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CHANGE IN TECHNOLOGICAL AND QUALITATIVE INDICATORS OF CARD SLIVER FROM LOW-GRADE FIBER AND FIBROUS WASTE DURING THE CARDING PROCESS ON MODERN CARDING MACHINES

Nafisa Odilkhonova
PhD, Senior teacher, Namangan Institute of Engineering and Technology, Namangan, Uzbekistan
E-mail: nilupa.op@mail.ru

Lastochkin Pavel
PhD student, Namangan Institute of Engineering and Technology, Namangan, Uzbekistan
E-mail: lastochkin_pavel92@mail.ru

Abstract

The study of the factors influencing the course of the carding process and the quality of the carding sliver produced from low-grade fiber and fibrous waste, or rather the modeling of its unevenness, is one of the most actual tasks in the modern textile industry.

In this article, researches and experiments were carried out to identify the influence of factors affecting the content of neps in the card sliver and a complex indicator of the structure of the card sliver.

Using mathematical methods for planning experiments, a general regression model of the object under study was obtained for a relatively small number of tests and an isometry of the dependence of the factors under study on the quality of the card sliver was constructed using the MatCad computer program.

Based on the studies of the process of carding low-grade cotton fiber and fibrous waste, as well as the joint analysis of the obtained regression and isometric equations based on technological and economic requirements, results were obtained for the analysis and optimization of the carding process on modern carding machines.

Keywords: carding, carding sliver, factors, low-grade fiber, fibrous waste, regression model, isometry, licker-in cylinder, flats.

Introduction

The rapid growth in demand for yarn, as well as the expansion of its assortment, requires the improvement of technological processes and equipment, as well as the expansion of the range of raw materials. Since the increase in prices for new equipment and raw materials will lead to an increase in the cost of yarn. The development of new complex scientific and practical approaches of the textile industry scientists is the optimal solution to this problem. [1; 2].

One of the ways to reduce the cost of yarn is the complex use of low-grade cotton fiber and fibrous waste. However, when using low-grade cotton fiber and fibrous waste, a new challenge arises - to identify opportunities to ensure production efficiency.

Today, textile manufacturers are interest in recycling textile waste. As you know, during processing of cotton fiber, depending on the technological process, waste of several types and various forms is formed. Recycling this fibrous waste can be a solution to reduce raw material costs as well as a contribution to environmental protection.

In order to reduce the negative impact of low-grade cotton fiber and fibrous waste when added to sorting, in the preliminary design of the yarn properties, it is necessary to take into account the factors of technological processes that affect its structural change.

Much research by researchers has focused on the use of recycled fiber in the production of various fiber products. So, for example, in the studies of J.P. Bruggemann [3] it is said that the recovered fibers can be reused in the production of yarn by the open end spinning method, and recommended to carefully study the proportion of secondary raw materials blended with the primary material. B. Wolfhorst [4] determined that up to 20% recycled fiber can be blended with virgin raw materials without noticeable quality changes. The qualitative composition of fibrous waste generated during various technological processes, their dependence on the composition of the primary fibrous blend for spinning, as well as the analysis of the possibility of further use were investigated in the work. [5].

Cleaning efficiency, which is an important and key indicator of fiber preparation systems for spinning, depends on the design and processing capabilities of the equipment installed.

At the first stage of processing, the fibers must be loosened, cleaned and mixed as much as possible. After processing on a blowroom, fibrous waste and low-grade fiber are re-cleaned on a card. In addition, scientists and researchers have theoretically and

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practically studied the integration of technologies and equipment for the processes of loosening and cleaning, carding and preparation of the sliver for spinning in the production of yarn, and also studied the factors affecting the fibrous product during carding. [6...14]. In studies devoted to the efficiency of the carding process, factors such as belt unevenness, carding quality and equipment productivity were taken into account. Each of the above factors was optimally adopted for specific conditions and raw materials[15].

In their research work, Z. Zhidan and S. Pengiz [16] conducted research to determine the layout between the fixed segments and the licker-in cylinder in the rear carding zone of the card, as well as the speed of the licker-in cylinder. H. R. Sheikh [17] also in his research studied the influence of the fixed segments of the carding machine on the produced carding sliver. D. Simpson [18] and others investigated the influence of the carding speed and rotation of the main drum on the productivity of the spinning process. The peculiarity of low-grade cotton fibers and fibrous waste is that they contain a large amount of defective fibers and trash. Therefore, this kind of fiber must be given special attention during carding and intensive processing.

On a card, the cleaning process is mostly carried out in the area of the licker-in cylinder. Licker-in cylinder speed is an important factor in maximizing fiber separation and cleaning. When studying the composition of fibrous waste, it was determined that they contain many tangled fibers and seed skins with fibers. Defects in fibrous waste lead to the formation of a number of problems during the process of silver forming and spinning, as well as to a decrease in the quality of the yarn produced.

On the basis of the above analyzes and studies, as well as our conclusions from preliminary practical studies, the task was set to study the effect of low-grade cotton fibers and fibrous waste on the course of the carding process and changes in the quality and composition of the fibrous product produced on modern carding machines.

Methods

Performing the above task requires a lot of practical research. The use of mathematical methods for planning experiments makes it possible to obtain a mathematical model of the investigated object in a relatively small number of tests, which simultaneously allows making optimal decisions.

When investigating the "stationary" extreme field of the factor space, the possibility of planning experiments at different levels was analyzed. Considering the possibility of changing the measurement levels taking into account three factors, it was decided to conduct research using a central non-composite experimental matrix (CNCEM)[19].

Taking into account all the conditions, a three-factor study of the process of carding fibrous waste was carried out to optimize it. The purpose of optimization is to identify important factors that influence the carding process.

In the study, the complex index (CI) of the structure of the sliver was investigated to assess the intensity of processing of the fibrous material. The complex fiber index indirectly characterizes the separation of complex elements (fiber bundles) into elementary fibers [20].

The optimization parameters, taking into account the quality requirements of the fleece and the card sliver made from fibrous waste, i.e. the degree of their cleaning and straightening, are as follows:

Y_1 - neps count in the card sliver;

Y_2 - CI of card sliver structure.

Taking into account theoretical studies of the carding process, the results of a literature review and preliminary studies, the following factors were selected that affect the qualitative parameters of the process optimization:

X_1 - licker-in cylinder speed, min^{-1};

X_2 - distance between the licker-in cylinder and the knife, mm;

X_3 - flats speed, mm/min.

Results

The factors influencing the optimization parameters, as well as their range of variability and justification are as follows:

Licker-in cylinder speed. It is known that the licker-in cylinder of a carding machine is designed for the rapid opening, cleaning and transfer of the fibrous layer to the main drum [21]. The licker-in cylinder area is important in separating the fiber bundles into filaments and removing trash and neps. In this area, 70-80% of the fiber bundles separated into individual fibers and foreign matter and neps released from the fibrous material to the same extent [12].

It was determined [22] from the research that with an increase in the rotation speed of the licker-in cylinder from 900 min^{-1} to 1500 min^{-1}, the number of undivided fiber

bundles is 25-17%, the neps count in 1 gram of carding is 110-230, and the unevenness of the card sliver decreased from 4,25% to 3,80%.
Based on the above, we decided in our research to take the licker-in cylinder speed in the range of 800-1060 min^{-1}. The cylinder speed limitation was determined by examining the influence of the licker-in cylinder rotation speed and the machine specifications.

Distance between the licker-in cylinder and the knife. The knife placed under the licker-in cylinder plays an important role in the cleaning of fibrous material. Changing the distance between the knife and the licker-in cylinder affects the cleaning efficiency and also affects the beating of the fibrous material particles. However, the same factor affects the amount of waste generated. Considering these and other aspects, we have adopted a distance of 0,12-0,38 mm.

Flats speed.
Researches have shown that the higher the degree of contamination of the fibrous material, the higher the speed of movement of the flats is assumed. As a result of an increase in the speed of the flats, the amount of the fiber waste from flats increases, thereby improving the cleaning of the fibrous mass [24-34]. Proceeding from this, it is recommended to take the speed of movement of the flats depending on the raw material being processed, that is, the staple length of the fiber, the degree of fiber clogging and the amount of the fiber waste from flats. Based on the analysis of practical experiments and technological requirements, the flats speed was taken in the range of 156-300 mm/min.
The levels of changes in the studied factors and their intervals are shown in Table 1.

Table 1. The levels of change of the factors under study and their intervals

Name and designation of factors	Symbol	Change levels			Interval of change
		-1	0	+1	
$n_{l.c.}$ - licker-in cylinder speed, min^{-1}	x_1	800	930	1060	130
r - distance between the licker-in cylinder and the knife, mm	x_2	0,12	0,25	0,38	0,13
ϑ_f - flats speed, mm/min	x_3	156	228	300	72

INNOVATIVE TECHNOLOGICA
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On a general basis, we are moving from the natural values of the coefficients to the coded designations. The results of constructing a central non-composite experimental matrix and preliminary processing of digital data obtained during the experiments are shown in Table 2.

Based on the results of the experiments, we calculate a multidimensional mathematical model of secondary regression. Because of this experiment, we can get the following general regression model:

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

Let's write down the equation taking into account the regression coefficients determined in the accepted order:

$$Y_R = 143{,}7 - 11{,}75x_1 + 24x_2 + 11{,}75x_3 - 0{,}5x_1x_2 + 0{,}5x_1x_3 + \\ + 2{,}5x_2x_3 + 4{,}166x_1^2 + 7{,}666x_2^2 + 4{,}416x_3^2. \quad (2)$$

Table 2. Central Non-Composite Experimental Matrix

№	Factors			x_1x_2	x_1x_3	x_2x_3	x_1^2	x_2^2	x_3^2	$\bar{Y}_1$	$\bar{Y}_2$	$S_u^2\{Y_1\}$	$S_u^2\{Y_2\}$
	x_1	x_2	x_3										
1	+	+	0	+	0	0	+	+	0	163	282	42	26
2	+	-	0	-	0	0	+	+	0	119	259	50	38
3	-	+	0	-	0	0	+	+	0	187	324	42	32
4	-	-	0	+	0	0	+	+	0	143	302	42	42
5	+	0	+	0	+	0	+	0	+	149	326	62	38
6	+	0	-	0	-	0	+	0	+	123	276	14	14
7	-	0	+	0	-	0	+	0	+	170	312	62	26
8	-	0	-	0	+	0	+	0	+	146	306	38	11
9	0	+	+	0	0	+	0	+	+	193	339	78	14
10	0	+	-	0	0	-	0	+	+	166	313	98	42
11	0	-	+	0	0	-	0	+	+	137	304	24	38
12	0	-	-	0	0	+	0	+	+	120	267	26	56
13	0	0	0	0	0	0	0	0	0	146	294	8	18
14	0	0	0	0	0	0	0	0	0	142	301	14	26
15	0	0	0	0	0	0	0	0	0	143	297	18	8

Then we estimate the significance of the regression coefficients using the Student's method.

$$t_R\{b_i\} = \frac{|b_i|}{S\{b_i\}} \quad (3)$$

$$t_R\{b_0\} = \frac{147{,}3}{2{,}0} = 71{,}85; \quad t_R\{b_1\} = \frac{11{,}75}{1{,}581} = 7{,}432;$$

ISSN: 2776-0987 Volume 2, Issue 12, Dec., 2021

$$t_R\{b_2\} = \frac{24}{1{,}581} = 15{,}18; \qquad t_R\{b_3\} = \frac{11{,}75}{1{,}581} = 7{,}432;$$

$$t_R\{b_{12}\} = \frac{0{,}5}{2{,}236} = 0{,}2236; \qquad t_R\{b_{13}\} = \frac{0{,}5}{2{,}236} = 0{,}2236; \quad t_R\{b_{23}\} = \frac{0{,}5}{2{,}236} = 1{,}118;$$

$$t_R\{b_{11}\} = \frac{4{,}166}{2{,}50} = 1{,}667; \quad t_R\{b_{22}\} = \frac{7{,}666}{2{,}50} = 3{,}066; \quad t_R\{b_{33}\} = \frac{4{,}416}{2{,}50} = 1{,}766.$$

The tabular value of the Student's criterion is obtained from Appendix 3 [19]:

$$t_m\left[P_Д = 0{,}95;\ f\left\{S_ц^2\right\} = 3-1=2\right] = 2{,}77$$

If the calculated value of the criterion is less than the table value, then the coefficient is not significant and we remove it from the equation.

Research has shown that the coefficients $b_0, b_1, b_2, b_3\, b_{22}$ are essential for the parameters under study:

Let's rewrite the equation with significant coefficients:

$$Y_{1R} = 143{,}7 - 11{,}75x_1 + 24x_2 + 11{,}75x_3 + 7{,}666x_2^2 \qquad (4)$$

We determine the adequacy of the above regression mathematical model using the Fisher criterion.

$$F_R = \frac{S_{над}^2\{Y\}}{S^2\{\bar{Y}\}}$$

For simplicity, calculations are shown in the form of Table 3.

Table 3. Adequacy of the regression mathematical model

№	$\bar{Y}_u$	Y_{Ru}	$(Y_{Ru} - \bar{Y}_u)$	$(Y_{Ru} - \bar{Y}_u)^2$
	163	162,916	-0,0840	0,0071
	119	114,916	-4,0840	16,6791
	187	186,416	-0,5840	0,3411
	143	138,416	-4,5840	21,0131
	149	143	-6,0000	36,0000
	123	119,5	-3,5000	12,2500
	170	166,5	-3,5000	12,2500
	146	143	-3,0000	9,0000
	193	186,416	-6,5840	43,3491
	166	162,916	-3,0840	9,5111
	137	138,416	1,4160	2,0051
	120	114,916	-5,0840	25,8471
				188,2524

ISSN: 2776-0987 Volume 2, Issue 12, Dec., 2021

$$\sum_{u=1}^{N-N_ц+1}(Y_{Ru}-\overline{Y}_u)^2=188{,}25$$

$$S^2_{над}\{Y\}=\frac{188{,}25}{4}=47{,}063$$

If the calculated value of the criterion is less than the value indicated in the table, then the coefficient is adequate and indicates the correctness of the calculations.

$$F_R=\frac{S^2_{над}\{Y\}}{S^2\{\overline{Y}\}}=\frac{47{,}063}{309}=0{,}152$$

$$F_{ж}\left[P_Д=0{,}95;\ f\left\{S^2_{над}\{Y\}\right\}=15-5-(3-1)=8;\ f\left\{S^2_u\right\}=3-1=2\right]=4{,}46\ (19{,}37)$$

$$F_R=5{,}72<19{,}3=F_{ж}$$

Thus, the resulting regression mathematical model with sufficient accuracy represents the process under study.
The processing of the results of the study of the CI of the structure of the tape carried out in full accordance with the above method.
According to the results, the equation for determining the regression coefficients has the following general form:

$$Y_R=297{,}3-12{,}62x_1+15{,}75x_2+14{,}875x_3+0{,}25x_1x_2+11{,}0x_1x_3-$$
$$-2{,}75x_2x_3+2{,}293x_1^2+2{,}668x_2^2+9{,}293x_3^2 \qquad (5)$$

Then we again determine the significance of the regression coefficients using the Student's method.
The equation with essential coefficients is as follows:

$$Y_{2R}=297{,}3-12{,}62\cdot x_1+15{,}75\cdot x_2+14{,}875\cdot x_3+11{,}0x_1x_3+9{,}293\cdot x_3^2 \qquad (6)$$

The adequacy of the above mathematical regression model was tested on the basis of Fisher's criterion. The results of the calculations showed that the mathematical regression model accurately reflects the process under study.

Discussion

On the basis of the above mathematical models, isolines were constructed using the MatCad computer program.

INNOVATIVE TECHNOLOGICA
METHODICAL RESEARCH JOURNAL
ISSN: 2776-0987 Volume 2, Issue 12, Dec., 2021

The change in the factors influencing the number of neps in the card sliver Y_1 showed in Figures 1, 2 and 3, and the change in the factors affecting the CI of the sliver structure Y_2 showed in Figures 4, 5 and 6.

Analyzing the obtained isolines, an increase in the speed of the licker-in cylinder of the card machine to an increase in the intensity of openning and cleaning efficiency. Reducing the distance between the licker-in cylinder and the knife not only increases cleaning efficiency, but also increases waste. An increase in the speed of the flats results in an increase in cleaning efficiency and improved fiber carding. However, excessively increasing the speed of the flats may cause the fibers break.

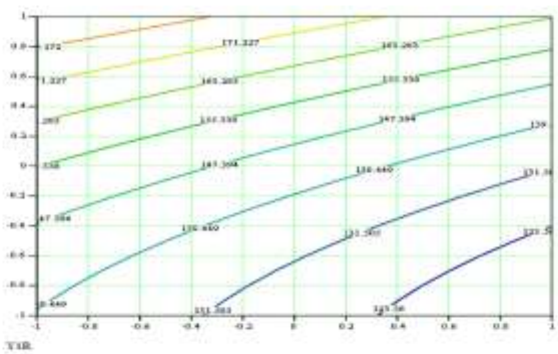

Figure. 1. $x_3 = const$. Isolines of the dependence of the neps count in the card sliver Y_1 on the speed of licker-in cylinder and the distance between the licker-in cylinder and the knife

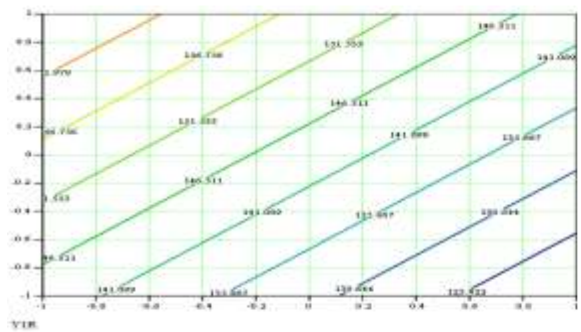

Figure. 2. $x_2 = const$. Isolines of the dependence of the neps count in the card sliver Y_1 on the speed of licker-in cylinder and flats

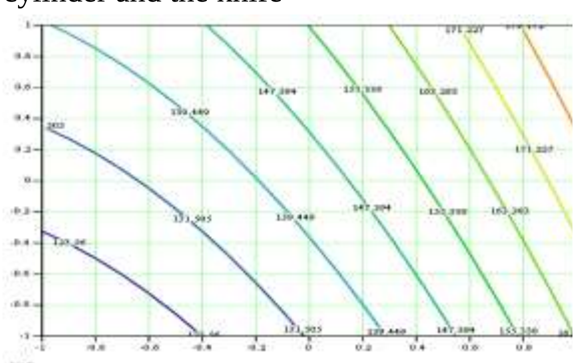

Figure. 3. $x_1 = const$. Isolines of the dependence of the neps count in the card sliver Y_1 on the distance between the licker-in cylinder and the knife and the speed of the flats

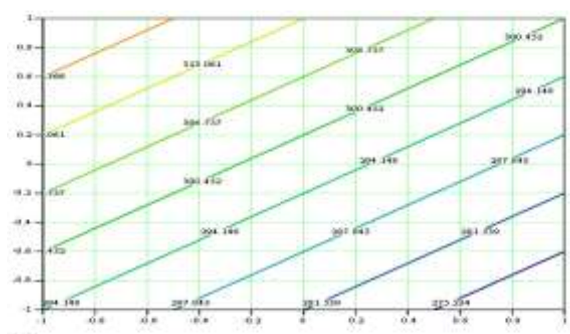

Figure. 4. $x_3 = const$. Isolines of the dependence of the CI of the structure of the card sliver Y_2 on the speed of the licker-in cylinder and the distance between the licker-in cylinder and the knife

INNOVATIVE TECHNOLOGICA
METHODICAL RESEARCH JOURNAL
ISSN: 2776-0987 Volume 2, Issue 12, Dec., 2021

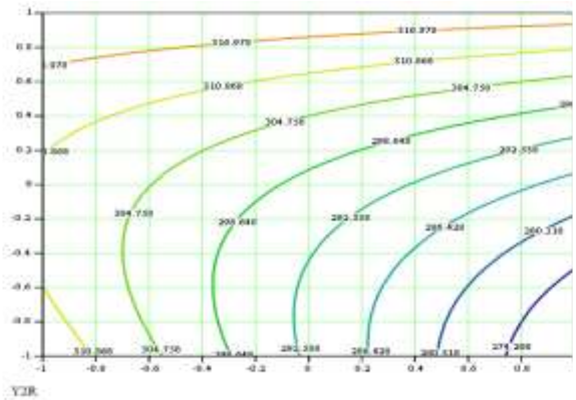

Figure. 5. $x_2 = const$. Isolines of the dependence of the CI of the structure of the card sliver Y_2 on the speed of the licker-in cylinder and flats

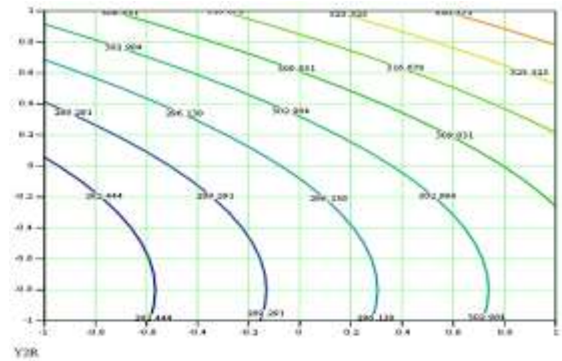

Figure. 6. $x_1 = const$. Isolines of the dependence of the CI of the structure of the card sliver Y_2 on the distance between the licker-in cylinder and the knife and the speed of the flats.

Conclusions

Based on the above research results and based on the calculation of the experiment planning matrix, the following conclusions were made:

Based on the research carried out on the process of carding low-grade cotton fiber and fibrous waste, as well as the joint analysis of the obtained regression and isometric equations based on technological and economic requirements, it gives sufficient results for the analysis and optimization of factors at the following values:

x_1 - licker-in cylinder speed $n_{l.c.}$=1060 min^{-1};

x_2 - distance between the licker-in cylinder and the knife, r = 0,20 mm;

x_3 - flats speed, ϑ_f=250 mm/min.

These results were taken on the basis of a study of the unevenness of the produced card sliver and fiber properties, as well as the amount of waste obtained during the carding process. Therefore, it is advisable to assume that the values of the factors slightly differ from the threshold value and are optimal.

ISSN: 2776-0987 Volume 2, Issue 12, Dec., 2021

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