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Advanced Control of Complex Technological Processes and Production on the Example of Drying and Granulation of Mineral Fertilizers

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ABSTRACT: In order to determine the type of process mapping of software to function in a mode of formation of functional failure it is presented as a process of operation of the fuzzy automata. Based on the results, the functioning of the software in the form of an algorithm of fuzzy automata for software reliability presented in a way soit is possible to estimate the ratio of ‘the total number of states - the number of functional failures’ as an implementation of the algorithm of fuzzy mathematics. The example of reliability estimation of a real computer system software is given.

KEYWORDS: software reliability, information-control systems, software failure, functional failure, formation mode, linguistic model of the system, cause-and- effect relationships.

I. INTRODUCTION

In the world, the problem of improved management of technological processes and production is supported by the powerful development of digital computer technology. Strategic changes in the principles of management led to corresponding changes in the structure of algorithms.

The substantive part of the control algorithms remains unchanged and is reduced to the sequential correction of technological regimes based on laboratory analyzes and monitoring of the current state of the object.

At the same time, the optimization component has significantly changed within the framework of the Advanced Process Control & Optimization (APC) methodology, which means advanced or advanced management.

This methodology is based on the ideas of operational-forecast or predicative management in terms of the quality of final products.

World leaders in industrial automation Honeywell (USA), Siemens (Germany), ABB (Switzerland), Allen Bradley (USA), Almston (France), Emerson Electric (USA), Yokogawa Electric Corporation (Japan), CCS-Continuous Control Solution, Inc. (USA) and others.

They actively apply APC-technologies, advanced management and optimization technologies, which ensure measurable and sustainable improvement of product quality and economic efficiency of industrial production.

In recent years, the processes of globalization of technical systems have actualized the construction, creation of information management systems in the context of the global Internet network, the modernization of technical and technological systems.

The request for structural-parametric analysis and synthesis of APC-systems for advanced control of complex technological processes has been significantly increased.

In Uzbekistan, much attention is paid to the application based on the concept of advanced management methods for structural-parametric synthesis, optimization and optimal control of complex technological processes and production.

In the Action Strategy for the Development of the Republic of Uzbekistan in 2017–2021, the following tasks in particular were noted: “... further modernization and industry diversification by transferring it to a qualitatively new level, aimed at advancing the development of high-tech manufacturing industries, primarily for the production of finished products high value added based on deep processing of local raw materials”[1].

The development of methods and algorithms for structural-parametric analysis and synthesis of APC-systems for advanced management of complex chemical-technological processes and systems is a demanded scientific and technical problem, the solution of which allows to significantly improve the efficiency and quality of management of technological processes and production.

II. THE CURRENT STATE OF THE THEORY AND PRACTICE OF ANALYSIS AND SYNTHESIS OF ADVANCED CONTROL SYSTEMS

The evolution of industrial automation systems allows us to identify several trends in the development of systems and controls [2]:

- widespread industrial networks for field automation;
- creation of field regulators, when the chain “primary measuring transducer - control device - transducer - executive mechanism” closes at the control object itself with synchronous improvement of field automation equipment;
- the emergence of Soft-Computing technology, the main principle of which is the fact that by admitting inaccuracy, uncertainty and partial truth, it is possible to achieve interpretability (expression in qualitative symbolic or linguistic form), robustness (rudeness and resistance to insignificant disturbances) when processing information;
- improvement and improvement of the quality of mathematical models:
  - the use of such models, which consider the random nature of the properties of the processed raw materials, auxiliary materials and semi-finished products, the drift characteristics of the process equipment;
  - use of adaptive models for predicting the composition of raw materials components, semi-finished products and methods for calculating their optimal composition based on the predictions made;
  - calculation of optimal settings of regulators and stabilization of material and energy flows;
  - development of the theory of group management of chain technological objects;
  - the emergence of new models of digital sensors with radio output;
  - integration of automated systems associated with the system analysis of the facility and management tasks with the formulation and formation of a set of management tasks as automation tasks according to the global efficiency criterion.
- The development of advanced control algorithms spawned the concept of a human-machine interface, which is divided into SCADA (Supervisory Control and Data Acquisition) and DCS (Distributed Control System) technologies, while simultaneously developing solutions for building operational management systems for the MES standard functions, ranging from the usual dispatching and calculation of technical and economic indicators to the problems of resource planning;
- creation of local computing systems of network architecture, implementation of decentralized distributed digital control systems, equipped with efficient means of integration into local networks of programmable controllers.

The listed tendencies, naturally, do not exhaust the whole variety of trends in the development of industrial automation systems, but appear to be dominant soon.

III. Problem statement of synthesis of an advanced process control system

Analysis of the production scheme of ammophos by evaporation, drying and granulation of pulp in the apparatus of a drum granulation dryer (BGS) of Ammophos-Maxam JSC (Almalyk) showed the feasibility of developing an adaptive control system for the BGS installation using a control system model with adjustable parameters (Figure1) [3,4].

The system contains two control loops - the main one (the control object (CO) and the main part of the control device (CD), the measuring transducer and the actuators are formed) and the self-tuning circuit.

This circuit includes the simulation subsystem of the control unit and the sensing element (SE) of the sensor of the measuring transducer and the subsystem for setting the parameters of the control system and the simulation subsystem.

The need to simulate the sensor's sensing element is associated with the imperfections of the moisture meter used as this sensing element, which is the source of dynamic errors in measuring the value of the controlled variable.

The simulation of the perceiving element makes it possible to take these errors into account in measurements and to obtain the true undistorted value of the controlled quantity.

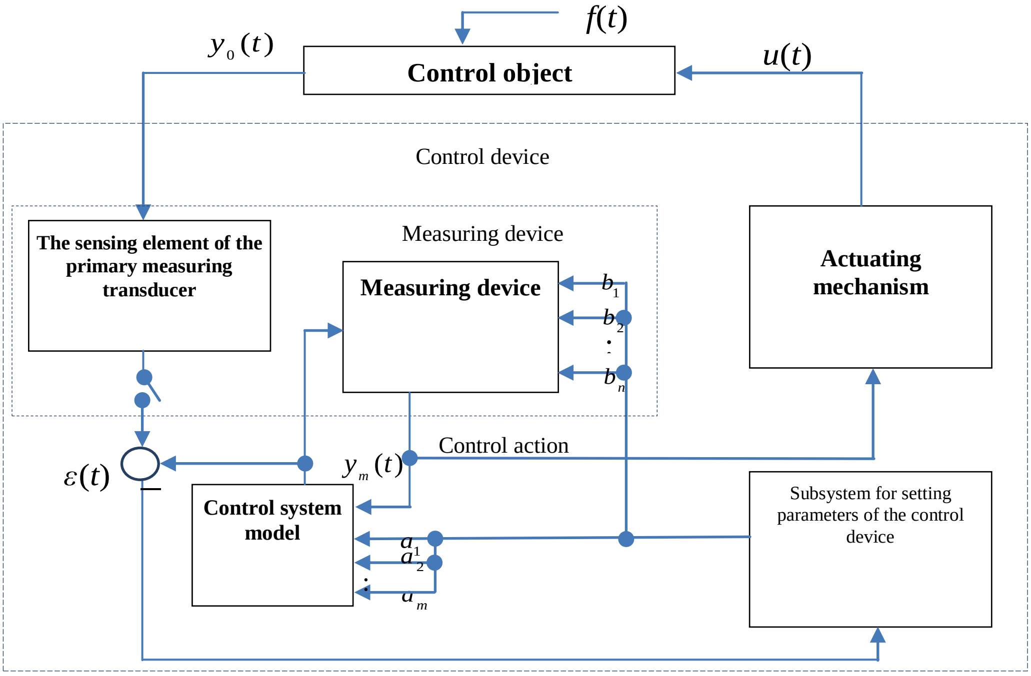

Fig. 1. Functional diagram of the adaptive APC drum-granulation dryer.

The control system under consideration is formalized as follows:

$$\dot{x} = Ax + Bv + Cf,\ y = \psi_y(x, v, f) \tag{1}$$

where $x = (x_1, x_2, \ldots, x_n)$ – system state coordinate vector; A – square matrix of coefficients $a_{ij} = a_{ij}(\lambda, \eta(d))(i = 1,2,\ldots,n)$; $v = (v_1, v_2, \ldots, v_n)$ – vector of control actions; λ – set of parameters of the control device, depending on the a vector of control parametric influences; B – matrix of $n \times m$ coefficients $b_{jk} = b_{jk}(\lambda, r(a))\ (k = 1,2,\ldots,m)$ – disturbance vector; C – $c_{ji} = c_{ij}(\lambda, \eta)(1,2,\ldots,r)$ coefficient matrixof dimension $n \times r$, y – controled coordinate system; ψ_y – nonlinear operator. The control task is to achieve the optimal trajectory of the system x°, whereby the quality index of control processes J reaches its minimum [5]:

$$J(x^{\circ}, v, t) \le J(x, v, t). \tag{2}$$

when measuring parameters, the control object λ to achieve the optimal trajectory consists in determining the optimal control law and optimal adjustment of the parameters both in relation to impacts v , and to changing parameters λ. The optimization condition, which includes solving two problems (ensuring the optimal ratio of parameters, under which the best trajectory of motion x° is realized and ensuring the optimization of measurement processes of control actions $\alpha_\eta (k = 1,2,\ldots,m)$ when moving in the parameter space to the extremum point), can be written as:

$$J(x^{\circ}, \eta^{\circ}, \alpha^{\circ}, v, t) \le J(x, \eta, a, v, t), \tag{3}$$

where η° - optimally tunable λ control parameters; α° - optimal parametric effect. The task is to ensure that when variables a_{ij} and b_k are rejected and to ensure that they change in such a way that condition (3) is fulfilled [6,7]. Quality Score in the management task:

$$J_y = \int_{t_0}^{t_a} \left\{ \left[y_0 - y_N \right]^2 + qu^2 \right\} dt \to \min_{\eta \in \Omega_\eta}, \tag{4}$$

where u – control vector; y_0 - value of the controlled variable; y_N - value of normal humidity; Ω_η – scope of allowable parameter changes η, q – weight vector. The control system model consists of modules of a mathematical description of an object, a control device, a humidity measuring transducer and an actuator. The mathematical description of the object is a model, the parametric identification of which, given the external influences, is presented as the task of minimizing the criterion

$$J = \int_0^T \left[y_0(t) - y_m(t) \right]^2 dt \to \min_{A \in \Omega_A} \Rightarrow A^\circ, \tag{5}$$

where $A-$ set of identifiable variables of the mathematical model, the domain of which $\Omega_A = [a_{ij}^{min}, a_{ij}^{max}],$, in which the model is sustainable; A° – set of optimal model parameters, T – simulation period. The model of the control object is expressed as a system of differential equations

$$\frac{dI}{dt} = -a_{11} I + a_{12} G + b_1 VI; \frac{dG}{dt} = -a_{21} I - a_{22} G + b_2 VG + G_I, \tag{6}$$

where I and G – pulp and product moisture levels; VI and VG – the speed of moisture removal from the pulp and product; G_I – the quantity characterizing the external known disturbance and determined by the ratio (5); a_{11} and a_{12} – parameters characterizing moisture removal; a_{21} and a_{22} – parameters reflecting the moisture removal rate; b_1 and b_2 – variables that characterize the degree of sensitivity of an object to pulp and product moisture fluctuations. External specified effects are expressed as functions

$$f(t) = \begin{cases} K_m (1 - e^{-\beta t}) \ if \ t \le t_m, \\ K_m (1 - e^{-\beta t}) e^{-\beta (t - t_m)} if \ t > t_m, \end{cases} \tag{7}$$

where t_m – the moment of reaching the set value of humidity; K_m – specific rate of change of humidity; β – variable expressing the intensity of output fluctuations. The model of the primary transducer is a system of algebraic differential equations:

$$y_T = y(t - T_z); y_{TH} = y_T + (-1)^{Nt} \Delta y_T;$$

$$\tau_{\text{Д}} \frac{dy_{THD}}{dt} - y_{THD} = y_{T_H}; y_{THDN} = \mathcal{F}_N (y_{THD}), \tag{8}$$

where N_T and Δy_T – parameters characterizing the fluctuation changes of the sensor; $\tau_{\text{Д}}$ – time constant taking into account the inertia of the primary measuring transducer; $\mathcal{F}_N$ – function reflecting the nonlinearity characteristics of the meter; T_z – transport lag value. The executive mechanism is formalized as an independent closed system with corrective links and is presented in the form of a stationary dynamic link. The process of adapting the system to changes in object parameters is ensured by periodically adjusting the model and adjusting the coefficients of the control algorithm. The adjustment of the model consists in determining the dynamic characteristics based on the use of parameter values obtained at certain time intervals from the object so that the model and object responses are as close as possible to each other. During this time interval, the control is carried out by the reaction model. The adjustment of the model parameters is carried out in two stages. On the first, the parameters of the specified disturbing influences K_m, β and t_m are optimized. If the purpose of the adjustment (the criterion J_a to achieve the permissible minimum value) is not met, then the model parameters a_{ij} and b_B, as well as the dynamic parameters, are optimally estimated using an algorithm built on the basis of the optimal control performance. The results of the calculation of the minimum humidity forecast are as follows:

$$v = \begin{cases} v_{max} \ if \quad G_m > G_z, G > G_v, \\ 0, \ \ if \quad G_m \le G_z, G \le G_v, \end{cases}$$

$$G_m = \left(G_0 - \frac{\dot{G}_0}{\lambda_2}\right)^{\frac{\lambda_2}{\lambda_2-\lambda_1}} \Big/ \left(G_0 - \frac{\dot{G}_0^q}{\lambda_1}\right)^{\frac{\lambda_2}{\lambda_2-\lambda_1}}; \tag{9}$$

where v_{max} – maximum speed of moisture removal; G_m – the calculated minimum value of the final product moisture; $G_я$ – set value of humidity; G_0 – moisture value at the time of calculation G_m; $\dot{G}_0$ – value of the rate of change of humidity at the time of calculation G_m; G_v – the specified upper limit value of humidity, determining the range of permissible oscillations; a_{ij} - model parameters (6); λ_1 and λ_2 – roots of the characteristic equation:

$$\lambda^2 + (a_{11} + a_{22})\lambda + a_{11}a_{22} + a_{12}a_{21} = 0 \tag{10}$$

where a_{ij} – functional model parameters (6). Optimization of control change processes α_A is solved as minimization of the function:

$$J = \int_{t_i}^{t_i+\tau} [y_o(t) - y_m(t)]^2 dt \to \min_{\alpha\in\Omega_\alpha} \Rightarrow \alpha^\circ, \tag{11}$$

where $y_m(t)$ – curve derived from the simulation subsystem on the control interval τ. The operation of the algorithm according to the combined criterion *f*(*t*) is as follows. At the time of calculating the control value is calculated G_m and, if this value reaches the level $G_я$, the calculation process is terminated. If the current humidity level reaches a level G_v, then the algorithm resumes operation. In this work, the control system for the drying process and pulp granulation in the production of ammophos has been synthesized. In a system with auxiliary value differentiation, the regulator functions according to the PI-law of regulation, and the differentiator in the auxiliary channel are a real differentiating link. The results of the calculations, the settings of the controller and the differentiator are presented in table 1 [8].

The results of the calculation of the parameters of the regulators. Table 1.

Setup Method	**ATS settings with differentiator**				**Integral criteria for $\lambda(t)=1$**	
	$W_р(p)$		$W_д(p)$		$I_{м,\lambda}$	$I_{л,\lambda}$
	$K_р$	$K_и$	$K_д$	$T_д$		
Analytical method	3.500	3.000	29.40	0.927	1.582	1.079
Multidimensional method scan	13.000	1.500	44.60	2.165	0.479	0.462

The nature of the transient processes in the studied automatic control systems is presented in Figure 2.

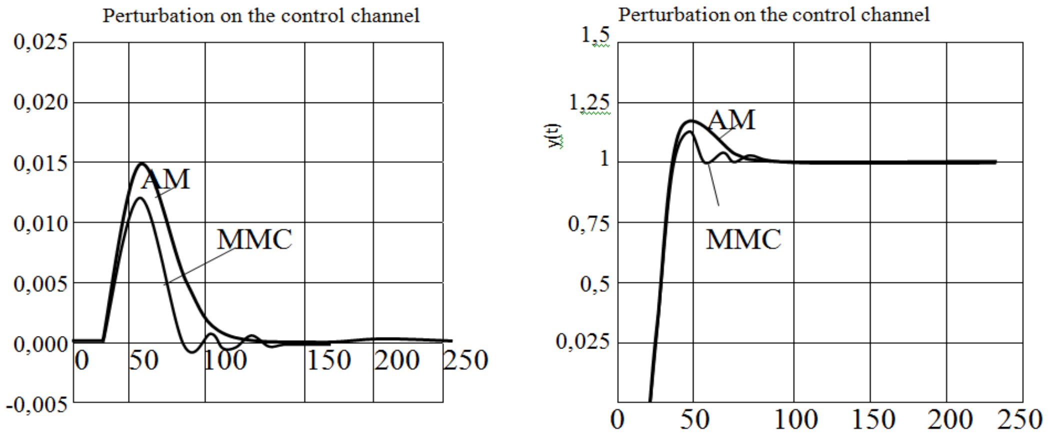

Fig. 2. Transients in the process control system drying and granulation of the pulp in a drum granulation drying

Studies show the ability of the algorithm to sustainably search for the settings of regulators, combines a positive random search method and a deformable polyhedron method. The noted goal and objectives of the research were implemented as an improved APC-system for controlling the evaporation process, drying and granulating the pulp in the apparatus of a drum granulation dryer at Ammophos-Maxam JSC (Almalyk).

IV. CONCLUSION

The current state of the theory and practice of the structural-parametric synthesis of APC-systems of advanced control of technological processes and production is analyzed and the trends of their further development and improvement are revealed. It is shown that advanced control of technological processes and production is a modern high-tech technology, the use of which in production can significantly improve the efficiency of existing control systems that implement complex control algorithms based on the use of a predictive object model.

An APC system of improved control of the drying and granulation of the pulp in a drum-type granulation drying of the production of ammophos was synthesized and the optimal settings of the PI controller and the real differentiator were found. This allowed the system to function in real time.

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