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SYNERGISTIC INTELLIGENT CONTROL OF NONLINEAR DYNAMIC OBJECTS

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Abstract: The article deals with the synthesis of effective algorithms for controlling a chemical reactor and developed a fuzzy synergistic controller for a class of indefinite nonlinear dynamic systems. The synthesis of control laws is performed by the method of analytical design of aggregated controllers (ADAR). Intelligent systems are used to assess the unknown nonlinear behavior of an object, and a new adaptive fuzzy controller is developed based on synergetic control theory. It consists of a fuzzy system for approximating unknown system dynamics using adaptive synergistic control to archive the desired characteristics.

Keywords: synergistic synthesis, intelligent synergetic controller, fuzzy logic system, synergetic control theory, ADAR method.

Аннотация: Мақолада кимёвий реакторни бошқаришнинг самарали алгоритмларини синтез қилиш масалалари ва ноаниқ синфли дискрет вақтли ночизиқли динамик тизимлар учун ноқатъий синергетик ростлагич ишлаб чиқилган. (АКАР) усулидан фойдаланиб синтез қилинди. Интеллектуал тизим объектнинг ноаниқ ночизиқли ҳолатини баҳолаш учун ишлатилади, янги адаптив ноқатъий контроллер эса синергетик бошқариш назарияси асосида ишлаб чиқилган. У зарурий характеристикаларни архивлашдаги адаптив синергетик бошқариш ёрдамида номаълум динамик тизимларни аппроксимациялашда қўлланиладиган ноқатъий тизимлардан иборат бўлади.

Калит сўзлар: синергетик синтез, ночизиқли синергетик ростлагич, ноқатъий мантиқ тизими, синергетик бошқариш назарияси, АКАР усули.

Аннотация. В статье рассмотрены вопросы синтеза эффективных алгоритмов управления химическим реактором и разработан нечеткий синергетический регулятор для класса неопределенных нелинейных динамических систем. Синтез законов управления выполнен методом аналитического конструирования агрегированных регуляторов (АКАР). Интеллектуальные системы используются для оценки неизвестного нелинейного поведения объекта, а новый адаптивный нечеткий контроллер разработан на основе синергетической теории управления. Он состоит из нечеткой системы для аппроксимации неизвестной динамики системы с помощью адаптивного синергетического управления для архивирования желаемых характеристик.

Ключевые слова: синергетический синтез, нечеткий синергетический регулятор, система нечеткой логики, теория синергетического управления, метод АКАР.

One of the main apparatuses of chemical industry is a chemical reactor, the purpose of which is to ensure at its output a predetermined optimal concentration value provided for in the technological regulations of the target product. It is known that a chemical reactor is an energy-consuming object. In this regard, the economic efficiency of the entire production largely depends on ensuring the normal functioning of the chemical reactor and its performance. The main feature of chemical reactors as control objects is their multidimensionality, as well as the uncertainty of the concentration of the initial mixture. The indicated super systems are nonlinear, multidimensional, and multiply connected, in which complex transient processes occur and critical and chaotic regimes arise. The control problems of such dynamic systems are very relevant, difficult and practically inaccessible to the existing control theory [1-4].

Research Methods and the Received Results. A chemical reactor is a volume-type apparatus equipped with a mechanical stirrer and cooling jacket (Fig.1). The device operates in isothermal mode. The multistep series-parallel reaction is carried out in the reactor as follows:

$$A+B\to C_1,\quad A+C_1\to C_2,\quad A+C_2\to C_3 \qquad (1)$$

The kinetics of the reaction is described by a system of equations

$$\begin{cases}\dfrac{dx_1}{dt}=-k_1\cdot x_1\cdot x_2-k_2\cdot x_1\cdot x_3-k_3\cdot x_1\cdot x_4\\ \dfrac{dx_2}{dt}=-k_1\cdot x_1\cdot x_2\\ \dfrac{dx_3}{dt}=k_1\cdot x_1\cdot x_2-k_2\cdot x_1\cdot x_3\\ \dfrac{dx_4}{dt}=k_2\cdot x_1\cdot x_3-k_3\cdot x_1\cdot x_4\\ \dfrac{dx_5}{dt}=k_3\cdot x_1\cdot x_4\end{cases} \qquad (2)$$

where x_1, x_2 - are the concentrations of reagents *A* and *B;* x_3, x_4, x_5 - concentration of reaction products; k_1, k_2, k_3 – stage speed constants [5].

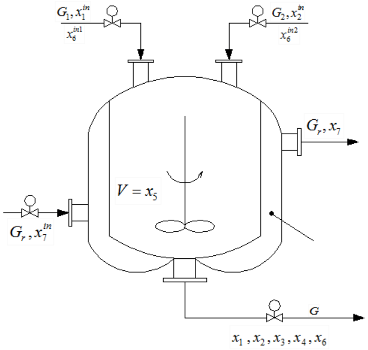

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Fig.1. Flow scheme of chemical reactor.

The apparatus implements a three-stage series-parallel exothermic reaction:

$$A+B\xrightarrow{k_1}C_1,\ A+C_1\xrightarrow{k_2}C_2,\ A+C_2\xrightarrow{k_3}C_3 \qquad (3)$$

where *A* and *B* are initial reagents; C_1, C_2, C_3 – reaction products; k_1, k_2, k_3 - stage speed constants. The target component is the substance C_2. Starting reagents *A* and *B* with concentrations x_1^{in}, x_2^{in} – served in the device in separate streams with costs G_1, G_2 – and temperatures x_6^{in1}, x_6^{in2} – respectively. G_{sv} – refrigerant consumption at the inlet and outlet of the apparatus; x_7^{in}, x_7 – refrigerant temperature at the inlet and outlet of the apparatus; G – mixture consumption at the outlet of the apparatus; x_1, x_2, x_3, x_4 – component concentrations $A,\ B,\ C_1,\ C_2$ in the reactor; x_6 – the temperature of the reaction mixture in the apparatus; $V=x_5$ – apparatus volume; G_{sv} – shirt refrigerant volume [6].

The mixture from the reactor is taken by the pump. Since an exothermic reaction proceeds in the apparatus, a coolant is fed into the reactor jacket to cool the reaction mass [7].

A mathematical model of the dynamics of a chemical reactor consists of material balance equations for each component in the reactor, heat balance equations of the reaction mixture and the coolant in the shirt [8-9]:

$$\begin{cases}\dfrac{dx_1}{dt}=R_1+\dfrac{G_1\cdot x_1^{in}}{V}-\dfrac{G\cdot x_1}{V},\\ \dfrac{dx_2}{dt}=R_2+\dfrac{G_2\cdot x_2^{in}}{V}-\dfrac{G\cdot x_2}{V},\\ \dfrac{dx_3}{dt}=R_3-\dfrac{G\cdot x_3}{V},\\ \dfrac{dx_4}{dt}=R_4-\dfrac{G\cdot x_4}{V},\\ \dfrac{dx_6}{dt}=\dfrac{G_1\cdot x_6^{in1}}{V}+\dfrac{G_2\cdot x_6^{in2}}{V}-\dfrac{G\ \cdot x_6}{V}+\dfrac{\Delta H_1\cdot k_1\cdot x_1\cdot x_2+\Delta H_2\cdot k_2\cdot x_1\cdot x_3+\Delta H_3\cdot k_3\cdot x_1\cdot x_4}{\rho\cdot C}-\dfrac{K_T\cdot F_T\cdot(x_6-x_7)}{V\cdot\rho\cdot C}\\ \dfrac{dx_7}{dt}=\dfrac{G_r\cdot x_7^{in}}{V_r}-\dfrac{G_{sv}\cdot x_7^{inp}}{V_r}+\dfrac{K_T\cdot F_T\cdot(x_6-x_7)}{V_r\cdot\rho_r\cdot C_r}\end{cases}$$

where $R_1=-k_1\cdot x_1\cdot x_2-k_2\cdot x_1\cdot x_3-k_3\cdot x_1\cdot x_4$, $R_2=-k_2\cdot x_1\cdot x_2$, $R_3=k_1\cdot x_1\cdot x_2-k_2\cdot x_1\cdot x_3\cdot x_4$, $R_4=k_2\cdot x_1\cdot x_3-k_3\cdot x_1\cdot x_4$ – is the rate of reaction on components. $\Delta H_i, i=1,\ldots 3$ – thermal effect of the corresponding reaction stage; K_T, F_T – heat transfer coefficient through the wall and heat transfer surface of the apparatus; ρ, C – density and heat capacity of the reaction mixture; ρ_r, C_r – density and heat capacity of the refrigerant.

In general, the problem of synergetic synthesis of the control system is formulated as follows: the control principle, $u=(u_1,..u_m)^T$, should be determined as the function of state variables of object $u_1=(u_1,..u_n)$, ..., $u_m=(u_1,..u_n)$, which transforms the representative point of system in phase space from the random initial state to the environment of the given invariant manifolds $\psi_s(x_1\ldots,x_n)=0$, *S* = *1,...,* *m* and subsequent motion along the intersection of manifolds to somewhat stationary point or to somewhat dynamic mode [10].

Macro variables $\psi_s(x_1\ldots,x_n)$ must satisfy the functional equation $T_1\dot{\psi}_1(t)+\psi_1(t)=0$, (10) which at $\varphi(\psi)\psi>0$ and $T>0$. Because the mathematical model of object (8) contains two external controlling effects $u_1=G_2$ and $u_2=G_r$, we use the ADAR method on the basis of parallel-series combination of invariant manifolds [11].

$$u_2=\frac{(x_7+\nu_1)x_4}{T_2\cdot x_7^{in}}-\frac{R_1\cdot x_4}{x_7^{in}}-\frac{\overline{G}\cdot x_1}{x_7^{in}}\cdot\frac{\partial\nu_1}{\partial x_6}\cdot\frac{(R_5\cdot x_4-x_5\cdot\overline{G})}{x_1^{in}}$$

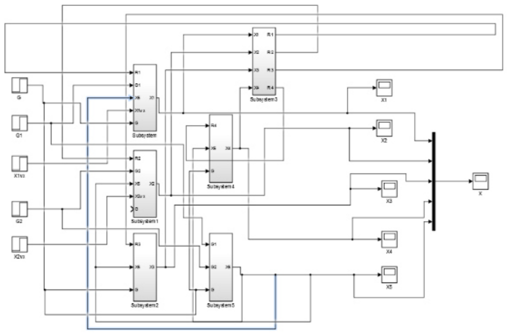

Fig. 2. Simulation model of the control system.

Let us introduce aggregate macrovariables to consideration, the first of which determines the relationship of x with controlled variable x and the second reflects the technological requirement to the volume of reaction system as follows

$$\psi_1=x_4-\overline{x}_4,\qquad \psi_2=x_7+\nu\cdot(x_6) \qquad (11)$$

where $\nu(x_6)$ is somewhat function, which should be determined at subsequent procedure of synthesis [12]. Macrovariables (11) should follow the solution of principal functional equation of ADAR method (10).

Let us introduce the macrovariables and of equation (11) to functional equation (10) for the synthesis of control principle, $u=(u_1,..u_m)^T$. As result, we obtain the following equations [13]:

$$T_1\frac{dx_4}{d\tau}+x_4-\overline{x}_4=0,$$ and

$$T_2\left[\frac{dx_7}{d\tau}+\frac{\partial\nu_1}{\partial x_6}.\frac{d\nu_1}{d\tau}\right]+x_7+\nu_7=0. \qquad (12)$$

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We obtain the following relationships for the control principle from equations (12):

$$u_1 = \frac{(x_4 - \overline{x}_4)}{T_1} + \overline{G} - u_1, \quad (13)$$

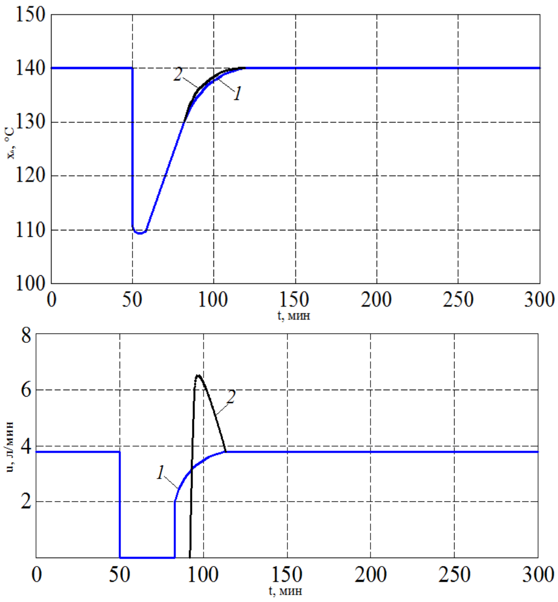

Fig.3. Transients of the output variable and control at the initial deviation of state variables from statics: 1 - the first embodiment of the control algorithm, 2 - the second option.

A fuzzy system is a collection of IF-THEN rules in the form:

$$R^{(l)}: IF\ x_1\ is\ F_1^l\ and\ \ldots\ and\ x_n\ is\ F_n^l\ THEN\ \ y\ is\ G^l$$

where $x = (x_1, \ldots, x_n)^T$ - is the input of the fuzzy systems.

The chemical rector model has input linguistic variables:

The linguistic rules for such a PID-like fuzzy controller are given in table.1.

table.1.

	Outputs	Errors						
		NB	NM	NS	SS	PS	PM	PB
Changes by mistake	NB	SS	NS	NM	NM	NB	NB	NB
	NM	PS	SS	NS	NM	NM	NB	NB
	NS	PM	PS	SS	NS	NM	NM	NB
	SS	PM	PM	PS	SS	NS	NM	NM
	PS	PB	PM	PM	PS	SS	NS	NM
	PM	PB	PB	PM	PM	PS	SS	NS
	PB	PB	PB	PB	PM	PM	PS	SS

PB: Positive big
PM: positive mean
PS: positive small
SS: steady state
NS: negative small
NM:negative environment
NB: negative big

The rules are applied in the IF-Then form as follows [14]:

IF Error is NB AND Change in Error is NB THEN Output is SS

IF Error is NM AND Change in Error is NB THEN Output is NS

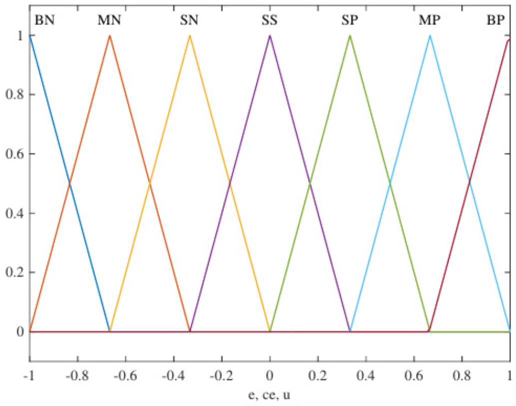

Fig. 4 Degree MF inputs and outputs FLC

The block diagram of the mathematical model of the system in the MatLab complex is shown in Fig.5.

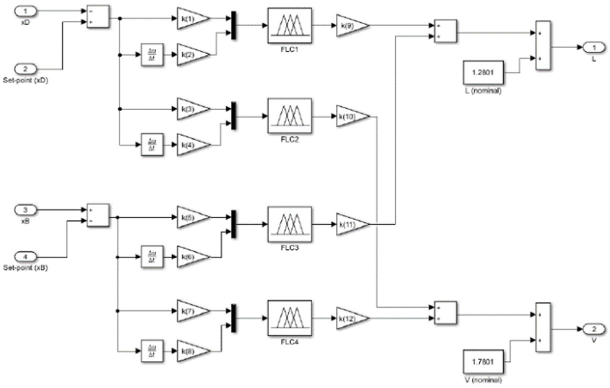

Fig.5. Block diagram of the mathematical model of the tension control system with a fuzzy controller

Step response of various fuzzy binary distillation column controllers, individually tunable GA [15]; GA - Genetic Algorithm; FLC- Fuzzy Logic Control; PSO-; MF;

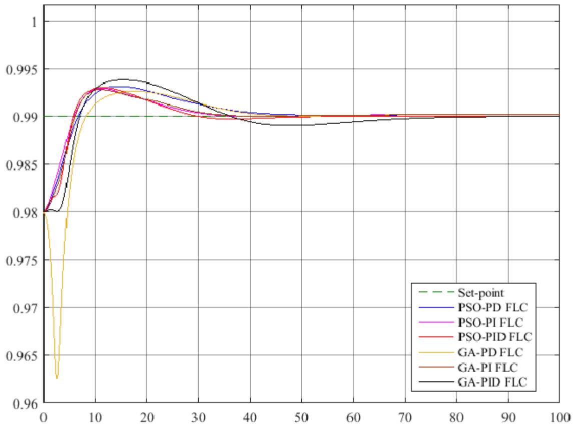

Fig.4. Simulink block diagram of a MIMO PD-like FLC with 12 scaling factors.

CONCLUSION

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In this paper, we have developed a fuzzy synergetic controller for regulating and tracking control of a class of nonlinear systems. The control law has been introduced by using methods of synergetic theory and fuzzy logic control which can handle the nonlinear systems with system uncertainties and external disturbances. The problem of analytical synthesis of nonlinear control laws, which stabilizes the temperature and concentration of the process in the chemical reactor by means of synergistic control methods, is solved.

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