotton 1s, 2s, 5s, 6s – polypropylene	20 × 2 16,7	496,80	120	150

Table 2: Experimental conditions.

Experimental conditions	i - factor coded values			i - factor natural values, мм		
	x_1	x_2	x_3	x_1	x_2	x_3
Main factor level	0	0	0	2	2.5	2
Interval varying factors	1	1	1	0.25	0.25	0.25
Upper level factor	+1	+1	+1	2.25	2.75	2.25
Lower level factor	-1	-1	-1	1.75	2.25	1.75

Table 3: Design matrix of experiment.

Factor	Research number and factor coded values							
	1	2	3	4	5	6	7	8
x_0	+	+	+	+	+	+	+	+
x_1	-	+	-	+	-	+	-	+
x_2	-	-	+	+	-	-	+	+
x_3	-	-	-	-	+	+	+	+

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Table 4: Experimental data processing results: objective functions y_i (quality metrics).

Regression mathematical dependences, fabric 1	Regression mathematical dependences, fabric 2
$y_1 = 12.87 + 5.0x_1 + 4.0x_2 + 4.5x_3$	$y_1 = -1.88 + 2.0x_1 + 3.5x_2 + 3.0x_3$
$y_2 = -8.36 + 3.5x_1 + 4.5x_2 + 3.0x_3$	$y_2 = 4.94 + 1.75x_1 + 1.25x_2 + 1.25x_3$
$y_3 = 21.38 - 1.0x_1 - 2.5x_2 - 1.0x_3$	$y_3 = 24.81 - 1.75x_1 - 1.75x_2 - 2.25x_3$
$y_4 = 22.3 - 1.5x_1 - 2.0x_2 - 1.5x_3$	$y_4 = 18.69 - 1.25x_1 - 1.25x_2 - 1.25x_3$
$y_5 = -23.44 + 4.25x_1 + 4.25x_2 + 3.75x_3$	$y_5 = -16.44 + 2.25x_1 + 3.25x_2 + 3.25x_3$
$y_6 = -7.06 + 1.75x_1 + 1.25x_2 + 1.25x_3$	$y_6 = -7.06 + 1.75x_1 + 1.25x_2 + 1.25x_3$
$y_7 = -10.81 + 1.75x_1 + 2.25x_2 + 1.75x_3$	$y_7 = -10.25 + 1.5x_1 + 2.0x_2 + 2.0x_3$
$y_8 = -14.53 + 2.5x_1 + 3.0x_2 + 2.0x_3$	$y_8 = -6.69 + 1.25x_1 + 1.25x_2 + 1.25x_3$
$y_9 = 199.44 + 7.25x_2$	$y_9 = 158.75 + 16.5x_2$
$y_{10} = 264.94 - 11.25x_2$	$y_{10} = 255.06 - 11.75x_2$
$y_{11} = 170.44 + 7.25x_1 + 6.25x_3$	$y_{11} = 141.94 + 13.25x_1 + 7.75x_3$
$y_{12} = 268.81 - 7.25x_1 - 10.25x_2 - 6.75x_3$	$y_{12} = 283.13 - 12.5x_1 - 11.0x_2 - 10.5x_3$
$y_{13} = 10.05 - 0.55x_1 - 0.44x_2$	$y_{13} = 13.19 - 1.14x_1 - 1.54x_2$
$y_{14} = -6.38 + 2.5x_1 + 2.5x_2 + 3.0x_3$	$y_{14} = -16.63 + 2.0x_1 + 3.0x_2 + 5.0x_3$
$y_{15} = 24.13 - 1.5x_1 - 2.0x_2 - 1.5x_3$	$y_{15} = 29.0 - 3.5x_1 - 1.5x_2 - 2.5x_3$
$y_{16} = -77.08 + 16.44x_1 + 29.2x_2 + 51.39x_3$	$y_{16} = -106.08 + 18.26x_1 + 24.29x_2 + 56.73x_3$
$y_{17} = 129.25 - 4x_3$	$y_{17} = 132.32 - 4.25x_3$
$y_{18} = 272.75 - 14.0x_1 - 19.5x_2 - 15.5x_3$	$y_{18} = 283.15 - 12.05x_1 - 13.55x_2 - 30.8x_3$
$y_{19} = 658.33 - 25.28x_1 - 29.63x_2 - 23.38x_3$	$y_{19} = 668.98 - 17.38x_1 - 23.93x_2 - 24.03x_3$
$y_{20} = 0.42 + 1.83x_1$	$y_{20} = 0.11 + 1.86x_1$
$y_{21} = -0.33 + 2.08x_2$	$y_{22} = 0.05 + 1.28x_1 + 1.95x_3$
$y_{22} = 0.05 + 1.28x_1 + 1.95x_3$	$y_{22} = 0.1 + 1.23x_1 + 1.75x_3$

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Table 5: The ranges of integrated knitted fabrics quality metrics.

The minimum value of the quality metric		Quality metric y_i	The maximum value of the quality metric	
fabric 1	fabric 2		fabric 1	fabric 2
12.76	14.75	y_1	19.51	19.00
13.14	13.00	y_2	18.64	15.13
10.01	11.00	y_3	12.26	13.87
10.05	9.63	y_4	12.55	11.50
0.12	0.50	y_5	6.25	4.87
0.50	1.00	y_6	4.75	3.13
0.38	0.38	y_7	3.25	3.13
0.10	0.50	y_8	3.85	2.37
215.75	195.88	y_9	219.38	204.13
234.00	222.75	y_{10}	239.63	228.62
194.07	178.69	y_{11}	200.82	189.19
209.12	201.13	y_{12}	221.25	218.13
7.60	6.39	y_{13}	8.10	7.73
8.87	2.37	y_{14}	12.87	7.37
11.88	11.38	y_{15}	14.38	15.13
107.32	79.81	y_{16}	155.84	129.45
120.25	122.76	y_{17}	122.25	124.88
152.75	149.48	y_{18}	177.25	177.68
467.36	510.00	y_{19}	506.51	542.67
3.62	3.37	y_{20}	4.538	4.30
4.35	4.35	y_{21}	5.39	5.36
5.70	5.32	y_{22}	7.32	6.81

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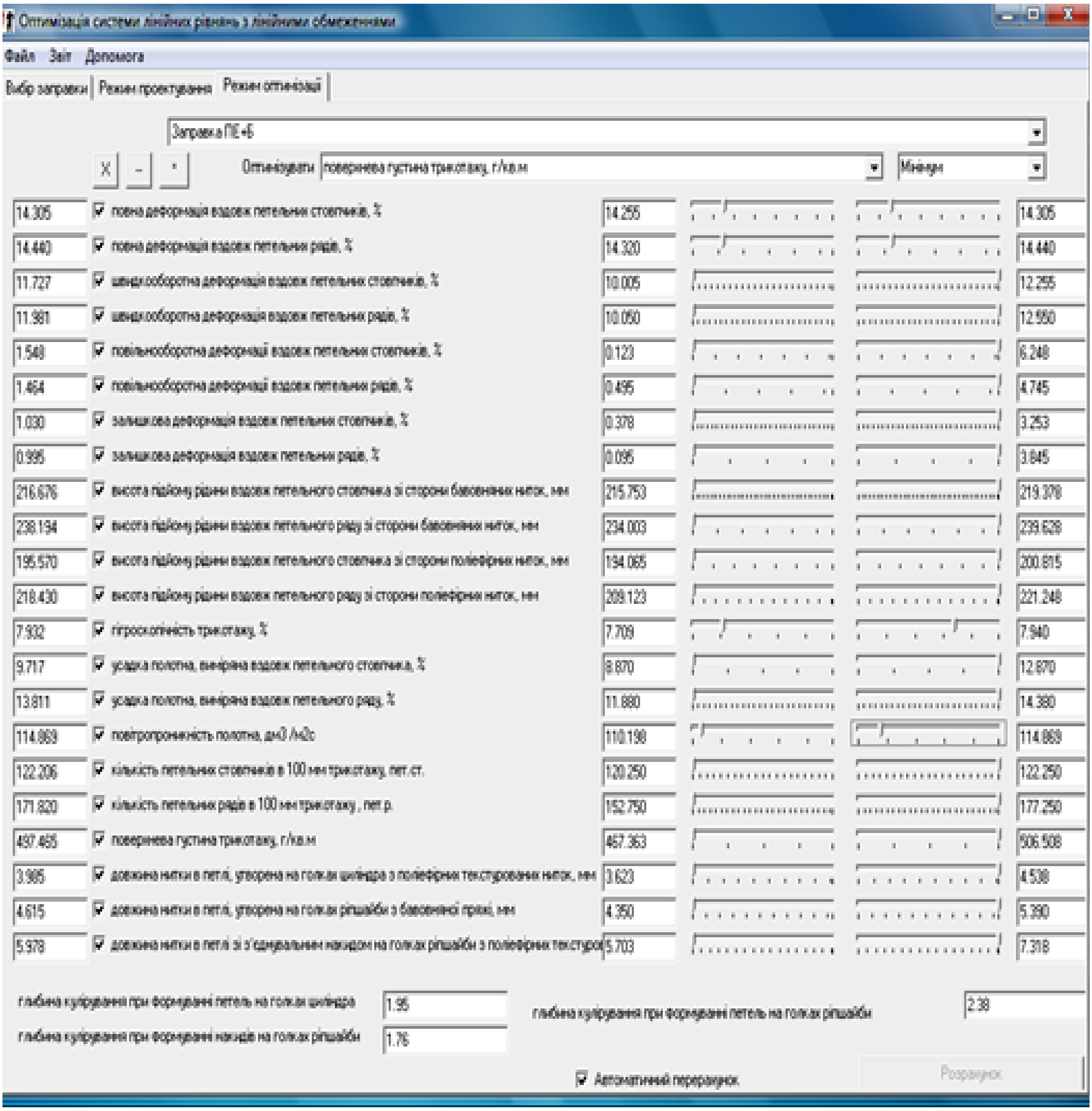

Figure 2: "Optimization mode" screen window.

of knitting parameters (selected factors x_1, x_2, x_3), that satisfies the demands stated by the user, and the expected values of quality metrics (objective functions y_i).

In the "design mode" the expected quality metrics of knitted fabric (objective functions y_i) are calculated on the basis of selected knitting parameters (input parameters x_1, x_2, x_3) within the possible range of their existence.

The developed software product application provides a solution to the search of rational technological modes of double-layer knitted fabrics production with specified structure parameters and properties; it allows to reduce the material costs for the development and implementation of its production. Optimization of quality metrics and the process of production of knitted fabric for the functional purpose by computer means provides a significant economic effect and is a component of successful functioning of any modern knitting enterprise.

Conclusion

Mathematical linear dependences $y_i = f(x_1, x_2, x_3)$ have been determined experimentally. They describe the interrelation between the knitting parameters $f(x_1, x_2, x_3)$ and consumer properties of double-layer knitted fabrics y_i (Table 3).

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The design optimization problem of integrated double-layer knitted fabrics with the specified structure parameters and properties has been solved by the simplex method of linear programming. The complex of specified knitwear quality metrics determines rationality of technological parameters of knitting process.

The computer software of knitting mode parameters designing (x_1, x_2, x_3) for production of integrated double-layer knitted fabrics with specified properties was created.

The software algorithm provides the choice of the best solution from the suggested ones, that satisfies fixed limitation on knitwear quality metrics (y_i) and technological knitting parameters (x_1, x_2, x_3).

The suggested algorithm can be used by technologist at double-layer knitted fabrics designing of another raw composition subject to availability of regression dependencies $y_i = f(x_1, x_2, x_3)$.

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