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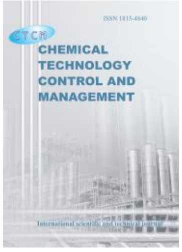

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RESEARCH OF THE FUZZY CONTROL SYSTEM FOR ADJUSTING THREAD TENSION DURING THE WARPING PROCESS

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Abstract. *The paper considered issues of research into a fuzzy control system for the warping process. During the warping process, the reasons that cause defects in the final finished product have been studied, firstly (remove this word) which are thread breakage, thread tangling, the formation of loops on or under the belt, hanging loose threads and similar factors. To study the warping process, its mathematical model is constructed. Kinematic parameters of stationary movement corresponding to the equilibrium mode were determined by solving the nonlinear functional matrix - equation of movement. The process of breakage the warp of the threads under oscillation conditions in a warping machine is considered. The forces and moments that arise due to oscillations, tensions and hanging threads and the influencing effects on the sag have been studied. In the initial mode, the time constant is reduced and additive disturbances are not taken into account; the transient process is not significantly improved by using a fuzzy controller. With an increase in the time constant or when taking into account external disturbances, the presence of a fuzzy controller made it possible to improve the quality of control.*

Key words: *a warping machine, a frame of warp, a tension of thread, a fuzzy controller, a fuzzy control system, warping threads, a model.*

Annotatsiya: *Tandalash jarayonini noqat'iy boshqarish tizimini tadqiq etish masalalari muhokama qilingan. Tandalash jarayonida avvalo tanda iplarining uzilishi, tanda iplarining o'zaro o'ralib ketishi, tasma ustida yoki ostida xalqalar hosil bo'lishi, sust tortilgan iplarini osilib qolishi va shu kabi omillar sababli yakuniy tayyor mahsulotda defektlar paydo bo'lishiga olib keladigan sabablar o'rganilgan.Tandalash jarayonini tadqiq etish uchun uning matematik modeli ko'rib chiqilgan. Muvozanat rejimiga mos keluvchi statsionar harakatning kinematik parametrlari, harakatning nochiziqli funksional matritsali tenglamasini yechish yo'li orqali aniqlangan. Tanda mashinasida tebranishlar hosil bo'lishi sharoitida tanda iplarining uzilish jarayoni ko'rib chiqilgan. Tebranish, taranglik va iplarning osilib qolishi sababli yuzaga keluvchi kuchlar va momentlar kabi ta'sir etuvchi g'alayonlar tadqiq qilingan. Vaqt doimiysi kamaytirilganda va additiv g'alayonlarni hisobga olmagandagi dastlabki rejimda, noqat'iy rostlagichni qo'llash natijasida o'tish jarayon sezilarli darajada yaxshilanmagan. Vaqt doimiysi oshirilganida yoki tashqi g'alayonlar hisobga olinganda noqat'iy rostlagichning mavjudligi boshqaruv sifatini oshirish imkonini bergan/*

Tayanch so'zlar*: tandalash mashinasi, tanda romi, ip tarangli, noqat'iy rostlagich, noqat'iy boshqarish tizimi, tanda iplari, model.*

Аннотация: *Обсуждаются вопросы исследования нечёткой системы управления процессом снования. Изучены причины, приводящие к появлению дефектов конечного готового изделия, и прежде всего, к обрыву сновальных нитей, их спутыванию, образованию петель на ленте или под ней, свисанию слабо натянутых нитей и рассмотрены др. подобные факторы. Для изучения процесса снования построена его математическая модель. Кинематические параметры стационарного движения, соответствующие равновесному режиму, определялись путем решения нелинейного функционально-матричного уравнения движения. Проанализирован процесс обрыва сновальных нитей в условиях возникновения вибраций в сновальной машине. Исследованы возмущающие факторы такие, как силы и моменты, вызванные вибрацией, натяжением и свисанием нитей, влияющие на процесс снования. На первичном режиме, когда постоянная времени уменьшена и не учтены аддитивные возмущения, показано, что переходный процесс в результате использования нечёткого регулятора существенно не улучшается. При* *увеличении же постоянной времени или при учете внешних возмущений наличие нечёткого регулятора позволяет улучшить качество управления.*

Ключевые слова: *Сновальная машина, сновальная шпалерник, натяжение нити, нечеткий регулятор, нечёткая система управления, основа, модель.*

Introduction

In recent years, as a result of growing demand and competition for textile products in the world, improving product quality and production efficiency has become urgent. To solve these problems locally, it is necessary to create and improve a high-quality and effective process of control system. Also, one of the important issues is the use of modern digital technologies, which allow saving energy and resources and increasing the efficiency of production.

The paper considered issues of research into a fuzzy control system for the warping process. During the warping process, the reasons that cause defects in the final finished product have been studied, firstly which are thread breakage, thread tangling, the formation of loops on or under the belt, hanging loose threads and similar factors [3,4-12].

Fig. 1. ***General view of a modern warping machine.***

Research Methods and the Received Results

For research of the warping process the warping process, its mathematical model was generally expressed as follows:

$$\dot{x} = Ax + B\delta + CW, \tag{1}$$

where

$$x = \begin{bmatrix} \omega_y \\ \beta \\ \varphi \end{bmatrix}, A = \begin{bmatrix} a_{11} & a_{12} & 0 \\ a_{21} & a_{22} & 0 \\ 1 & 0 & 0 \end{bmatrix}, B = \begin{bmatrix} b_{11} \\ b_{21} \\ 0 \end{bmatrix}, C = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \\ 0 & 0 \end{bmatrix}, W = \begin{bmatrix} w \\ \theta_\gamma \end{bmatrix}$$

φ – a tension of thread; ω_y – the speed of the angular shaft of the warp; β – thread speed; δ – condition of thread frame; $\theta_\gamma(t)$ – changing of thread shaft diameter; w – various impacts in the warp frame; $a_{11}, a_{12}, a_{21}, a_{22}, b_{11}, b_{21}, c_{11}, c_{12}, c_{21}, c_{22}$ – parameters of the warping process model.

The warping process and the parameters of its model are presented in the Table 1. For the research and synthesis process, consider a fuzzy controller as an object for controlling the warping process with the above parameters:

Table 1.

Warping machine parameters.

Determination of warping parameters	Size of measurement	Designation and unit of measurement
The linear density of warp	29	V, m^3
Length of thread on spool	14875	L, m
Width of warping machine	54	B, m
Distance between warp spool coils	1.8	T, m

Table 2.

Kinematic parameters of the warping process model

a_{11}	a_{12}	a_{21}	a_{22}	b_{11}	b_{21}	c_{11}	c_{21}	c_{12}	c_{22}
-0.159	0.0048	0.584	-0.002	0.167	0.0088	0.0048	0.0021	0.345	0.82

Kinematic parameters of stationary movement, this mode of balancing the renewal process, economic solutions to the equation of movement with a nonlinear functional matrix [13-15,16].

However, this task represents a separate issue beyond the scope of this study, therefore, in the work under review, values corresponding to this type of warping machine were used.

If there are fluctuations (conditionally up to 4 points), the process of breaking the thread warp is considered. Influences affecting tension include forces and moments caused by oscillations, tension and sag of the warp thread [16,17].

Table 4 shows the values of the dispersion $D_r = 0.0358 * h^2$ oscillation ordinate D_r depending on the level of oscillation for oscillations with several characteristics.

Table 3.

Characteristics of oscillations

Scores of oscillations	h , sm	Scores of oscillations	h, sm	Scores of oscillations	h, sm
1	0-0,25	4	1,25-2	7	6-8,5
2	0,25-0,75	5	2-3,5	8	8,5-11
3	0,75-1,25	6	3,5-6	9	Above 11

The approximate spectrum of wave ordinates for the selected speed of the warping process has the following form:

$$S_B(\omega) = \frac{4D_r\alpha_k\omega^2}{\omega^4 + 2(\alpha_k^2 - \beta_k^2)\omega^2 + (\alpha_k^2 + \beta_k^2)^2}, \quad (2)$$

The transfer function of the filter that forms the indicated wave effect was obtained in the following form

$$H(s) = \frac{2\sqrt{D_r\alpha_k s}}{s^2 + 2\alpha_k s + (\alpha_k^2 + \beta_k^2)}, \quad (3)$$

$$\beta_k = \beta(1 + (V/g)\cos\varsigma), \alpha_k = \alpha\beta_k,$$

Herein α – the attenuation coefficient of oscillatory impacts; β_k – the angular frequency of the correlation function of the wave ordinate ς – collisions angle with oscillation; $s = j\omega$

The speed of the threads is V=2.57 m/s and at different values of oscillations the transfer function of the shaper filter H(s) and the spectral density SB(ω) are equal to the following:

1) when 1-point oscillation occurs $(D_r = 0.0358 * h^2 = 0.0022 m^2)$.

$$S_B(\omega)\frac{0.0000372\omega^2}{\omega^4 - 9.673\omega^2 + 30.046}, H(s) = \frac{0.61s}{s^2 + 1.136s + 5.48}, (w = 0.195) \quad (4)$$

2) when 2-point oscillation occurs $(D_r = 0.0358 * h^2 = 0.0201 m^2)$.

$$S_B(\omega)\frac{0.00035\omega^2}{\omega^4 - 8.1906\omega^2 + 21.54}, H(s) = \frac{0.0187s}{s^2 + 1.045s + 4.64}, (w = 0.78) \quad (5)$$

3) when 3-point oscillation occurs $(D_r = 0.0358 * h^2 = 0.0559 m^2)$.

$$S_B(\omega)\frac{0.001\omega^2}{\omega^4 - 5.698\omega^2 + 10.42}, H(s) = \frac{0.033s}{s^2 + 0.8716s + 3.23}, (w = 1.362) \quad (6)$$

4) when 4-point oscillation occurs $(D_r = 0.0358 * h^2 = 0.1432 m^2)$.

$$S_B(\omega)\frac{0.0031\omega^2}{\omega^4-3.77\omega^2+4.6},H(s)=\frac{0.051s}{s^2+0.71s+2.134},(w=2.14) \quad (7)$$

According to the basic technical requirements for the warp thread speed control system, the speed overshoot should not exceed 10%.

If the thread tension varies under different conditions, the coefficients, which cannot be achieved by automatic means, must include a system allowing manual adjustment in the automatic control system.

During the warping process, the tension of the threads does not allow for high - quality control, which is constructed by traditional methods, external influences and parameters of the control plant under non-stationary conditions. This situation is characterized by the need to constantly adjust the controller coefficients and the fact that it is impossible to estimate the exact value of all parameters [2,18].

Figure 2 shows a structural scheme of a typical warping process control system with an optimal controller (OC).

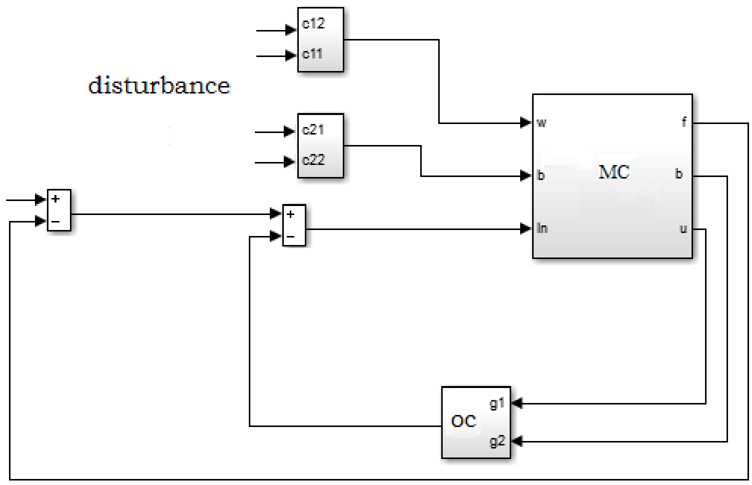

Fig. 2. ***Structural scheme of the warping process control system with an optimal controller.***

Based on the structural scheme presented above, a fuzzy control system for the warping process was developed. In Fig. 3 shows a scheme for modelling a fuzzy control system in the Matlab program, this model allows the evaluation of the quality of control systems with an optimal and fuzzy controller (FC) [1].

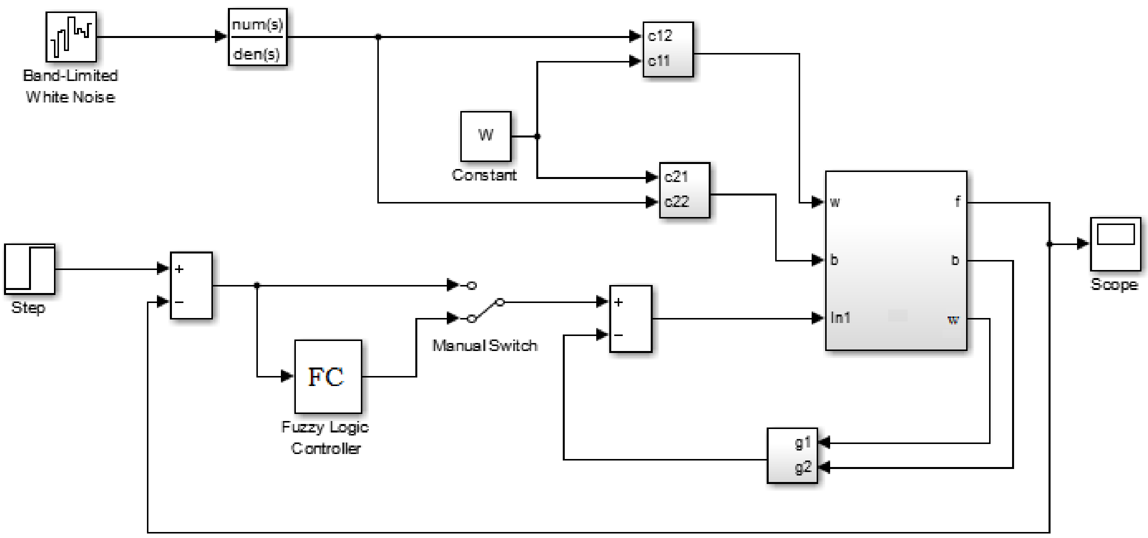

Fig. 3. ***Scheme of research of control systems with an optimal controller and a fuzzy optimal controller.***

The parameters of the control function $u = G_x, G = -\lambda^{-1} B^T k$ for vector coefficients $G = [G_1\, G_2\, G_3]$ of the optimal controller were calculated using the equation

$$kA + A^T k - kB\lambda_u^{-1} B^T k = -\lambda_x, \tag{8}$$

herein k – Positive definite solution to the Riccat equation; λ_x, λ_u – matrices of integer quadratic functional.

The solution of the Riccat equation with real parameters given in Table 2 is carried out using the Care Control System function of the Matlab program. The control law is selected based on the condition of ensuring a minimum of the integral criterion.

$$J = \frac{1}{2}\int_0^\infty \left(x^T \lambda_x x + u^T \lambda_u u\right) dt \tag{9}$$

therein

$$\lambda_x = \begin{bmatrix} \lambda_\omega & 0 & 0 \\ 0 & \lambda_\beta & 0 \\ 0 & 0 & \lambda_\varphi \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0.01 & 0 \\ 0 & 0 & 1 \end{bmatrix} u\ \lambda_u = 1.$$

The invariant part of the system (8) is specified by the model and the quality indicator criterion (9) is equal to the inverse coupling vector coefficients $G = [2.8 \quad 0.03 \quad 1]$ of the law u=Gx [8,9].

To reduce the complexity of the database analysis process, we set the number of terms to 3 for each fuzzification of the fuzzy controller input variable (l_e=3), (l_{de}=3): N,Z,P - negative, zero, positive. Therefore, the number of fuzzy outputs of the fuzzy controller is 3x3=9. Fuzzy outputs and membership functions for the fuzzy controller parameters NM (N, Z, R) are defined using the ANFIS editor in the “Fuzzy” section: : e-[-14.85 42]; de-[-4.636 4.64]. The membership function of the input variables is presented in Figure 3, e-(a), de-(b). (R_k) fuzzy rules of the fuzzy controller are presented in Table 4. The fuzzy conclusion parameters y_k are presented in Table 6. Limit for changing the control signal y_k: [-1.26 100.1].

Table 4.

Fuzzy rules of fuzzy controller

e	de		
	N	Z	P
N	y_1	y_2	y_3
Z	y_4	y_5	y_6
P	y_7	y_8	y_9

Table 5.

Parameters of fuzzy conclusion

y	b_0	b_1	b_2
y_1	1	10	0
y_2	20	-0.11	-0.01
y_3	1	100.1	-0.001067
y_4	1	0.4724	0.2073
y_5	1	0.7175	0.0002176
y_6	1	-2121	0.007882
y_7	1	-0.31	-1.26
y_8	1	0.3	0.92
y_9	1	10.45	0.72

Based on the fuzzification of the error $e = -Gx$ and its derivative $de = \grave{e}$, we obtain a set of productive rules $G_r(e, de)$ for synthesizing the signal of a fuzzy optimal controller.

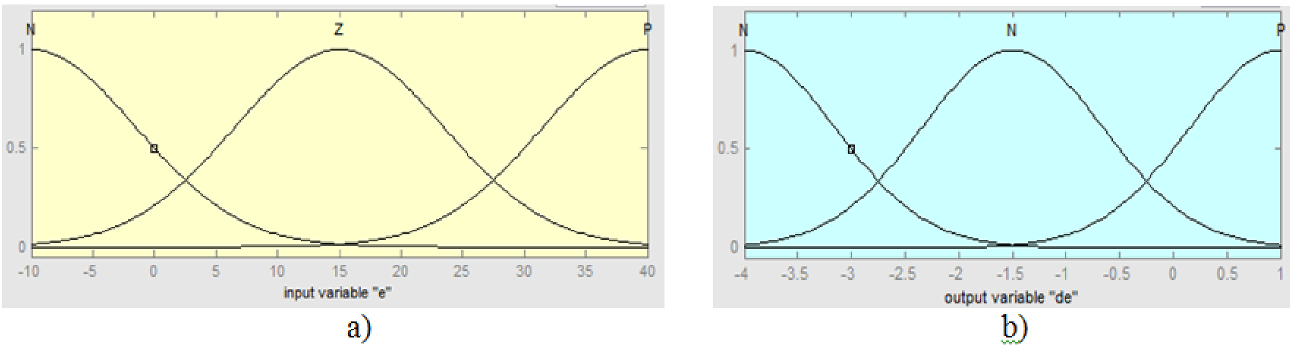

Fig. 4. ***Membership function of input values of the fuzzy controller.***

For a comparative analysis of the efficiency of regulators in the case of non-stationary parameters of the control plant $a_{ii}, \gamma a_{ii},$, the plant parameter changes (in this case, γ - multiple change).

To preserve the input and output relationships, the matrix elements A and B are changed in the i - row accordingly. This configuration of changes in matrix elements A and B is equivalent to a change in the values of the time constants corresponding to the aperiodic link of the process model. Changing the parameters in this way reflects real changes in the dynamics of the plant under study [10,19,20].

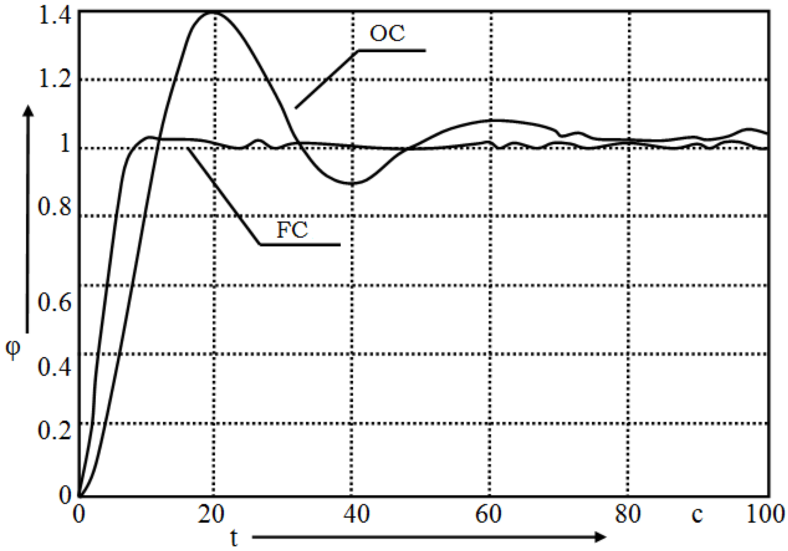

Fig. 5. ***Change curves of a real process.***

Conclusion

In the initial mode and with a decrease in the time constant and without taking into account the influence of the additive disturbances, the quality of the process did not decrease due to the use of a fuzzy controller. By increasing the time constant of the plant or taking into account external disturbances, the fuzzy controller significantly improves the quality of control.

The result of comparing fuzzy control with optimal control in regulation thread tension during the warping process shows that the fuzzy controller demonstrates its advantages when taking into account the influence of the disturbances and non-stationary parameters of the plant. The system setup time using a fuzzy controller is $t_p = 10s,$ overshoot is $\sigma = 0.3\%,$ and for a system with an optimal controller - the setup time is $t_p = 68s,$ overshoot is $\sigma = 40\%$

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