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ANALYSIS OF METHODS FOR ADAPTATION OF INDUSTRIAL CONTROL SYSTEMS OF THERMAL PROCESSES

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АНАЛІЗ ПРОМИСЛОВИХ МЕТОДІВ АДАПТАЦІЇ СИСТЕМ УПРАВЛІННЯ ТЕПЛОВИМИ ПРОЦЕСАМИ

Purpose. The aim is to analyze the effectiveness of traditional and intelligent adaptation methods of automatic control systems of thermal power processes at a thermal power plant (TPP).

Methods. In the course of the study the classical methods of active identification and adaptation of automatic control systems (ACS) were used. Test excitation of ACS starts a transient process which allows to obtain parameters of the object transfer function and calculate the conventional adjustment knob. However, active identification introduces additional disturbance to the site and degrades the quality of control as a whole. Thus, it is proposed to use a heuristic method of experts – fixers in the processes of remote adaptation of single loop ACSs with regard to the trajectory of the transient characteristic.

Results. The inefficiency of standard adaptation methods of thermal objects in ACS adjustment mode, on the basis of the channel temperature control of superheated steam from TPP was demonstrated experimentally. At the same time, ussng fuzzy logic theory in modeling actions of personnel in the processes of ACS adjustment and adaptation, it was possible to obtain transient processes with the expected quality indicators.

Scientific novelty. To expedite the process of adaptation of control systems and reduce the impact of additional perturbations, caused by active identification, intelligent approach to calculating settings of proportional-integral-derivative (PID) controller on the basis of Mamdani algorithm was proposed.

The practical significance. Currently, more than 90% of Ukraine's coal plants units expired their design life and require modernization. At the same time, the vast majority of TPP work with hourly load change in the adjusting mode with the corresponding change in the properties of the control subsystems. The use of intelligent technologies in TPP (ACS) in the processes of identification and adaptation of local ACS with a proportional-integral (PI) and PID controllers will significantly reduce the operating costs, related to excessive consumption of solid fuel because of inefficient transient processes.

Keywords: *identification, adaptation, complex frequency response, PI controller, power block unit, fuzzy adapter*

Introduction. Despite the fact that the share of thermal power plants (TPP) in the national power exceeds 53% , the majority of power units working in TPP are equipped with outdated equipment, which implements traditional control algorithms that do not allow to increase economic performance and, consequently, the efficiency of coal power plants is not more than 30%. At the same time, 92.1% of power units in Ukraine worked out their design life and need modernization [1]. This problem requires a comprehensive research into selection of optimal operation modes of power units that are only possible with adaptive control actions.

In industrial environment of TPP equipment, with frequent load changes and the impact of random disturbances, the plant parameter values are subject to the dynamism which requires that ACS adjuster install new values of the controller settings or its adaptation . However, due to time constraints, inability to control disturbances, complexity of the identification process, etc., experts often cannot calculate the adaptive settings of standard PI and PID controllers, which reduces the efficiency of the entire production. Hence, arises the problem of optimizing adaptation procedures, in particular of finding methods with minimal time and information consumption. Analytical models obtained by solving a system of differential equations, are ineffective because some parameters of objects are represented in a simplified form, and some cannot be taken into account because of simplified models. Accordingly, assessment of the object model at the pre- stage of the control system synthesis contains a number of unaccounted factors which affects the results accuracy of ACS design and operation [2].

In addition, mathematical modeling of, for example, superheated steam temperature, is usually associated with approximation of the acceleration curves obtained experimentally, and as a result mathematical description becomes inaccurate a priori. In view of this, the adaptive management practices receive particular relevance [2].

Recently, a number of Ukrainian thermal power systems of local ACSs have been using Remicont, Aries, Siemens controllers with integrated adaptive control software algorithms, which usually implement the classical methods of adaptive control or upgrading [3–8]. It should be noted that adaptive ASC has not yet received a significant spreading in domestic TPP for a number of reasons of financial and industrial character. As a rule, expert-adjusters of ACS disable adaptive blocks of standard regulators in conditions of heavy disturbances. Thus, the questions of finding optimal adaptive methods for managing complex thermal processes remain open.

Analysis of the classical methods of adaptive control. Given the importance and necessity of using the principles of adaptation, we analyze the most common methods used at thermal plants. In the process of automatic adaptation, the controller can be set in accordance with the classical structural diagram (fig.1).

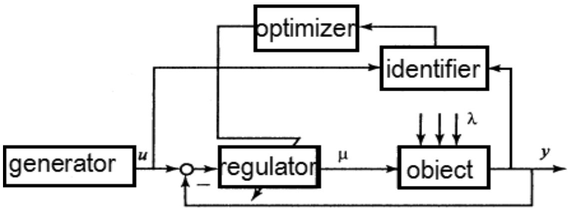


Fig. 1. Active adaptation in ACS: u – impact test; μ – control action; λ – perturbations; y – output parameter

The structure includes an identifier, which analyzes the object model, the optimizer, which calculates controller settings at the next step of proceeding to the optimum, and the corresponding regulator unit. For arbitrary setting, providing stability control of the system, the regulator comes into operation, after which it is subjected to step external $u(t)$ identifying impact. The response to this effect (change in time of the controlled variable y(t)) will be the corresponding transient response of the closed system up to the amplitude of the input action. With a known algorithm of the regulator functioning, we can obtain a transfer function or complex frequency response (CFR) of the object. Designing a mathematical model of the object, we can calculate the optimal settings for PI or PID-controller. It should be noted that assessment of the transient response of the closed loop in actual operation of control systems typically is relatively unstable, i.e. if the experiment is repeated several times, very different results will be obtained which will affect adequacy of the object model. However, if the response is oscillatory, then it is possible to assess the degree of oscillations damping and their period [2]. Therefore, the analysis of adaptation method was performed, wherein the loop dynamics will be evaluated by these characteristics of the transient loap parameters, because similar approach is used in many adaptive microcontrollers' of various brands specializing in automation [3].

We investigated the adaptation process of PI-controller, wherein the unknown transfer function of the adaptive system of an object – a powerful TPP boiler superheater channel – is defined along "the movement of the regulatory body of cooling water consumption to the superheater" – "temperature change of the superheated steam" in the regulatory system and is determinated by the transfer function – inertia link of the third order delay

$$W(s) = \frac{0,55}{(1,5s+1)^3} e^{-0,52s}, \qquad (1)$$

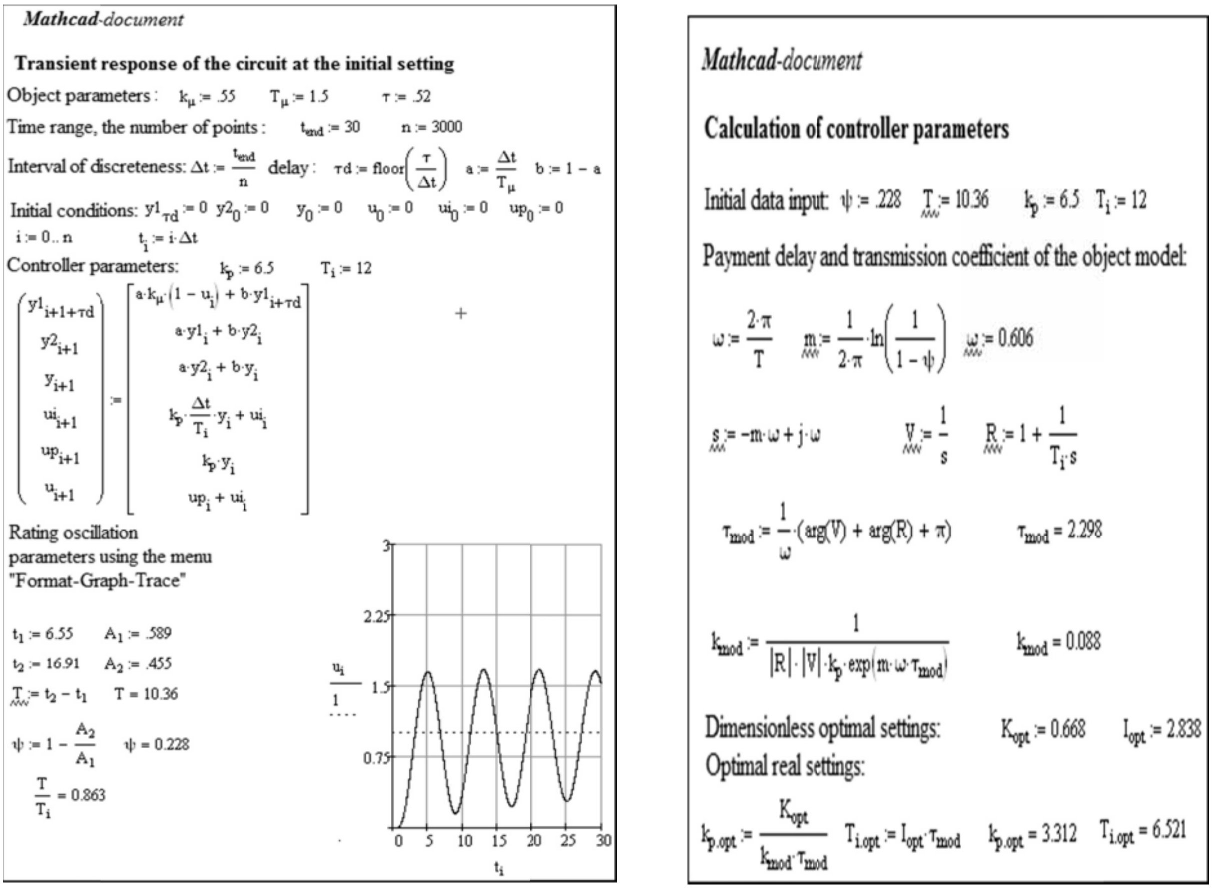
where s – laplace operator; $e^{-0,52s}$ – link delay.

This characteristic can be considered typical for objects and processes with automatic compensation [6].

According to conditions of operation, it is necessary that, for the optimum settings, the degree of attenuation is $\Psi = 0.9$. We choose the initial value of the integration constant controller $T_i = 12$ min. Let us assume that the transmission coefficient is sufficiently small (you can generally start with a zero). By including regulators into work and due to gradual increase in its transmission coefficient we will achieve that transient response of the circuit has become self-oscillating and not exceeding the permissible limits. If the factor of proportionality $k_p = 6.5$, we obtain the process, shown in fig. 2. Handling the process yields the following quality indicators: degree of attenuation Ψ=0.228 and oscillation period: $T = 10.36$ min. Since the degree of attenuation does not correspond to the desired degree: $\Psi^{mp} = 0,9$ the adapter starts the procedure of adapting (fig. 2).

Simulation result of the system's transient response with this setup is shown in fig. 2. From the resulting graph, we define the new values: the degree of attenuation and oscillation period. These parameters were equal to 0.71 and 13.43 min. Recalculation by the formulas for new oscillation parameters gives the following result: object model gain $k_{\text{mod}} = 0.076$; model delay $\tau_{mod} = 2.04$ min; optimal controller settings: $k_{\text{p.opt}} = 4.31$; $T_{\text{i.opt}} = 5.81$. From the analysis of values Ψ and T follows that they do not meet the specified settings according to the requirements of the technological process. Thus, the controller continues the process of adaptation. The third stage of the settings calculation is similar to the previous one. In fig. 3, besides transient characteristics of a closed loop, by which we assess oscillations parameters, the dashed line shows transient response of the control system under disturbances, acting on an object during the regulatory impact. This allows to assess the quality of the regulatory system in terms of its main task – suppression of disturbances acting on the object.

As can be seen from fig. 3, the degree of attenuation $\Psi = 0.86$ remains unchanged, consequently, adaptation process is finished. But, since Ψ does not correspond to the preset value 0.9, and the process is not aperiodic, as required for the key facilities of TPP, we can conclude that the adaptive ACS, which operates according to the proposed method, is robust but not effective in terms of energy efficiency and reliability, and requires additional manual settings by automation specialist. The adaptation process is characterized by considerable duration (3–4 stages). This fact introduces additional disturbances in the control channel and affects the output (adjustable) value.



Mathcad-document

Transient response of the circuit at the initial setting

Object parameters : $k_\mu := .55$ $T_\mu := 1.5$ $\tau := .52$

Time range, the number of points : $t_{end} := 30$ $n := 3000$

Interval of discreteness: $\Delta t := \frac{t_{end}}{n}$ delay : $\tau d := \mathrm{floor}\left(\frac{\tau}{\Delta t}\right)$ $a := \frac{\Delta t}{T_\mu}$ $b := 1 - a$

Initial conditions: $y1_{\tau d} := 0$ $y2_0 := 0$ $y_0 := 0$ $u_0 := 0$ $ui_0 := 0$ $up_0 := 0$

$i := 0..n$ $t_i := i \cdot \Delta t$

Controller parameters: $k_p := 6.5$ $T_i := 12$

$$\begin{pmatrix} y1_{i+1+\tau d} \\ y2_{i+1} \\ y_{i+1} \\ ui_{i+1} \\ up_{i+1} \\ u_{i+1} \end{pmatrix} := \begin{bmatrix} a \cdot k_\mu \cdot (1 - u_i) + b \cdot y1_{i+\tau d} \\ a \cdot y1_i + b \cdot y2_i \\ a \cdot y2_i + b \cdot y_i \\ k_p \cdot \frac{\Delta t}{T_i} \cdot y_i + ui_i \\ k_p \cdot y_i \\ up_i + ui_i \end{bmatrix}$$

Rating oscillation
parameters using the menu
"Format-Graph-Trace"

$t_1 := 6.55$ $A_1 := .589$

$t_2 := 16.91$ $A_2 := .455$

$T := t_2 - t_1$ $T = 10.36$

$\psi := 1 - \frac{A_2}{A_1}$ $\psi = 0.228$

$\frac{T}{T_i} = 0.863$

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Calculation of controller parameters

Initial data input: $\psi := .228$ $T := 10.36$ $k_p := 6.5$ $T_i := 12$

Payment delay and transmission coefficient of the object model:

$\omega := \frac{2 \cdot \pi}{T}$ $m := \frac{1}{2 \cdot \pi} \cdot \ln\left(\frac{1}{1 - \psi}\right)$ $\omega := 0.606$

$s := -m \cdot \omega + j \cdot \omega$ $V := \frac{1}{s}$ $R := 1 + \frac{1}{T_i \cdot s}$

$\tau_{mod} := \frac{1}{\omega} \cdot (\arg(V) + \arg(R) + \pi)$ $\tau_{mod} = 2.298$

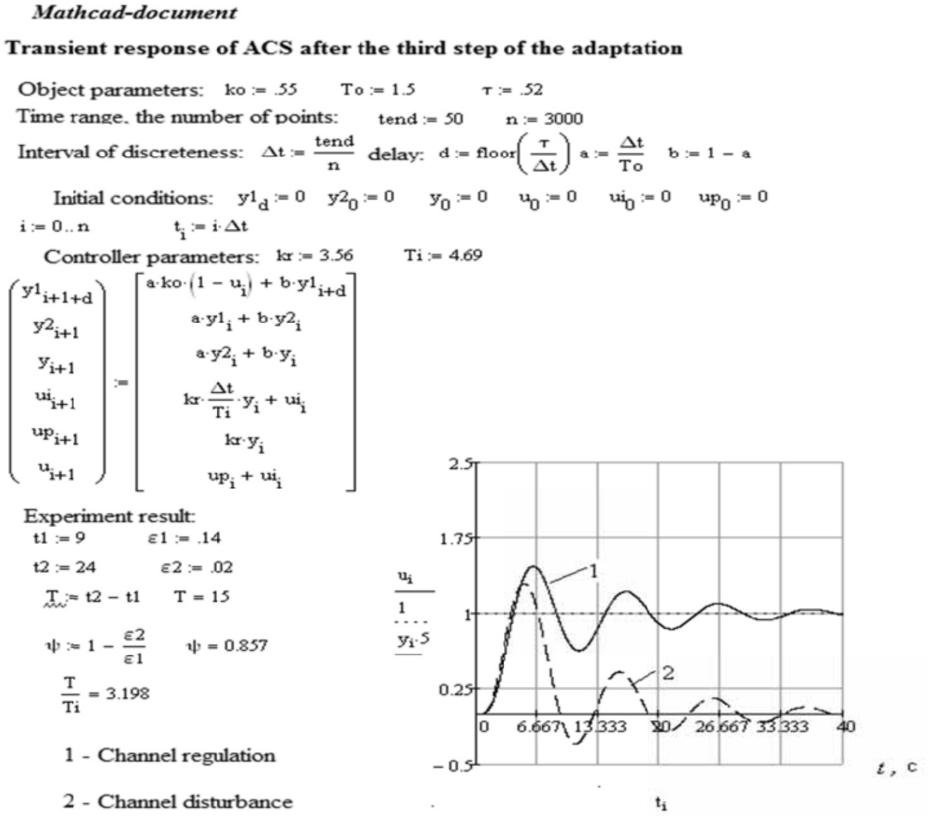
$k_{mod} := \frac{1}{|R| \cdot |V| \cdot k_p \cdot \exp(m \cdot \omega \cdot \tau_{mod})}$ $k_{mod} = 0.088$

Dimensionless optimal settings: $K_{opt} := 0.668$ $I_{opt} := 2.838$

Optimal real settings:

$k_{p.opt} := \frac{K_{opt}}{k_{mod} \cdot \tau_{mod}}$ $T_{i.opt} := I_{opt} \cdot \tau_{mod}$ $k_{p.opt} = 3.312$ $T_{i.opt} = 6.521$

Fig. 2. Self-oscillatory process and its parameters



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Transient response of ACS after the third step of the adaptation

Object parameters: $ko := .55$ $To := 1.5$ $\tau := .52$

Time range, the number of points: $tend := 50$ $n := 3000$

Interval of discreteness: $\Delta t := \frac{tend}{n}$ delay: $d := \mathrm{floor}\left(\frac{\tau}{\Delta t}\right)$ $a := \frac{\Delta t}{To}$ $b := 1 - a$

Initial conditions: $y1_d := 0$ $y2_0 := 0$ $y_0 := 0$ $u_0 := 0$ $ui_0 := 0$ $up_0 := 0$

$i := 0..n$ $t_i := i \cdot \Delta t$

Controller parameters: $kr := 3.56$ $Ti := 4.69$

$$\begin{pmatrix} y1_{i+1+d} \\ y2_{i+1} \\ y_{i+1} \\ ui_{i+1} \\ up_{i+1} \\ u_{i+1} \end{pmatrix} := \begin{bmatrix} a \cdot ko \cdot (1 - u_i) + b \cdot y1_{i+d} \\ a \cdot y1_i + b \cdot y2_i \\ a \cdot y2_i + b \cdot y_i \\ kr \cdot \frac{\Delta t}{Ti} \cdot y_i + ui_i \\ kr \cdot y_i \\ up_i + ui_i \end{bmatrix}$$

Experiment result:

$t1 := 9$ $\varepsilon 1 := .14$

$t2 := 24$ $\varepsilon 2 := .02$

$T := t2 - t1$ $T = 15$

$\psi := 1 - \frac{\varepsilon 2}{\varepsilon 1}$ $\psi = 0.857$

$\frac{T}{Ti} = 3.198$

1 - Channel regulation

2 - Channel disturbance

Fig. 3. Transient processes of adaptive ACS

The disadvantage of this method, according to the authors, is that the initial settings of the regulator must be specially selected only for the reasons of control loop stability and is not optimal for this mode of thermal object operation. We can assert that the economic component of the operation of this ACS increases due to the need for expensive equipment, which generates test signals, as well as for communication lines and additional maintenance personnel.

Adapting to the transient response of the system with a preliminary estimation of customizable object model. As a rule, the transfer function of the customizable object models is selected as multiple identical aperiodic links with delay. Hence rational function *V*(*s*) is defined by the formula

$$\mathrm{V(s)} = \frac{1}{(\mathrm{T}_{\mathrm{mod}}\, s + 1)^n},$$

where T_{mod} – time constant model; *n* – model order.

The number of parameters to be assessed in this case is equal to four. Therefore, evaluation of all parameters of the model, knowing only the degree of attenuation and the oscillation period of the transient response would be impossible. However, as a matter of practice [6], one can get a satisfactory solution to the problem, if the time constant is associated with the fixed delay by the equation

$$\mathrm{V(s)} = \frac{1}{(\beta\tau_{\mathrm{mod}}\, s + 1)^n}; \qquad (1)$$
$$T_{\mathrm{mod}} = \beta\tau_{\mathrm{mod}}$$

and fix the value of *n*, where β – coefficient to the model equal 3.5. The coefficients of the model transfer function, which can independently change during adjustment, may be called free, while the other coefficients (in this case T_{mod} and *n*) can be called associated. In imposing such associations the gain ajustment in the control loop can be taken into account by the change in the transmission coefficient, and the phase shift can be reflected in the delay change. It is common to conduct expert evaluation of the associated coefficients of this transfer function $\beta = 4$; $n = 2$ [6].

Before the beginning of the adaptation process, we experimentally assess the transient response of the object (when the controller is switched off). It determines the approximate values of β for the selected *n*, and usually, it suffices to choose a rough approximation ($n < 2$). Then, to obtain computational formulas for the optimum settings, we produce replacement of $S = \tau_{\text{мод}}{}^{S}$ in the transfer function of the open-loop system with the considered customizable model

$$\mathrm{W(s)} = \frac{\exp(-S)}{(\beta S + 1)^n} K \left(1 + \frac{1}{1S}\right);$$

$$K = k_{\mathrm{mod}} k_p;\ I = T_u / \tau_{\mathrm{mod}}.$$

According to the dimensionless transfer function of customizable object models

$$\mathrm{W(s)} = \frac{\exp(-S)}{(\beta S + 1)^n},$$

we calculate the controller optimal dimensionless parameters. Transition to the real optimal settings to be installed in the controller is provided by the formulas

$$T_{u.опт} = I_{опт}\tau_{\mathrm{mod}};\, k_{p.опт} = K_{опт} / k_{мод};\, \omega = \Omega_{дом} / \tau_{мод}.$$

Let us adapt the system for the analysis of the test method. Transfer function is given by

$$W(s) = \frac{0{,}55}{(1{,}5s + 1)^3} e^{-0{,}52s}.$$

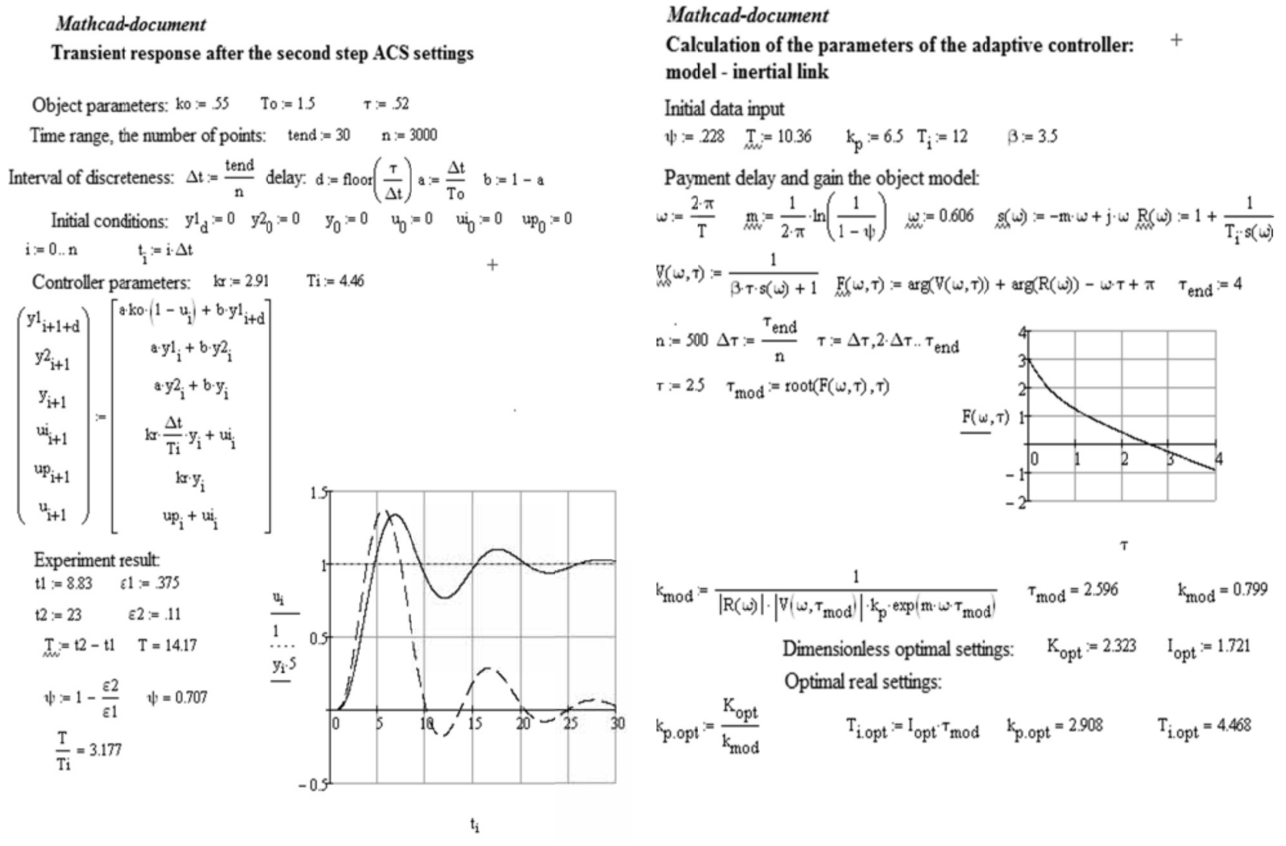
We will use the presetting procedure, that is, let us assume that before the adaptation, we evaluate object transient response (identification), and, departing from it, through the tangent at the inflection point we obtained the simplest model in the form of aperiodic element with delay. Assume that the time constant and the model delay are respectively 7 min and 2 min , i.e. the coefficient β in formula (1) may be taken 3.5 .

It is assumed that the initial process of regulation is determined by acceptable self-oscillations with $\Psi = 0.228$ and $T = 10.36$ min. To determine the free model parameters and definable values of settings, let us do calculation (fig. 4). As a result we obtain the following settings for *PI* – controller: $k_{\mathrm{p.opt}} = 2{,}91$, $T_{\mathrm{i\ opt}} = 4.47$. Modeling of regulatory process yielded the degree of attenuation value $\Psi = 0.71$, and the oscillation period $T = 14.2$ min. Recalculation of settings resulted in the similar quality criteria.

Thus, it is noteworthy that the best indicators of quality in the present approximation methods are: $\Psi = 0.71$, regulation time $T_{\mathrm{p}} = 20$ s. To reach a value $\Psi = 0.9$ is impossible. Thus, the method is not optimal, although it takes less time for adaptation. At the same time, this method is characterized by deficiencies that are associated with inaccurate mathematical model parameters, which are related to the approximation of the transient response and impossibility to obtain an aperiodic process.

The disadvantages of the method include the need for special equipment for test actions, and the duration of the process related to the search for a mathematical model and calculation of the optimal settings. Also, if during the experiment, the system is under profound disturbance, noise and interference, then the estimation of the mathematical model can involve considerable errors. Thus, the generator may require additional equipment with adaptive filter settings. However, the issue of the development and implementation of the adaptive filter remains open up to the present time.

Method of adaptive adjustment of PID-controller by fuzzy identification of the transiend process. Despite the fact that the passive identification, according to some scientists [2, 5], is not effective, it can be assumed that expert knowledge and experience of the ACS adjuster may bring success during manual setting of ACS and the analysis of the transition process.



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Transient response after the second step ACS settings

Object parameters: $ko := .55$ $To := 1.5$ $\tau := .52$

Time range, the number of points: $tend := 30$ $n := 3000$

Interval of discreteness: $\Delta t := \frac{tend}{n}$ delay: $d := floor\left(\frac{\tau}{\Delta t}\right)$ $a := \frac{\Delta t}{To}$ $b := 1 - a$

Initial conditions: $y1_d := 0$ $y2_0 := 0$ $y_0 := 0$ $u_0 := 0$ $ui_0 := 0$ $up_0 := 0$

$i := 0..n$ $t_i := i \cdot \Delta t$

Controller parameters: $kr := 2.91$ $Ti := 4.46$

$$\begin{pmatrix} y1_{i+1+d} \\ y2_{i+1} \\ y_{i+1} \\ ui_{i+1} \\ up_{i+1} \\ u_{i+1} \end{pmatrix} := \begin{bmatrix} a \cdot ko \cdot (1 - u_i) + b \cdot y1_{i+d} \\ a \cdot y1_i + b \cdot y2_i \\ a \cdot y2_i + b \cdot y_i \\ kr \cdot \frac{\Delta t}{Ti} \cdot y_i + ui_i \\ kr \cdot y_i \\ up_i + ui_i \end{bmatrix}$$

Experiment result:

$t1 := 8.83$ $\varepsilon 1 := .375$

$t2 := 23$ $\varepsilon 2 := .11$

$T := t2 - t1$ $T = 14.17$

$\psi := 1 - \frac{\varepsilon 2}{\varepsilon 1}$ $\psi = 0.707$

$\frac{T}{Ti} = 3.177$

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Calculation of the parameters of the adaptive controller: model - inertial link

Initial data input

$\psi := .228$ $T := 10.36$ $k_p := 6.5$ $T_i := 12$ $\beta := 3.5$

Payment delay and gain the object model:

$\omega := \frac{2 \cdot \pi}{T}$ $m := \frac{1}{2 \cdot \pi} \cdot \ln\left(\frac{1}{1 - \psi}\right)$ $\omega := 0.606$ $s(\omega) := -m \cdot \omega + j \cdot \omega$ $R(\omega) := 1 + \frac{1}{T_i \cdot s(\omega)}$

$V(\omega, \tau) := \frac{1}{\beta \cdot \tau \cdot s(\omega) + 1}$ $F(\omega, \tau) := arg(V(\omega, \tau)) + arg(R(\omega)) - \omega \cdot \tau + \pi$ $\tau_{end} := 4$

$n := 500$ $\Delta\tau := \frac{\tau_{end}}{n}$ $\tau := \Delta\tau, 2 \cdot \Delta\tau .. \tau_{end}$

$\tau := 2.5$ $\tau_{mod} := root(F(\omega, \tau), \tau)$

$k_{mod} := \frac{1}{|R(\omega)| \cdot |V(\omega, \tau_{mod})| \cdot k_p \cdot \exp(m \cdot \omega \cdot \tau_{mod})}$ $\tau_{mod} = 2.596$ $k_{mod} = 0.799$

Dimensionless optimal settings: $K_{opt} := 2.323$ $I_{opt} := 1.721$

Optimal real settings:

$k_{p.opt} := \frac{K_{opt}}{k_{mod}}$ $T_{i.opt} := I_{opt} \cdot \tau_{mod}$ $k_{p.opt} = 2.908$ $T_{i.opt} = 4.468$

Fig. 4. Testing of the method in the package MatCad

Let us consider the main aspects of the passive approach. It is known that setting traditional PI and PID – regulators is quite a complex task that requires detailed adjustments of controller parameters. During start-up and conventional mode, this operation is carried out usually by hand. At the same time, troubleshooting staff adjust the regulators to the transient response of the system. Adjustment of the controller settings is produced by fixing this characteristic with some initial robust setup, taking into account a certain idea about the influence of the controller parameters on the transient process. Considering this circumstance, it is advisable to analyze this method from the standpoint of fuzzy logic theory. The aim of this study is to develop a fuzzy model of PID-controller adapter and to conduct computer testing of the resulting model in an uncertain environment, namely under the impact of parametric perturbation (changing values of the transfer function of the object through the channels of tasks and external disturbance).

A common approach to adjusting parameters of dynamic configuration with respect to the calculated values may be qualitative or fuzzy, i. e. in the form of linguistic rules, drawn up by experienced adjusters and investigators in the field of ACS:

- if the transition process is characterized by weak or absent oscillativity, but long duration, then k_p should be increased, and T_i – decreased;
- if the transition process is very oscillatory, then K_p must be reduced;
- with decreasing integral component, control error decreases faster, in the course of time;
- decrease in the integration constant reduces the stability margin;
- growth of the differential component increases the stability margin and speed.

Also, the choice of optimal values for PID parameter is influenced by the delay in ACS.

As a criterion for the quality of ACS, the authors propose to take a dimensionless total index of the regulation time values of the transition process T_p and of the first deviation

$$P = (T_p + \Delta G_1) \rightarrow \min \ ,$$

where P – summary measure of the quality of the transition process; T_p – regulation time of the transition process; ΔG_1 – time to reach the first deviation transition process .

Thus, fuzzy adapter will take into account both the speed and the oscillation of the regulatory process.

The proposed structure of the fuzzy adaptive ACS with the PID-controller is shown in fig. 5.

In developing the model of fuzzy adapter in the package MatLab (FLT) we used three inputs – “first deviation”, “adjustment time”, “delay” and three outputs – “proportionality coefficient”, “integration constant”, “differentiation coefficient” (fig.6). Identification function may be exercised by an adjusting specialist or by

SCADA system, which visualizes the transition process and calculates the quality parameters.

In elaborating the model of fuzzy adapter and carrying out fuzzification stage, we used three membership functions: *Z, S* – shaped and triangular type [9]. Universum of term-sets (low, medium, high) and the knowledge base of the adapter were configured during multiple experiments with respect to the range of changes in the values of the transfer functions parameters and parameters of transients processes. Also the recommendations [10] about the impact of each PID parameter on the trajectory of the transition process were taken into account.

As a method of defuzzification we chose the method of the gravity center [9]

$$Kp=\frac{\sum_{i=1}^{n}Kp_i\mu(Kp_i)}{\sum_{i=1}^{n}\mu(Kp_i)};\quad Ti=\frac{\sum_{i=1}^{n}Ti_i\mu(Ti_i)}{\sum_{i=1}^{n}\mu(Ti_i)};\quad Kd=\frac{\sum_{i=1}^{n}Kd_i\mu(Kd_i)}{\sum_{i=1}^{n}\mu(Kd_i)},$$

where μ – truth degree of membership function; n – number ofи term-sets.

Window of working of fuzzy adapter shown in fig. 7.

The window of fuzzy adapter working results (fig. 7) shows the calculated values of the adaptive PID parameter: $K_p = 16.9$; $T_i = 2.48$; $K_d = 0.75$ that must be set on the controller for the following values of the transient process of a single loop ACS: $G_1 = 0.584$; $T_p = 19.2$; $\tau = 1.32$. These settings allow to obtain the expected transient process with improved quality parametrs.

Comparative testing of settings recommended by fuzzy adapter of PID-controller with inertial object of the third order in Simulink program resulted in anticipated transients processes with improved quality, in contrast to the processes, of classical adaptive ACSs. The proposed method for constructing adaptive PID controller eliminates the step of active adaptation from the setup process and allows to evade deterioration of the object work. The disadvantage of the fuzzy approach is the need for a significant amount of experiments at the stage of evaluation and adjustments of fuzzy model parameters, as well as impossibility to use it for multi-loop ACS.

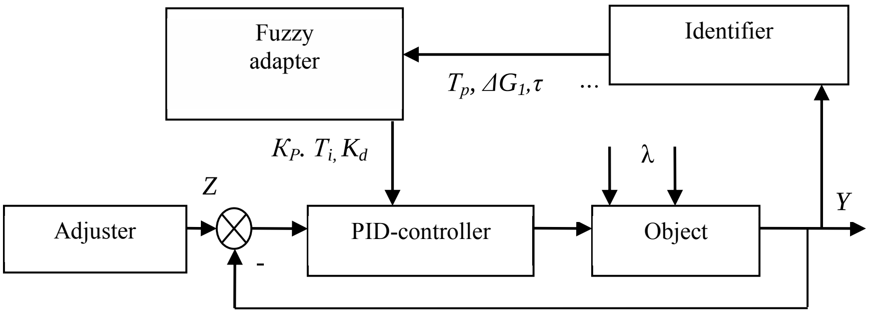

Fig. 5. The structure of the fuzzy adaptive ACS: λ – external perturbation; Z – task; T_p – regulation time; ΔG_1 – time to reach the of the first deviation of the transition process; τ – delay; Y – output parameter; K_d – differentiation coefficient; K_p – proportionality coefficient; T_i – integration time

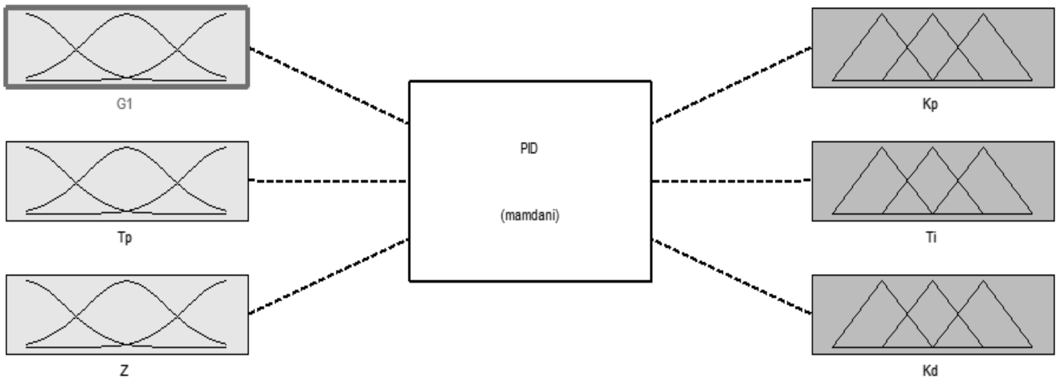

Fig. 6. Kind of the fuzzy model (adapter) in program FLT (MatLab), which implemented by Mamdani algorithm: G_1 – block of the first deflection; T_p – time control of the transition process; τ – delay; K_p – proportionality coefficient; T_i – integration time; K_d – differentiation coefficient; PID – knowledge base

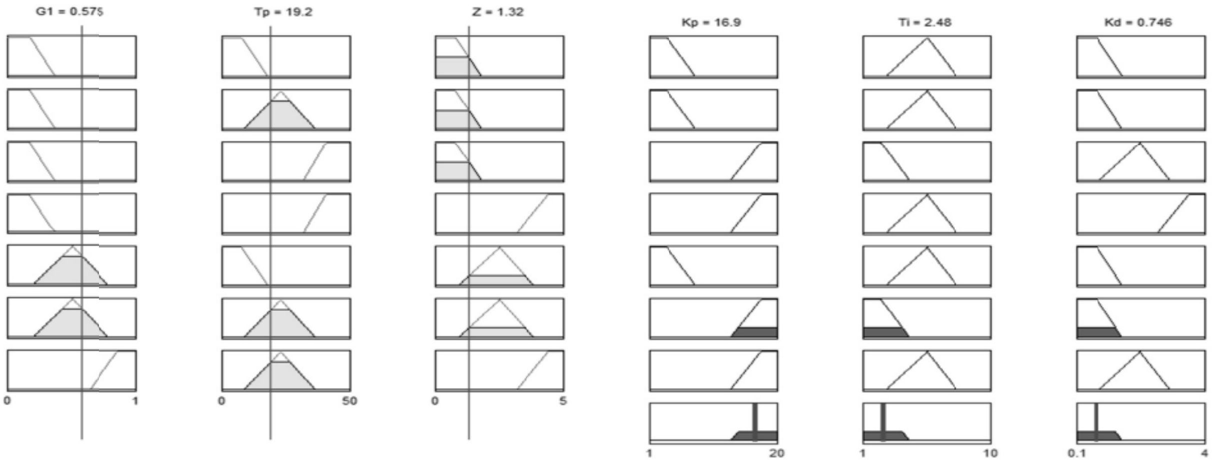

Fig. 7. Window of working of fuzzy adapter

Conclusion. Summarizing analysis of the considered adaptation methods it is possible to conclude:

Inefficient exploitation of the classical adaptive devices in industrial environment in many cases is explained by using active identification methods in algorithms (to clarify the characteristics of objects). Testing impacts on some thermal objects are technologically unacceptable, in other cases, they cause self-oscillating reaction of controlled parameters, leading to overuse of energy-resources and decrease in equipment reliability, under the influence of deep perturbations, this situation can lead to loss of stability in the entire ACS TP. Simulation modeling showed that the classical methods of adaptation are multi-stage, rather complicated to implement, and time-consuming to calculate the adaptive settings. Thus, the principles of classical dual controls that implement the simultaneous identification of object parameters and adaptation of ACS, under varying operating parameters, are ineffective for heat and power systems in the adjustment mode. One solution to this problem can be the use of technology based on intelligent management methods for calculating the adaptive settings via transients that occur in closed systems under disturbances by load, or by task.

Introduction of a fuzzy approach to the adaptation technique, as evident from the computer experiments, will improve the quality of ACS. This is possible through the use of expert knowledge and experience avoiding the stage of active identification, lengthy processes of calculating controller's parameters and degradation of TP ACS performance.

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Мета. Аналіз ефективності традиційних та інтелектуальних методів адаптації систем автоматичного регулювання теплоенергетичних процесів теплових електричних станцій (ТЕС) .

Методика. У ході проведеного дослідження використовувалися класичні методи активної ідентифікації та адаптації систем автоматичного регулювання (САР). Подача тестового впливу на САР призводить до виникнення перехідного процесу, аналіз якого дозволяє отримати параметри передавальної функції об'єкта та розрахувати налаштування типового регулятора. Однак, активна ідентифікація вносить додаткові збурення на об'єкт і погіршує якість управління в цілому. Таким чином, пропонується скористатися евристичною методикою експертів-наладчиків у процесах дистанційної адаптації одноконтурних САР по виду траєкторії перехідної характеристики.

Результати. Експериментально доведено неефективність типових методів адаптації САР теплових об'єктів регулювального режиму роботи на прикладі каналу керування температурою перегрітої пари ТЕС. Разом з тим, використання теорії нечіткої логіки при моделюванні дій експлуатаційного персоналу у процесах налагодження та адаптації САР дозволило отримати перехідні процеси з очікуваними показниками якості.

Наукова новизна. Для прискорення процесу адаптації систем регулювання й зменшення впливу додаткових збурень, викликаних активною ідентифікацією, запропоновано інтелектуальний підхід розрахунку налаштувань пропорційно-інтегрально-диференціального регулятора (ПІД-регулятора), що діє на основі алгоритму Мамдані.

Практична значимість. У даний час більше 90% енергоблоків вугільних ТЕС України вичерпали розрахунковий термін експлуатації та потребують проведення модернізації. При цьому переважна частина ТЕС працює в регулювальному режимі з погодинною зміною навантаження та відповідною зміною властивостей підсистем управління. Використання в автоматизованих системах управління (АСУ) ТЕС інтелектуальних технологій у процесах ідентифікації та адаптації локальних САР з пропорційно інтегральним (ПІ) і ПІД-регуляторами дозволить істотно скоротити виробничі витрати, пов'язані з перевитратою твердого палива в силу неоптимальності перехідних процесів.

Ключові слова: *ідентифікація, адаптація, комплексно-частотна характеристика, ПІ-регулятор, енергоблок, нечіткий адаптер*

Цель. Анализ эффективности традиционных и интеллектуальных методов адаптации систем автоматического регулирования теплоэнергетических процессов тепловых электрических станций (ТЭС).

Методика. В ходе проведенного исследования использовались классические методы активной идентификации и адаптации систем автоматического регулирования (САР). Подача тестового воздействия на САР приводит к возникновению переходного процесса, анализ которого позволяет получить параметры передаточной функции объекта и рассчитать настройки типового регулятора. Однако, активная идентификация вносит дополнительные возмущения на объект и ухудшает качество управления в целом. Таким образом, предлагается воспользоваться эвристической методикой экспертов-наладчиков в процессах дистанционной адаптации одноконтурных САР по виду траектории переходной характеристики.

Результаты. Экспериментально доказана неэффективность типовых методов адаптации САР тепловых объектов регулировочного режима работы на примере канала управления температурой перегретого пара ТЭС. Вместе с тем, использование теории нечеткой логики при моделировании действий обслуживающего персонала в процессах наладки и адаптации САР позволило получить переходные процессы с ожидаемыми показателями качества.

Научная новизна. Для ускорения процесса адаптации систем регулирования и уменьшения влияния дополнительных возмущений, вызванных активной идентификацией, предложен интеллектуальный подход расчета настроек пропорционально-интегрально-дифференциального регулятора (ПИД-регулятора), действующий на основе алгоритма Мамдани.

Практическая значимость. В настоящее время более 90% энергоблоков угольных ТЭС Украины исчерпали расчетный срок эксплуатации и требуют проведения модернизации. При этом подавляющая часть ТЭС работает в регулировочном режиме с почасовой сменой нагрузки и соответствующим изменением свойств подсистем управления. И использование в автоматизированных системах управления (АСУ) ТЭС интеллектуальных технологий в процессах идентификации и адаптации локальных САР с пропорционально-интегральными (ПИ) и ПИД-регуляторами позволит существенно сократить производственные издержки, связанные с перерасходом твердого топлива в силу неоптимальности переходных процессов.

Ключевые слова: *идентификация, адаптация, комплексно-частотная характеристика, ПИ-регулятор, энергоблок, нечеткий адаптер*

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