Conclusion

Specialist model construction is one of the most important stages of KCS construction, as the existence of such model, and also its support in actual condition allow solving the problems of knowledge and experience search in the organization, KCS personalization to specific user requirements and specialists grouping into interests community. Thereby, users simulation allows improving the process of collection and distribution of explicit and hidden knowledge from organization employees.

REFERENCES

1. Davenport T., Prusak L. Working Knowledge: how organizations manage what they know. – Boston: Harvard Business School Press, 1998. – 200 p.
2. Nonaka I., Tekeuchy H. The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation. – Moscow: Olymp-Business, 2003. – 384 p.
3. Tusovskiy A.F., Chirikov S.V., Yampolskiy V.Z. Knowledge control systems (methods and techniques). – Tomsk: STL Press, 2005. – 260 p.
4. W3C, «RDF/XML Syntax Specification (Revised)» // [Electronic resource]. – 2003. – Access mode: http://www.w3.org/TR/rdf-syntax-grammar/

Received on 17.11.2006

UDC 681.521

ADAPTIVE SYSTEM WITH FREQUENCY CONTROL CHANNEL DEVISION AND BOOTSTRAPPING

D.M. Taskaev, V.S. Avramchuk *

Organization: «Tsentrsibnefteprovod», Tomsk
*Tomsk Polytechnic University
E-mail: Taskaev.dima@mail.ru

Construction of adaptive control system on the basis of the principle of frequency-dependable feedback and with application of multi-frequency identification action has been shown. The adaptation algorithm possesses relative simplicity, accuracy suitable for most of the industrial enterprises, does not require large calculating resources and is capable of operating in the real time mode.

Technological advance in industry development and investigations in scientific field have set a problem of creation automatic control systems of extremely high accuracy and minimal complexity. Such automatic systems should search out the conditions of high-performance behavior for technological and production processes in the given conditions of system operation without operator's control. The systems meeting this requirement were called adaptive or self-adjusting.

One of significant peculiarities of applying the majority of adaptation techniques in practice is unsuitability for control of some technological processes (TP), as the sources of inner uncontrolled random disturbance may exist in the object itself. It makes control object (CO) stochastic and involves the necessity of constant control in control process of its current state and on-line correction of generic parameters or control action.

The suggested technique of adaptive control system construction (AdCS) is based on using active frequency methods of objects identification. Frequency methods application allows for interference protection of algorithm as well as an active experiment at the operating (working in normal operating conditions) system in terms of minimization of interference into its work. Block diagram of suggested adaptive system is presented in Fig. 1: where BHA is the block of harmonic analysis; FG_1 and FG_2 are the frequency packet generators; K_1, K_2 are the controlled keys; $\overline{\beta}=\{K_П, T_И, T_Д\}$ is the vector of regulator generic parameters; $\overline{k}=\{Am_1...Am_n;f_1...f_n\}$ is the vector of amplitudes and frequencies of harmonics (forming trial testing signal); $\overline{\alpha}=\{Am_1^*...Am_n^*;\varphi_1...\varphi_n\}$ are the results of BHA operating in the form of vector, representing the combination of amplitudes and phases, singled out in harmonic signal, on frequencies $(f_1...f_n)$ of the trial testing signals; g is the setting (master control); ε is the error (error signal); y is the control action; x is the output signal; x_{fs} is the feedback signal; U_t is the trial identifying signal; U_t^* is the signal of compensation.

In structure organization of adaptive system three levels of hierarchy in its functioning are clearly singled out, and namely:

- the 1st level includes the main circuit of the system and consists of adjustable proportional integro-differential regulator (PID-regulator), CO, two controlled keys K_1 and K_2 and three adders;
- the 2d level, the adaptation circuit, contains two programmed signals generators, FG_1 and FG_2, BHA and block «Analyzer»;
- the3d level consists of coordination and control block, realizing general control over the processes of adaptation, identification and control as well as elaborates AdCS behavior at contingencies, for example instability.

Self-adjustment (adaptation) circuit is functioning in the following way: FG_1 generator forms the trial sig-

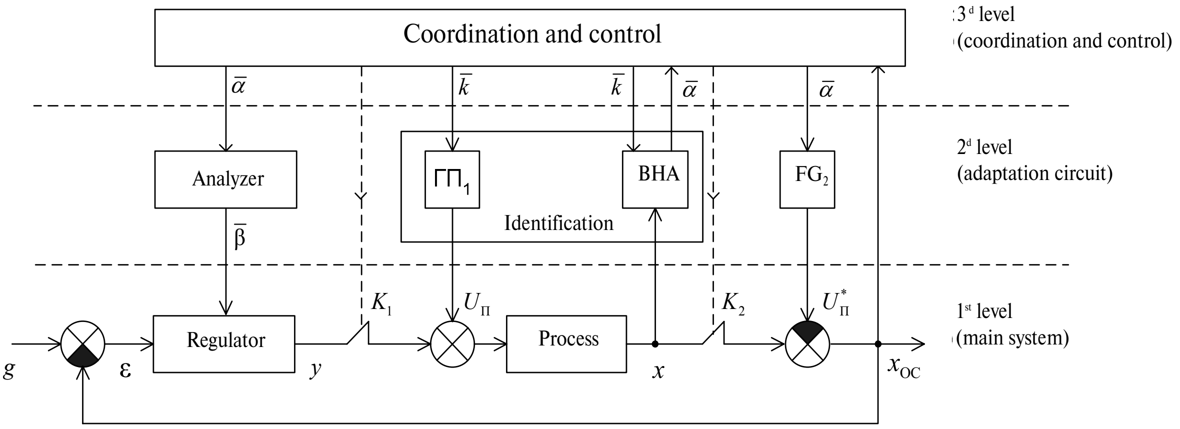

Fig. 1. *Block diagram of adaptive system*

nal U_t at its output (according to current adjustments, entering from the block «Coordination and control» in the form of parameters $\bar{k}$ vector). The trial signal, entering to the entrance of CO, consists of harmonics sum and is described by the following formula:

$$U_{\Pi} = \sum_{i=1}^{m} Am_i \sin(f_i\, t),$$

where i is the number of harmonic, m is the general number of harmonics in trial testing signal; $f_i = \Delta fi$ is the frequency of i harmonic, Δf is the frequency pitch, $\Delta F = \Delta f$ determines the width of frequency slot of scanning by trial signal.

Possible laws of change of harmonic amplitudes, constituting trial signal, may be different, for example, steady, linear decreasing, exponentially decreasing. It was stated experimentally that the choice of law for amplitude change influences the quality factors of main system control.

For extraction of the trial testing signal at the output of CO, BHA is suggested to be included into AdCS composition. The main function of BHA is the search of harmonic amplitudes and phases on frequencies ($f_1 \ldots f_n$) of the trial testing signal in the output signal of CO and results representation in the form of vector $\bar{\alpha} = \{Am_1^* \ldots Am_n^*; \varphi_1 \ldots \varphi_n\}$. The results of BHA operation in the form of found parameters vector enter to the generator FG_2, at the output of which the compensating signal U_t^* of trial signal U_t influence on CO is formed. Then the signal U_t^* is subtracted at the 3d adder from the output signal of CO eliminating thereby negative influence of the trial signal on the main system in the process of identification.

The main function of the block «Analyzer» consists in tracing steady-state value of phase shift $\varphi_{КР}$ and defining object critical frequency $f_{КР}$, on which the phase shift between input and output equals $\varphi_{КР} = -3{,}14$ rad and determining amplitude $Am_{КР}$ of steady-state oscillations. The calculation of regulator $\bar{\beta}$ parameters is carried out by the found frequency and amplitude, obtained as the result of carrying out frequency identification of CO.

Normally closed controlled keys K_1 and K_2 switch off CO at signal injection from the block «Coordination and control», opening closed circuit of the main system at:

- realization of primary identification of CO, which is carried out automatically at first operation of adaptive system for obtaining initial values of regulator generic parameters;
- contingencies occurrence, for example, system instability owing to quick change of CO state and spillover of controlled access.

For identification of divergent transient process in block «Coordination and control» the analysis of output signal x_{fs} is carried out, specifically, the statistical treatment (calculation of mathematical expectation and dispersity) is carried out. It allows defining the moment of adaptive system instability for timely elimination.

Among engineering approaches of regulator adjustment calculation some of them are more accurate, but laborious for manual computation, other ones are simple but approximate. The most widely used method, reflecting the technique of exact and approximate setup calculation, is the method of continuous waves (Ziegler-Nichols) based on the output of the operating system with a proportional regulator (P-regulator) to the stability boundary and calculation by the critical frequency and transmission coefficient of optimal setup parameters. The formulas of calculation of the analog PID-regulator parameters are given below [1]:

$$K_{\Pi} = 0{,}6\, K_{КР};$$

$$T_{И} = 1{,}2\, K_{КР}\, f_{КР};$$

$$T_{Д} = 0{,}075 \frac{K_{КР}}{f_{КР}},$$

where $K_{КР} = \dfrac{Am_0}{Am_{КР}}$, Am_0 is the amplitude of testing harmonic at the output of CO, f_{cr} and Am_{cr} is respectively the steady critical frequency and the amplitude at the output of CO. Therefore, K_{cr} is found as a result of solving two equations reflecting the method of continuous waves:

$$\begin{cases} \varphi_{КР}(f_{КР}) + \pi = 0; \\ K_{КР} = \dfrac{1}{Am_{КР}(f_{КР})}. \end{cases}$$

In this case, to define the amplitude-phase-frequency characteristic (APFC) of the object in the short range – in the near resonance frequency region (critical frequency) is enough for accurate system setup.

The Ziegler-Nichols method forms the basis of many setup methods of sampled-data PID-regulators. Particularly, if the recurrent control algorithm, corresponding to analog PID-law, has the view [2]:

$$y[k] = -K_0 \cdot \varepsilon[k] - K_1 \cdot \sum_{i=0}^{k-1} \varepsilon[i] - K_2 \cdot (\varepsilon[k] - \varepsilon[k-1]),$$

where $y[k]$ is the current calculated value of control action; $\varepsilon[k]$, $\varepsilon[k-1]$ are the current value and the value at the previous stage for the error signal; k is the number of a calculated pitch (integration). Then the setup parameters of the regulator K_0, K_1 and K_2 may be found by the formula:

$$K_0 = (0{,}6 - 0{,}27\, T_0\, f_{\text{КР}})\, K_{\text{КР}};$$
$$K_1 = 1{,}2\, K_{\text{КР}}\, T_0\, f_{\text{КР}};$$
$$K_2 = 0{,}075\, K_{\text{КР}} \frac{1}{T_0 \cdot f_{\text{КР}}},$$

where T_0 is the sampling period (interval).

It is necessary to note that the parameters of PID-regulator calculated by the formula (1) and (2) are of suboptimal character and will provide accuracy optimal parameters for various types of CO corresponding to APEC point with vector length Am=0,8 and angle φ=–2,62 rad [3]. It is proved analytically that PID-regulator setups, optimal by the minimum of average squared error (ASE), may be obtained by determining critical frequency and vector magnitude of the object APEC, corresponding to phase shift –2,11 rad [4].

It should be noted that the optimality of the obtained setups is not guaranteed for the objects with long delay. It is connected with the fact that the Ziegler-Nichols formulas are of empirical character and meant for the objects with ratio τ/T from 0 to 0,5 (where τ is the delay of CO, T is the time constant of CO). At τ/T>(0,5...0,7) it is appropriate to use special regulators with delay compensation.

To apply the above mentioned technique of PID-regulator setup it is necessary to determine the steady-state value of Am_{cr} amplitude and f_{cr} frequency of CO critical oscillations according to the results of frequency identification. In this connection one of the most important tasks at the performance of suggested AdCS system is the task of determination of harmonic signals phase shift at the input and output of CO. To determine the value of phase shift the following methods are applied: geometrical; spectral; loss cosine.

It should be noted that there is no universal method of phase shift determination having both high accuracy, and conversion rate, and low requirements for analyzed signals at the same time. Therefore, the choice is made individually at every concrete case depending on stated requirements. As a rule, only one method of the mentioned above is realized in practical task of phase shift searching. It impairs the quality indices of this algorithm performance.

Owing to the stated reasons, the Fourier algorithm of rapid transformation (FRT), combining with the advantages of geometrical method, is used as the method of harmonic analysis for system functioning in real-time mode. However, it should be noted that there are the alternative algorithms requiring less real operations per one reading. For example, periodical lattice functions application due to significant reduction of a number of treated readings may result in considerable 20...40 % reducing in algorithm hours of service (depending on a number of readings) in comparison with classical FRT algorithm [5].

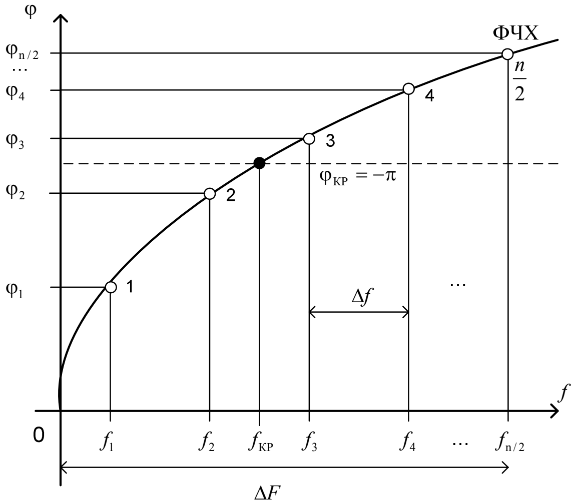

Fig. 2. *Determination of critical frequency by PFC*

The method of phase shift calculation according to the results of frequency analysis is illustrated in Fig. 3, in which the following notations are accepted: ΔF is the frequency scanning range by testing signal, Δf is the pitch by the frequency of harmonic constituents of testing signal, f_{cr} and φ_{cr} are (respectively) the critical frequency and phase of CO, n is the size of a sample.

If the nonlinearities of phase-frequency characteristic (PFC) are neglected and considered to be conditionally linear in the neighborhood of the point corresponding to the critical frequency, then f_{cr} may be found by the following formula:

$$f_{\text{КР}} = \frac{f_{\text{В}} - f_{\text{Н}}}{\varphi_{\text{В}} - \varphi_{\text{Н}}}(\varphi_{\text{КР}} - \varphi_{\text{Н}}) + f_{\text{Н}},$$

where $f_{\text{В}}$, $f_{\text{Н}}$ and $\varphi_{\text{В}}$, $\varphi_{\text{Н}}$ are the frequency and phases of the signals, being higher or lower than the critical point (these points are denoted by «3» and «2» in Fig. 3).

According to the suggested method of construction of the adaptive system with frequency division of control and identification channel, Fig. 1, the analogue dynamic model was developed in Simulink (Matlab) medium (Fig. 3).

Among the AdCS using active frequency identification method the most widely spread is the AdCS containing in its structure the generator for a testing harmonic signal and synchronous detector for critical frequency extraction [6]. The curves of current calculated value of critical frequency f_{cr} of the suggested adaptive system in comparison with the AdCS with synchronous detector are presented in Fig. 4. The following notations are ac-

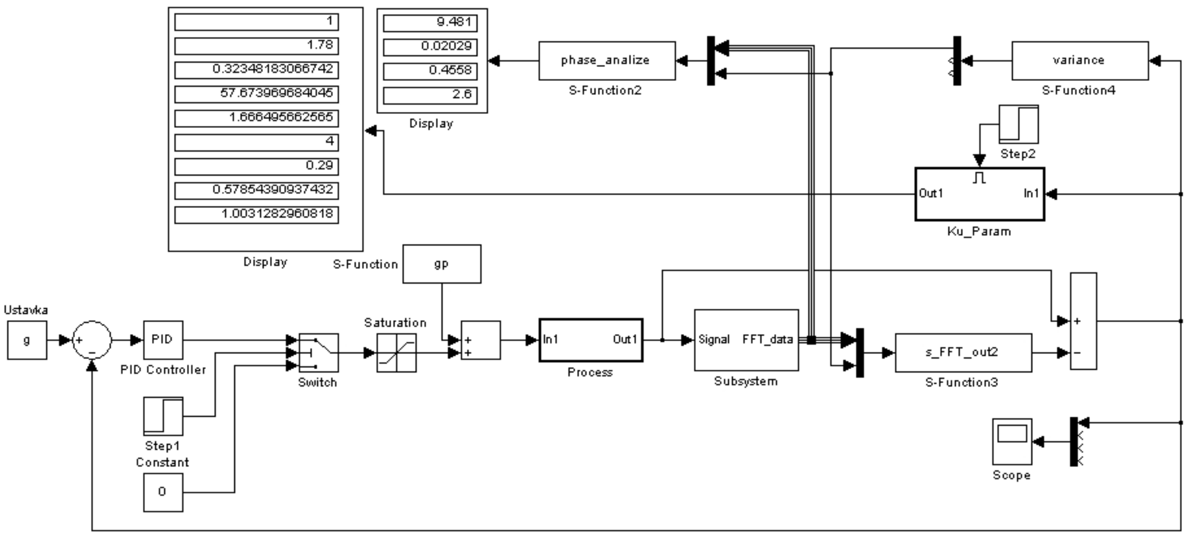

Fig. 3. *The model of the adaptive system with frequency division of control and self-adjustment channel in Simulink (Matlab) medium*

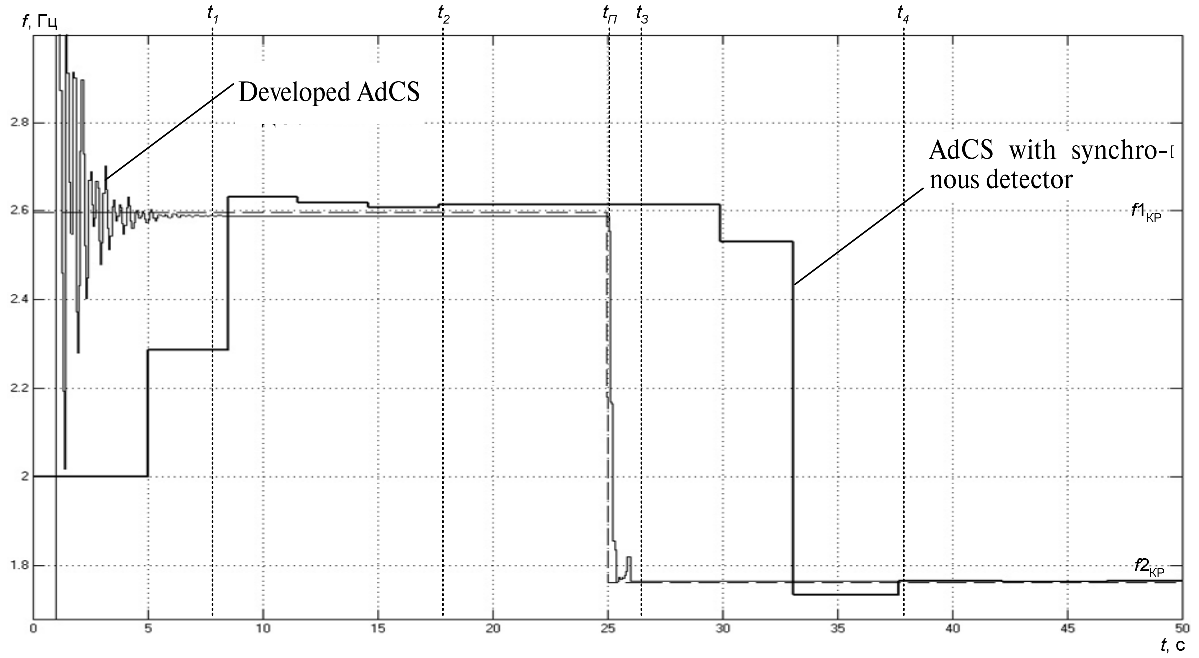

Fig. 4. *The procedure of identification of an object by frequency technique*

cepted in Fig. 4: $t_п$ is the moment of changing the state of an object (critical frequency change from $f1_{КР}$ to $f2_{КР}$), t_1 and t_2 are the moments of identification ending for the adaptive system, t_3 are t_4 are the moments of identification ending for AdCS with synchronous detector.

As it is seen from the given diagram (Fig. 4) the setup rate of the developed AdCS in comparison with the AdCS with synchronous detector is considerably higher, namely: at initial identification (at zero initial conditions) the setup rate is more than 2 times higher, and at current identification differs significantly. The ratio of setups rates approximately remain at other CO types and different conditions of experiment, it was confirmed by the series of experiments.

The diagram of determination of PID-regulator $\bar{\beta}=\{K_П, T_И, T_Д\}$ current parameters at initial identification (at zero initial conditions) as well as at treatment of various types of CO nonstationarities is presented in Fig. 5.

On the whole, the accuracy of identification and PID-regulator parameters calculated according to its results may be characterized as rather high and acceptable for the most part of TP. More detailed qualitative estimation of carried out calculations accuracy by means of ASE computation for different frequency pitch of trial testing signal is tabulated.

It should be noted that the period of trial testing signal increases at the decrease of a frequency pitch Δf. And this results, in its turn, in increasing transient process duration and, as a result, self-adjustment time, therefore, in practice, it is necessary to search reasonable compromise between the rate of self-adjustment and accuracy of its calculations.

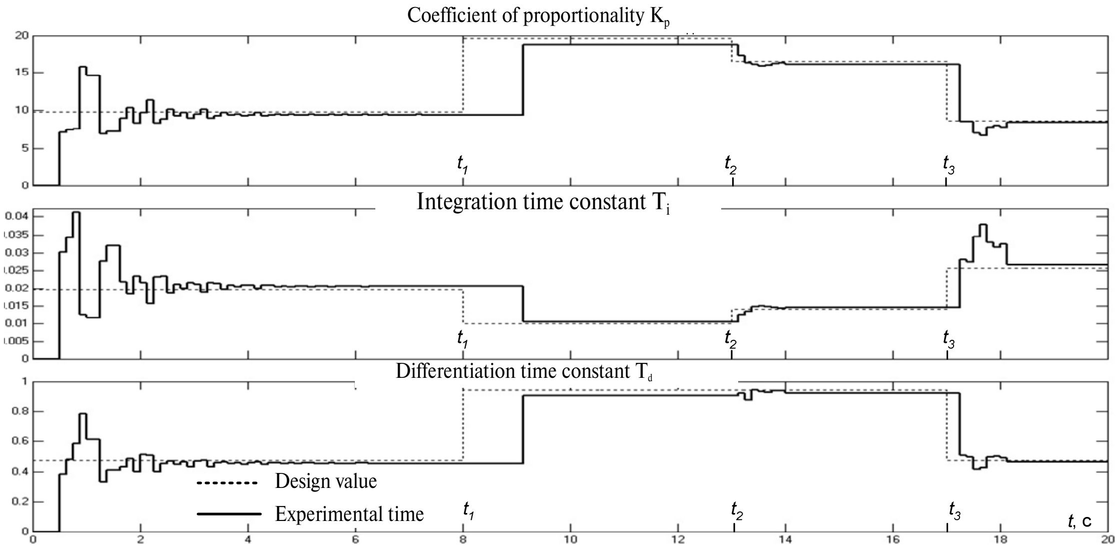

Fig. 5. *Diagrams of determination of PID-regulator parameters (where t_1, t_2, t_3 are the moments of CO nonstationarity occurrence)*

Table. *The results of the experiments in estimation of calculations accuracy*

Results		Pitch by frequency, Δf, Hz				
		1,0	0,8	0,5	0,2	0,1
F_{CR}	Calculation	2,59739996136133				
	Experiment	2,5712	2,5781	2,5850	2,5886	2,5887
	ASE, %	1,0106	0,7448	0,4790	0,3380	0,3349
A_{CR}	Calculation	3,0580003724e-3				
	Experiment	0,0032	0,0031	0,0030	0,0030	0,0030
	ASE, %	4,0921	2,6894	1,2867	0,9131	0,7496
K_P	Calculation	9,8103323567				
	Experiment	9,4197	9,5351	9,6504	9,7402	9,7602
	ASE, %	3,9818	2,8060	1,6302	0,7199	0,5321
T_I	Calculation	1,9622189e-2				
	Experiment	0,0200	0,0199	0,0199	0,0197	0,0195
	ASE, %	1,8513	1,6349	1,4186	0,6151	0,5432
T_D	Calculation	4,721227238e-1				
	Experiment	0,4540	0,4620	0,4700	0,4731	0,4730
	ASE, %	3,8363	2,1418	0,4474	0,1974	0,1931

The possibility of determination of PID-regulator parameters without using mathematical models of CO, the construction of which is significantly complicated for the most part of real objects, may be also referred to the advantages of the developed adaptation method.

Application of the adaptive regulator with frequency division of control channel and self-adjustment allows for:

1. automatic determination of suboptimum setups of control PID-algorithms for the objects with different dynamics;
2. the process of self-adjustment at minimum-trial signal level, which does not result in disturbance of CO normal duty, in this case the amplitude of trial signal at CO output is not more than 0,3...0,5 %, at the output1...1,5 %;
3. starting up the process of self-adjustment simultaneously at all the regulators installed in TP;
4. control of self-adjustment and setup updating processes from the side of operator;
5. control of the process of self-adjustment in automatic mode for excepting system erratic operation;
6. setting up the control loop with different sampling periods unknown beforehand.

On the basis of stated above, the conclusion can be made that the use of adaptive system with frequency division of control channel and self-adjustment in terms of PID-regulator allows increasing significantly the operation speed of closed-loop control in comparison with adaptive control system with synchronous detector as well as achieving acceptable quality indices of transient processes for the most part of industrial CO. In this case the control loop of AdCS is not broken and operates simultaneously with adaptation circuit. Change of setup of RTF algorithm performance, being in the basis of BHA operation, allows for configuration of the adaptive control system operation in real-time mode.

REFERENCES

1. Rotach V.Ya. Adaptation in control systems of technological processes // Promyshlennyie ASU I Kontrollery. – 2005. – № 1. – P. 4–10.
2. Rotach V.Ya. Calculation of industrial control systems setup. – Moscow-Leningrad: Gosenergoizdat, 1961. – 344 p.
3. Rotach V.Ya., Klyuev A.S. et al. Automatization of control systems setup / Ed. by V.Ya. Rotach – Moscow: Energoatomizdat, 1984. – 272 p.
4. Mazurov V.M. Construction principles and methods of realization of optimal and adaptive regulators for objects with delay: Abstract of a thesis ... of a cand. of techn. science. – Tula: TulSTU, 1994. – 40 p.
5. Pat. 2229139 RF. ICI G01R 23/16. The way of spectral analysis of complex nonsinusoidal periodic signals represented by digital indication / V.S. Avramchuk, E.I. Goldshtein. Reported 10.12.02; Published 20.05.2004, Bulletin № 14. – 10 p.: ill.
6. Spitsin A.V. Adaptive regulators with trial harmonic signal for objects with variable parameters: Abstract of a thesis ... of a Cand. of techn. science. – Tula, 2001. – 20 p.

Received on 14.09.2006