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THE INFLUENCE OF CARDING PARAMETERS OPTIMIZATION ON THE USEFUL TIME COEFFICIENT OF A ROTOR SPINNING MACHINE

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Abstract: The article presents the results of a study aimed at optimizing the technological parameters of the spinning process using methods of mathematical experiment design and modeling. The main focus is on the influence of the speed regimes of the WEBFEED and IDF-2 systems of modern carding machines on the quality indicators of the carded sliver and yarn, particularly on the linear density irregularity. Experiments conducted under real production conditions made it possible to reduce the number of yarn breaks from 42 to 28 per 1000 spinning positions, increase the winding coefficient from 0.992 to 0.995, and increase the operational time coefficient from 0.979 to 0.988. As a result of implementing the optimized parameters, yarn quality significantly improved: irregularity decreased, breaking strength increased, and the number of defects was minimized. Based on the developed methodology, key operational indicators for the AUTOCORO 9 rotor spinning machine were calculated. It was established that the machine's Useful Time Coefficient (UTC) increased from 0.95 to 0.97, and the Production Rate (PR) increased from 128.25 kg/h to 130.95 kg/h. The annual increase in yarn production volume per machine amounted to 22.68 tons. The obtained results confirm the high efficiency of applying mathematical modeling for improving both the technological and economic indicators of spinning production.

Keywords: spinning process optimization, mathematical modeling, experiment design, yarn quality, useful time coefficient (UTC), production rate, carding machine, rotor spinning machine AUTOCORO 9, economic efficiency, yarn breaks.

Introduction. In the yarn spinning process, key factors determining its properties are the qualitative characteristics of the fiber and the setting parameters of the technological equipment. Establishing optimal parameters that ensure effective interaction of these factors requires conducting a significant number of experimental studies. The application of mathematical methods for experimental design, unlike traditional empirical approaches, allowed for the identification and systematization of a set of factors exerting a combined influence on the process. As a result, a dynamic model of the carding process was developed, as well as a mathematical model of the object under study, which serves as a tool for optimizing technological solutions [1,2].

The conducted research revealed that the choice of optimal parameters for the speed of the receiving rollers of the WEBFEED system on modern carding machines, as well as the speed of the IDF-2 drafting system, significantly affects the quality indicators of the carded sliver and yarn. In particular, these parameters are directly related to linear density irregularity. Experiments conducted under real production conditions allowed for a reduction in linear density irregularity, improvement of the structural and mechanical properties of yarn, minimization of the number of defects, an increase in breaking load, and a reduction in the frequency of sliver and yarn breaks. As a result, yarn with improved qualitative characteristics was obtained, confirming the effectiveness of the proposed methodology[3].

Thus, the optimization of technological parameters in the spinning process based on mathematical modeling and experimental analysis not only enhances the quality of the manufactured product but also ensures the economic efficiency of production by reducing the proportion of waste and improving the operational properties of yarn. [4]

The reduction in the number of sliver and yarn breaks contributes to an increase in the equipment's Useful Time Coefficient (UTC), which, in turn, leads to higher productivity of the spinning machine and an increase in output volumes. This positively impacts the annual economic efficiency of the enterprise, enhancing its profitability [5].

When calculating economic efficiency, a comparison was made between practical and experimental data, including indicators such as the Useful Time Coefficient (UTC) and the Production Rate (PR) of the spinning machine, as well as the qualitative characteristics of the obtained yarn [6,7].

II. Methods. The calculation of the Coefficient of Useful Time (UTC) and the Production Rate (PR) for the AUTOCORO 9 rotor spinning machine was performed as follows [8,9]:

The standard service rate for a spinner (S_s) was determined, taking into account automated bobbin doffing and yarn breakage elimination, using the following formula:

$$S_s = \frac{80000(1-К_{н.о.})\upsilon К_{ф.з.} - (6a-2c)N_b}{(l+b+c+a)2N_b/М + 1{,}33\upsilon(1-К_{н.о.})[N_b t_{л.о.} + 6n_к\sqrt{Т^3} \times \times C_{o.t.}/(10^4\alpha_Т)(t_{с.т.}C_w К_{Т.}/m_{л.} + t_{с.б.}/m_б) + t_{у.}]}, \tag{1}$$

where: Nb - Number of yarn breaks per 1000 spinning positions, units (in practice, this indicator was 42 breaks; during the experiment, it improved to 28 breaks); Cw - Winding coefficient accounting for losses due to non-winding as a result of breaks (according to practical data, the indicator was 0.992, and according to experimental data - 0.995); Co.t. - Coefficient showing the proportion of operational time during a shift (in our case, in practice, this indicator was 0.979, and during the experiment, it amounted to 0.988).

The duration of the spinner's first patrol of the machine service zone after start-up (S_{p1}) was calculated using the following formula:

$$S_{p_1} = \frac{S_s\left[100qt_{b.e.} + \frac{n_к\sqrt{Т^3}S_{p0}t_{c.ch.}}{2\cdot10^4\alpha_Т m_{s.}} + \frac{(l+b+c+a)10^4}{m\upsilon} + \frac{(6a-2c)10^{-4}}{\upsilon S_s}\right]}{10^4\left[1-\frac{S_s}{10^4}\left(\frac{N_b t_{b.e.}}{12} + \frac{n_к\sqrt{Т^3}t_{c.ch.}}{2\cdot10^4\alpha_Т m_{s.}}\right)\right]C_{a.e.}}, \tag{2}$$

where: q - non-spinning (unthreaded) percentage, % (in practice, this indicator was 5.9%; during the experiment, it reached 3.9%); m - number of positions on one side of the machine; $\bar{S}_{p.}$ - average patrol duration:

$$\bar{S}_{p.} = [80000(1-C_{w.})]/N_b$$

The duration of the spinner's second patrol of the service zone (S_{p2}) was determined using the formula:

$$S_{p_2} = \frac{S_s\left[\frac{N_b t_{b.e.}Sp_1}{12} + \frac{n_к\sqrt{Т^3}Sp_1 t_{c.ch.}}{2\cdot10^4\alpha_Т m_{s.}} + \frac{(l+b+c+a)10^4}{m\upsilon} + \frac{(6a-2c)10^4}{\upsilon S_s}\right]}{10^4\left[1-\frac{S_s}{10^4}\left(\frac{N_b t_{b.e.}}{12} + \frac{n_к\sqrt{Т^3}t_{c.ch.}}{2\cdot10^4\alpha_Т m_{s.}}\right)\right]C_{a.e.}}. \tag{3}$$

Table 1. Standardization Chart for the AUTOCORO 9 Pneumomechanical Spinning Machine

No.	Indicators	Unit	Designation	Value
1	2	3	4	5
1	Linear density of yarn	tex	T	19,7
2	Yarn twist coefficient	-	αT	37,9
3	Mass of bobbin with yarn	kg	m_b	2,72
4	Mass of sliver in can	kg	m_s	14
5	Number of spinning rotors on maschine	pcs	M	720
6	Rotation speed of spinning rotor	rpm	n_r	130 000
7	Machine length	m	l	90
8	Machine width	m	b	2,5
9	Spinner's movement speed	m/min	υ	42
10	Distance from machine to spinner's patrol line	m	a	0,75
11	Passage width between machines	m	c	1,5
13	Time spent on yarn break elimination	min	$t_{b.e.}$	0,117
14	Time spent on can change	min	$t_{c.ch.}$	0,5
15	Time spent on bobbin doffing	min	$t_{b.d.}$	0,167
16	Time spent on machine maintenance	min	$t_{y.}$	11
17	Shift duration	min	T_{sh}	480
12	Number of shifts	шт	n_{sh}	3
14	Actual time expenditure coefficient	-	$C_{a.e.}$	0,95
15	Winding coefficient	-	$C_{wind.}$	0,99
16	Non-winding coefficient	-	$C_{n\text{-}w}$	0,993

Using the following formula, the percentage of winding loss due to non-spinning was found:

$$W_l = \frac{0{,}5qS_{p_1}}{T_{sh}n_{sh}} + \frac{\frac{N_b}{1200}\left[(S_{p_1} - \overline{S_p})S_{p_1} + 0{,}5(S_{p_1} - \overline{S_p})S_{P_2} + (S_{P_2} - \overline{S_p})S_{Po_2}\right]}{T_{sh}n_{sh}}. \quad (4)$$

The threading coefficient (C_t) was determined using the following formula:

$$C_t = 1 - W_l/100 \quad (5)$$

Using the following formula and the indicator values obtained above, the Coefficient of Useful Time (UTC) for the AUTOCORO 9 rotor spinning machine was calculated:

$$UTC = C_{o.t.}C_wC_tC_{wind}C_{n-w} \quad (6)$$

The production rate per one AUTOCORO 9 rotor spinning machine, kg/h, was determined using the following formula:

$$P_r = P_{\mathrm{T}} \cdot UTC, \quad (7)$$

where: PT - theoretical productivity of one spinning machine.

Results.

Standard service rate for a spinner in practice:

$$S_{s.p.}=\frac{80000\cdot(1-0{,}992)\cdot 42\cdot 0{,}95-(6\cdot 0{,}75-2\cdot 1{,}5)\cdot 42}{(90+2{,}5+1{,}5+0{,}75)\cdot 2\cdot 42/720+1{,}33\cdot 42\cdot(1-0{,}992)\times}=1008{,}2$$

$$\times\left[42\cdot 0{,}117+6\cdot 130000\cdot\sqrt{19,7^3}\cdot 0{,}979/(10^4\cdot 37{,}9)\times\right.$$

$$\left.\times(0{,}5\cdot 0{,}992\cdot 0{,}99/14+0{,}167/2{,}72)+11\right]$$

Standard service rate for a spinner during the experiment:

$$S_{s.e.}=\frac{80000\cdot(1-0{,}995)\cdot 42\cdot 0{,}95-(6\cdot 0{,}75-2\cdot 1{,}5)\cdot 28}{(90+2{,}5+1{,}5+0{,}75)\cdot 2\cdot 28/720+1{,}33\cdot 42\cdot(1-0{,}995)\times}=996{,}8$$

$$\times\left[28\cdot 0{,}117+6\cdot 130000\cdot\sqrt{19,7^3}\cdot 0{,}988/(10^4\cdot 37{,}9)\times\right.$$

$$\left.\times(0{,}5\cdot 0{,}995\cdot 0{,}99/14+0{,}167/2{,}72)+11\right]$$

Average duration of a service zone patrol:

in practice:

$$\bar{S}_{p.p.}=[80000\cdot(1-0{,}992)]/42=15$$

during the experiment:

$$\bar{S}_{p.e.}=[80000\cdot(1-0{,}995)]/28=14$$

Duration of the spinner's first patrol of the machine service zone after start-up in practice ($S_{p1.p.}$):

$$S_{p_{1p.}}=\frac{1008{,}2\cdot\left[\begin{array}{l}100\cdot 5{,}8\cdot 0{,}117+\dfrac{130000\cdot\sqrt{19,7^3}\cdot 15\cdot 0{,}5}{2\cdot 10^4\cdot 37{,}9\cdot 14}+\\+\dfrac{(90+2{,}5+1{,}5+0{,}75)\cdot 10^4}{360\cdot 42}+\dfrac{(6\cdot 0{,}75-2\cdot 1{,}5)\cdot 10^{-4}}{42\cdot 1008{,}2}\end{array}\right]}{10^4\cdot\left[1-\dfrac{1008{,}2}{10^4}\cdot\left(\dfrac{42\cdot 0{,}117}{12}+\dfrac{130000\cdot\sqrt{19,7^3}\cdot 0{,}5}{2\cdot 10^4\cdot 37{,}9\cdot 14}\right)\right]\cdot 0{,}95}=14{,}6$$

Duration of the spinner's first patrol of the machine service zone after start-up during the experiment ($S_{p1.e}$):

$$S_{p_{1e.}}=\frac{996{,}8\cdot\left[\begin{array}{l}100\cdot 3{,}9\cdot 0{,}117+\dfrac{130000\cdot\sqrt{19,7^3}\cdot 14\cdot 0{,}5}{2\cdot 10^4\cdot 37{,}9\cdot 14}+\\+\dfrac{(90+2{,}5+1{,}5+0{,}75)\cdot 10^4}{360\cdot 42}+\dfrac{(6\cdot 0{,}75-2\cdot 1{,}5)\cdot 10^{-4}}{42\cdot 996{,}8}\end{array}\right]}{10^4\cdot\left[1-\dfrac{996{,}8}{10^4}\cdot\left(\dfrac{28\cdot 0{,}117}{12}+\dfrac{130000\cdot\sqrt{19,7^3}\cdot 0{,}5}{2\cdot 10^4\cdot 37{,}9\cdot 14}\right)\right]\cdot 0{,}95}=12{,}1$$

Duration of the spinner's second patrol of the machine service zone

in practice:

$$S_{p_{2p.}}=\frac{1008{,}2\cdot\left[\begin{array}{l}\dfrac{42\cdot 0{,}117\cdot 14{,}6}{12}+\dfrac{130000\cdot\sqrt{19,7^3}\cdot 14{,}6\cdot 0{,}5}{2\cdot 10^4\cdot 37{,}9\cdot 14}+\\+\dfrac{(90+2{,}5+1{,}5+0{,}75)\cdot 10^4}{360\cdot 42}+\dfrac{(6\cdot 0{,}75-2\cdot 1{,}5)\cdot 10^4}{42\cdot 1008{,}2}\end{array}\right]}{10^4\cdot\left[1-\dfrac{1008{,}2}{10^4}\cdot\left(\dfrac{42\cdot 0{,}117}{12}+\dfrac{130000\cdot\sqrt{19,7^3}\cdot 0{,}5}{2\cdot 10^4\cdot 37{,}9\cdot 14}\right)\right]\cdot 0{,}95}=8{,}1$$

during the experiment:

$$S_{p_{2e.}} = \frac{996{,}8 \cdot \left[\begin{array}{l} \dfrac{28 \cdot 0{,}117 \cdot 12{,}1}{12} + \dfrac{130000 \cdot \sqrt{19{,}7^3} \cdot 12{,}1 \cdot 0{,}5}{2 \cdot 10^4 \cdot 37{,}9 \cdot 14} + \\ + \dfrac{(90 + 2{,}5 + 1{,}5 + 0{,}75) \cdot 10^4}{360 \cdot 42} + \dfrac{(6 \cdot 0{,}75 - 2 \cdot 1{,}5) \cdot 10^4}{42 \cdot 996{,}8} \end{array}\right]}{10^4 \cdot \left[1 - \dfrac{996{,}8}{10^4} \cdot \left(\dfrac{28 \cdot 0{,}117}{12} + \dfrac{130000 \cdot \sqrt{19{,}7^3} \cdot 0{,}5}{2 \cdot 10^4 \cdot 37{,}9 \cdot 14}\right)\right] \cdot 0{,}95} = 7{,}6$$

Percentage of winding loss due to non-spinning

in practice:

$$W_{l.p.} = \frac{0{,}5 \cdot 5{,}8 \cdot 14{,}6}{480 \cdot 3} + \frac{\dfrac{42}{1200} \cdot \left[\begin{array}{c} (14{,}6 - 15) \cdot 14{,}6 + 0{,}5 \times \\ \times\, (14{,}6 - 15) \cdot 8{,}1 + (8{,}1 - 15) \cdot 8{,}1 \end{array}\right]}{480 \cdot 3} = 0{,}031$$

during the experiment:

$$W_{l.e.} = \frac{0{,}5 \cdot 3{,}9 \cdot 12{,}1}{480 \cdot 3} + \frac{\dfrac{28}{1200} \cdot \left[\begin{array}{c} (12{,}1 - 14) \cdot 12{,}1 + 0{,}5 \times \\ \times\, (12{,}1 - 14) \cdot 7{,}6 + (7{,}6 - 14) \cdot 7{,}6 \end{array}\right]}{480 \cdot 3} = 0{,}018$$

Threading coefficient (Ct)

in practice:

$$C_{t.p.} = 1 - 0{,}031/100 = 0{,}99969$$

during the experiment:

$$C_{t.e.} = 1 - 0{,}018/100 = 0{,}99982$$

Coefficient of Useful Time (UTC) for the AUTOCORO 9 rotor spinning machine

in practice:

$$UTC_{p.} = 0{,}979 \cdot 0{,}992 \cdot 0{,}99969 \cdot 0{,}99 \cdot 0{,}993 = 0{,}95$$

during the experiment:

$$UTC_{e.} = 0{,}988 \cdot 0{,}995 \cdot 0{,}99982 \cdot 0{,}99 \cdot 0{,}993 = 0{,}97$$

Productivity per one AUTOCORO 9 rotor spinning machine, kg/h

$$P_T = \frac{n_{\text{к}} \cdot 60 \cdot \text{M} \cdot \text{T}_y}{\text{К} \cdot 1000^2} = \frac{130000 \cdot 60 \cdot 720 \cdot 19{,}7}{820 \cdot 1000^2} = 135 \text{ кг/ч}$$

the standard productivity per one rotor spinning machine in practice was

$$P_{r.p.} = P_{\text{T}} \cdot UTC_{p.} = 135 \cdot 0{,}95 = 128{,}25 kg/\text{h},$$

and during the experiment amounted to

$$P_{r.e.} = P_{\text{T}} \cdot UTC_{e.} = 135 \cdot 0{,}97 = 130{,}95 kg/\text{h}.$$

During the experiment, the following difference in the volume of yarn produced by one machine per year was achieved (considering the annual working time fund - $\text{T}_{y.} = \text{T}_{sh} \times n_{sh.} \times \text{P}_{\text{д}} = 8 \times 3 \times 350 = 8400h.$):

$$\text{P}_{\text{o}} = \left(P_{r.p.} - P_{r.e.}\right)\text{T}_y = (130{,}95 - 128{,}25) \cdot 8400 = 22680kg. = 22{,}68\ tona.$$

Discussion. The conducted research and calculations clearly demonstrate a significant relationship between the settings of technological equipment and the final qualitative and economic results. The traditional empirical approach to adjusting parameters, such as the speed of the WEBFEED delivery rollers and the IDF-2 drafting system, did not allow for a systematic consideration of their combined influence on the process. The application of mathematical experimental design methods made it possible to identify optimal operating zones, which led to a significant reduction in the number of yarn breaks (by 33.3%) and non-spinning (from 5.9% to 3.9%).

The calculation of the spinner's standard service rate (S_s) showed its insignificant change (from 1008.2 to 996.8), indicating the stability of the service system with improved technological indicators. More substantial is the reduction in the duration of service zone patrols: the first patrol (S_{p1}) from 14.6 to 12.1 min and the second patrol (S_{p2}) from 8.1 to 7.6 min. This indicates a decrease in the operational load on personnel and an increase in process stability [10].

A key result is the increase in the integral indicator of equipment efficiency - the Coefficient of Useful Time (UTC) - from 0.95 to 0.97. This increase, due to the improvement of all components ($C_{o.t.}$, C_w, C_t, $C_{wind.}$, C_{n-w}), directly affected the production rate, increasing it by 2.7 kg/h. The cumulative effect over one year of operation of a single machine yields a significant increase in product output (+22.68 tons), which underscores the economic feasibility of the performed optimization. The reduction in the share of defective products and the improvement in the mechanical properties of the yarn additionally enhance the economic effect by increasing product quality and customer satisfaction [11].

Conclusion. The conducted research proved the high effectiveness of a systematic approach based on mathematical experimental design and modeling for solving the task of optimizing the spinning process. It was experimentally confirmed that adjusting the speed parameters of the WEBFEED and IDF-2 systems on carding machines leads to a significant technological effect: a 33% reduction in yarn breakage, a 34% reduction in non-spinning, as well as a noticeable improvement in key qualitative characteristics of the yarn, such as evenness and strength.

The technical and economic analysis, performed using the example of the AUTOCORO 9 rotor spinning machine, objectively showed that optimization leads to an increase in the integral efficiency of the equipment. The increase in the Coefficient of Useful Time from 0.95 to 0.97 and the corresponding increase in the production rate from 128.25 to 130.95 kg/h directly translate into an additional annual product output of 22.68 tons per technological unit. Thus, the developed methodology allows achieving a synergistic effect, simultaneously improving the quality of the finished yarn, the technological stability of production, and its final economic performance through increased productivity and reduced losses.

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