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Jasur Usmonovich Sevinov

Abdishukurov Maqsud o'g'li Shavkat Mr

Nasriddin Xasanovich Bobomurodov

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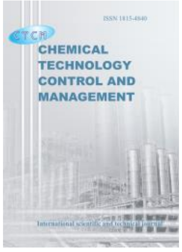

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SYNTHESIS PROBLEM OF ADAPTIVE CONTROL SYSTEMS FOR MULTI-CHANNEL AND MULTI-MODE OBJECTS

Sevinov Jasur Usmonovich[1], Abdishukurov Shavkat Maqsud o'g'li[2]
Bobomurodov Nasriddin Xasanovich[3]

[1,2,3]Tashkent state technical university named after Islom Karimov. Address: 2 University st. 100095, Tashkent city, Republic of Uzbekistan.
E-mail: [2]shavkatabdishukurov66@gmail.com.

Abstract. *The issue of synthesis of an adaptive control system for multi-channel and multi-mode objects is considered. Development that of effective adaptive control algorithms for nonlinear dynamic systems ensure quality indicators of processes. In technological processes, it is necessary to control several parameters or several systems at the same time. For such a process control system, an adaptive control system is created. Work has been carried out on structural projects for the installation of adaptive systems. The stable requirements for the correction of adaptive control systems are seen. A review of several parametric deviation detections, based on the reference model and analyzer performance. Adaptive systems based on the indicators of analyzer, the identification of deviations and reference modules are mentioned there. Methods of connecting for linear controlling objects and the number of controls loops, the in the multi-mode objects is mentioned there. An exemplified for adaptive control system as the gas turbine engine in the control object. The method of connecting the adaptive system to the control object is seen as an exemplified of the gas turbine engine process.*
Keywords: *control object, adaptive control, tuning loop, parametric deviations, identification, uncontrolled disturbances, gas turbine engine.*

Annotatsiya: *Ko'p kanalli va ko'p rejimli obyektlar uchun adaptiv boshqarish tizmini sintezlash masalasi ko'rib chiqilgan. Nochiziqli dinamik tizimlar uchun tez o'tadigan jarayonlarning sifat ko'rsatkichlarini ta'minlaydigan samarali adaptiv boshqarish algoritmlari ishlab chiqilgan. Texnologik jarayonlarda bir vaqtni o'zida bir nechta parametrlar yoki tizimlarni boshqarishga to'g'ri keladi. Bunday texnologik jarayonlarni boshqarish tizimi uchun adaptiv boshqarish tizimi yaratiladi. Adaptiv tizimlarda strukturaviy sxemalarni tahlil qilish va sintezlash bo'yicha tadqiqotlar olib borilgan. Tuzatishga chidamli adaptiv boshqarish tizimlarini yaratish talablari qayta ko'rib chiqilgan. Parametrli og'ishlarni aniqlash, o'z-o'zini tiklash modellari asosidagi tizimlar va adaptiv tizim analizatorining ko'rsatkichlaridan foydalanish asosida parametrlar va tizimlarni tuzatish masalalari ko'rib chiqilgan. Adaptiv boshqarish tizimlarini yaratishda kichik og'ishlar bilan sezgirlik parametrlariga tegishli bo'lgan boshqa vazifa qo'yiladi. Ko'p rejimli boshqarish obyektlarida ularni soddalashtirish uchun sozlash halqalari sonini kamaytirish masalalari ko'rib chiqilgan. adaptiv tizimni boshqarish obyektiga ulash uchun jamoa tomonidan ishlab chiqilgan usullar asosida gaz turbinalaridagi sovutish jarayonlarini tadqiq etish natijalari taqdim etilgan.*
Tayanch so'zlar: *boshqarish obyekti, adaptiv boshqarish, rostlash konturi, parametrik og'ishlar, identifikatsiyalash, boshqarilmaydigan ga'layon, gaz-turbinali issiqlik almashinish qurilmasi.*

Аннотация: *Рассмотрены задачи синтеза адаптивной системы управления многоканальными и многорежимными объектами. Разработаны эффективные алгоритмы адаптивного управления нелинейными динамическими системами, обеспечивающие качественные параметрами быстропротекающих процессов. В технологических процессах необходимо одновременно контролировать несколько параметров или решать несколько задач. Для такой системы управления технологическим процессом применяются технологии адаптивного управления. Проведены исследования по анализу и синтезу структурных схем в адаптивных системах. Пересмотрены требования к созданию устойчивых к коррекциям адаптивных систем управления. Рассмотрены вопросы обнаружения параметрических отклонений, системы на основе моделей самовосстановления и коррекции параметров и систем на основе использования показателей анализатора адаптивной системы. При создании адаптивных систем управления ставится еще одна задача, которую применим к параметрам чувствительности с* *малыми отклонениями. В многорежимных объектах управления с целью их упрощения рассмотрены вопросы уменьшения количества регулировочных колец. Приведены результаты исследования процессов охлаждения в газотурбинах на основе разработанных методов подключения адаптивной системы к объекту управления.*

Ключевые слова: *объект управления, адаптивное управление, контур управления регулятор, параметрические отклонения, идентификация, неуправляемые возмущения, газотурбинный теплообменник.*

I. Introduction

The relevance of adaptive control is due to the implementation of researches in science and technology. Technologies are created for intelligent navigation, control systems, creating new types of transport systems and managing them. The research is connected with the solution of one of the fundamental problems of the modern theory of automatic control. The synthesis algorithms of effective adaptive control provide several indicators that are guaranteed. The quality of transient processes for nonlinear dynamic systems under uncertainty [1-4].

Prior to now, the theory of adaptive control has been enriched with many interesting concepts and methods. However, as noted in a number of works, practical achievements are more modest in comparison with their results. Despite the existing dissatisfaction with the implementation of theoretical results in practice, adaptive controllers are increasingly being used. Achieving new qualitative properties of adaptive systems without complicating the control device is an important direction in the theory of automatic control.

II. The main synthesis problems of adaptive system

In the general case, the complexity of structures is explained by a large number of parameter tuning loops. The high order of adaptive systems with a reference model needs to use a state identifier. This makes it difficult to analyze the stability of closed systems. To obtain calculated ratios for the adapter parameters, which make the process of regulating adaptive systems quite laborious [4-6].

Therefore, one of the important tasks is associated with a decrease in the order of adaptive systems. It must significantly larger than the order of control objects. Research in this area is aimed at improving reliability, reducing the time and complexity of putting adaptive controllers into operation. Thus, the most developed methods for calculating adaptive control systems for dynamic objects with unknown constant or slowly changing (compared to the main processes) perturbations of multiplicative-parametric and additive types [1,7,8].

The problem that requires further research is the creation of adaptive systems with low sensitivity to variable disturbances of many types. The development of methods that make it possible to simplify the structure of control devices by reducing the number of tuning loops in adapters and in the case of multi-mode objects and controllers.

III. The methods of connecting adaptive systems to the control objects.

Adaptive systems can be connected to the control system using several different methods.

Adaptive system based on the indicators of the analyzer. It works based on a predictive model to recover parameter values under data incomplete conditions. When setting up the analyzer, the indicator values are taken and a signal is sent to the adjustment system [4,9,10].

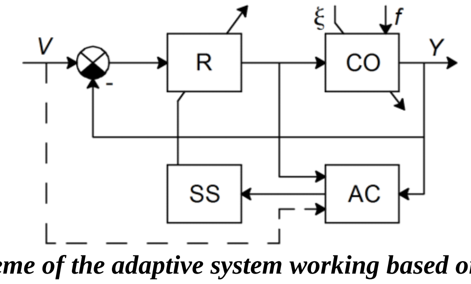

Figure 1. ***Structural scheme of the adaptive system working based on the analyzer indicators:***
R – Regulator. CO – Control object. SS – Self-regulating structure. AC – Analyzer characteristic.

The installed analyzer controls on the basis of two algorithms. The first one is based on the function that minimizes deviations in the parameters of the control object. The next one is based on the minimization of the deviation function in the change of parameters representing the quality of the process.

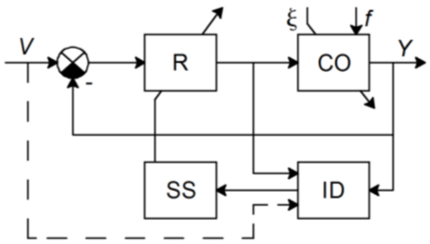

Figure 2. ***Structural diagram of an adaptive system based on the identification of deviations.***

Adaptive system based on parallel connected standard module. An optimal mode benchmark module is developed for the system. It works based on comparing the values in the working mode to the reference module [4,10].

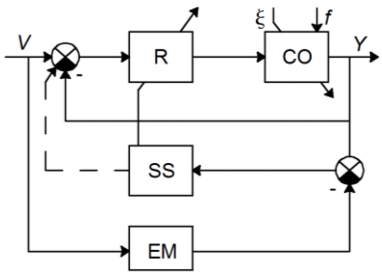

Figure 3. ***Structural diagram of an adaptive system based on a parallel connected reference module.***

An adaptive system based on reference modules may be connected serially:

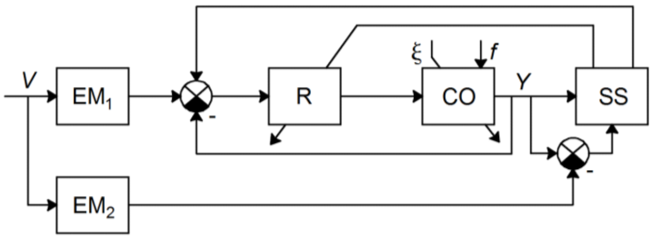

Figure 4. ***Structural diagram of an adaptive system based on a serially connected reference module.***

Therefore, the following tasks are relevant: the synthesis of adaptive control systems for multi-channel and multi-mode objects operating under conditions of variable disturbances of various types. The development and justification of ways to simplify the structures of adaptive control devices. Taking into account the specified quality indicators for transient and steady processes. The purpose of the research work is to create on the basis of existing concepts the theoretical foundations for the analysis and synthesis of adaptive control systems for multi-channel and multi-mode objects, aimed at improving the quality of work in conditions of uncontrolled variable disturbances of various types [9,11,12].

The goal is achieved by solving the following problems:

1. Select mathematical models of multi-channel and multi-mode objects as the basic basis for solving problems of synthesis of adaptive control systems;

2. To develop theoretical foundations for the analysis and synthesis of adaptive control systems for multi-channel and multi-mode objects that are insensitive to uncontrolled variable disturbances of various types;

Investigate the performance of adaptive control systems with uncontrolled variable disturbances; Apply developments in specific examples. The object of the dissertation research is the system of adaptive control of multi-channel and multi-mode objects under conditions of uncertainty. The subject of the dissertation research is the theoretical foundations, adaptation algorithms, structures of adaptive control systems for multi-channel and multi-mode objects operating in conditions of changing environmental characteristics and incomplete information about mathematical models.

Throughout the history of the existence of the theory of automatic control, the development of methods for the synthesis of control devices is associated with the expansion of the class of objects for which the independence of the characteristics of a closed system from the inaccuracy of the mathematical model and from the influence of the external environment in which the systems operate is achieved. Using the Generic Control Object Model

$$x'(t) = \overline{f}(x(t), u(t), \alpha, t),\ y(t) = g(x(t), u(t), \alpha, t),$$

here is $x \in R^n$ – the state vector; $y \in R^l$ – output vectors; $u \in R^m$ – control vector, $n \geq m$; $\alpha \in R^s$; - the vector of unknown parameters of the control object and the environmental effect – $s \leq m$. For solving the problem of adaptive controller synthesis, on the one hand, is aimed at illustrating the capabilities of the method, on the other hand, it leads to the fact that the solution is possible with significant restrictions on the form of the right side of the equation. The restrictions are related to the conditions for the solvability of the synthesis problem and the stability of the closed system.

$$x'(t) = f(x(t), \alpha(t)) + b(x(t), \alpha(t))u(t) + \xi(t),$$

$$x'(t) = A(t)x(t) + B(t)u(t) + \xi(t),\ y(t) = C(t)x(t),$$

here is $\xi(t)$ – an additive perturbation. It seems promising to describe non-linear non-stationary objects by models of switched systems. The non-linear characteristic is approximated by piecewise linear functions, and thus a set of linear systems is assigned to a non-linear general system [1,8].

$$x'(t) = A_1(t)x(t) + B(t)u(t) + \xi(t),$$

$A_1 \in R^{n \times n}$, $x \in R^n$, $B \in R^{n \times m}$, $u \in R^m$, $l : [0, \infty) \to P$ – switching signal; each of which operates in a limited time range, and the transition from one system to another is carried out according to some rule, which, in turn, can be either known or unknown. These models are also convenient because in many systems encountered in practice, there are switching between several subsystems depending on various environmental factors and operating modes. The terms "switchable" and "hybrid" systems are borrowed from the English literature. In Russian-language publications, "multi-mode systems", "logical-dynamic systems" and "systems with a variable structure" are conceptually close. These systems are united by the presence of dynamic and logical parts in them.

In adaptive control systems of the class under consideration, the implementation of the controller and adapter is possible if current information about the state coordinates or derivatives of the output variable is available. For this purpose, either state observers or derivative estimation filters (DEFs) are introduced into the systems. Thus, the order of adaptive systems depends both on the orders of the object, state observer, or DEF, and on the number of adjustable controller parameters. In the theory of adaptive control, the methods for calculating adaptive control systems for dynamic objects with unknown constant or slowly changing (compared to the main processes) perturbations of multiplicative-parametric or additive types are most developed. The indicated features distinguish several of the most important directions in the development of the theory of direct adaptive control systems. These include the development of a methodology for the synthesis of adaptive systems with the required quality of output processes under conditions of variable disturbances of various types. Another direction is connected with the development of a methodology for the synthesis of adaptive systems that are insensitive to variable disturbances, the total order of which is less than the order of the systems of the class under consideration.

IV. Synthesis of the adaptive system to regulate temperature

Consider is an algorithm for indirect measurement of gas turbine engine parameters based on its mathematical model. Moreover, here is a method for synthesizing an adaptive temperature controller.

Simulation results are presented. The gas temperature is one of the main gas-dynamic parameters of the controlled process in the gas turbine engine (GTE). It determines the efficiency of the power plant and the reliability of the turbine. Therefore, it is important to maintain the optimal value of the gas temperature depending on the operating modes of the gas turbine engine and the flight conditions. It is achieved along with improving the design of the turbine and improving the performance of the automatic control system (ACS).

Following that block diagram of the automatic gas temperature control system is shown.

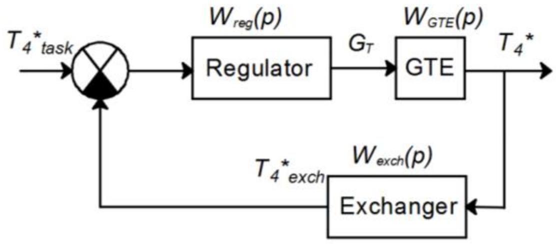

Figure 5. ***Block diagram of automatic control system for temperature in the gas turbine engine.***

Transfer function of closed-loop automatic control system:

$$W(p) = \frac{W_C(p)W_{CO}(p)}{1 + W_C(p)W_{CO}(p)W_{EXCHAN}(p)}.$$

The gas temperature must be measured with high accuracy.

$$W_{EXCHAN}(p) = 1.$$

Therefore, the problem of synthesizing this ACS can be solved as a synthesis of a direct circuit regulator. Must be adaptive gas temperature meter, with the gas temperature accurately measured [2,13-15].

Equating the transfer function of the closed-loop system to the transfer function of the desired system. Under condition that, obtain the transfer function of the controller $W(p) = W^*(p)$

$$W(p) = \frac{1}{W_{CO}(p)} \cdot \frac{W^*(p)}{1 - W^*(p)}.$$

To obtain the specified quality of the transient processes in the ACS. Firstly, it is necessary to accurately measure the gas temperature of the gas turbine engine. Direct measurement methods include thermocouple temperature sensors, which are characterized by large time constants. Indirect methods consist of measuring various parameters of gas turbine engines. The rotor speed and their derivatives, and using these data to determine coordinates that are otherwise difficult to measure using high-speed computers.

The thermocouple time constant T_t depends on the gas flow rate G_{gas} [14,16]:

$$T_t = T_{tC}(G_{Cgas} / G_{gas})^{0.5}.$$

A two-shaft two-circuit gas turbine engine can be described by the following system of equations in afterburner coordinates [14,15]:

$$\dot{n}_1 = K_{n_1G_T}(n_2)\Delta G_T + K_{n_1n_1}(n_2)\Delta n_1 + K_{n_1F_3}(n_2)\Delta F_E;$$

$$\dot{n}_2 = K_{n_2G_T}(n_2)\Delta G_T + K_{n_2n_1}(n_2)\Delta n_1 + K_{n_2F_3}(n_2)\Delta F_E;$$

$$\Delta X_i = K_{X_iG_T}(n_2)\Delta G_T + K_{X_in_1}(n_2)\Delta n_1 + K_{X_iF_3}(n_2)\Delta F_E.$$

here, n_1 – rotation speed of the low-pressure rotor; n_2 – rotation speed of the high-pressure rotor; and other parameters X_i correspond to T_4^*, G_{gas}.

ΔG_T and ΔF_E by solving the system of equations (4), (5) for quantities and substituting the obtained results into equation (6), we get the algorithm for calculating any parameters:

$$X_i = X_{i0}(n_2) + A_1(n_2)\Delta n_1 + A_2(n_2)n_2 + A_3(n_2)n_1$$

Therefore, the self-adjusting gas temperature gauge of the gas turbine engine with an open self-adjusting loop (figure. 6) indirectly measures the gas o according to the expression and the nonlinear converter can be built based on the measurement model. which implements the dependency. And when correcting the time constant T_k, the function n_i of the rotor speed increases, which increases the dynamic accuracy of the gas temperature measurement.

Modeling of the considered automatic gas turbine engine using the Simulink package of the MATLAB system showed a good quality of the transient processes in the gas temperature.

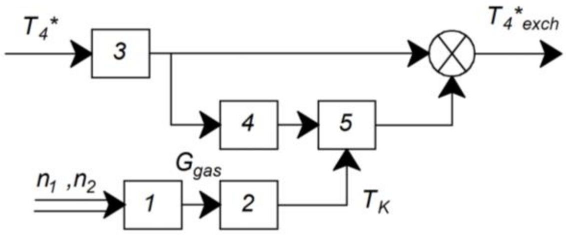

Figure 6. ***Block diagram of gas temperature meter that indirectly measures gas flow:***
1 – indirect gas flow measurement model; 2 – non-linear converter; 3 – temperature sensor; 4 – differentiator; 5 – multiplication block.

In such cases, can be seen that the issue of adaptive systems synthesis is complex. In such cases, an adaptive control system for multi-channel and multi-mode objects is created using neural network technologies.

Conclusion

Creating an adaptive system is to control multi-channel and multi-mode objects. Analysis of adaptive control systems aimed at increasing the quality of work in the conditions of uncontrollable variable deviations. It is the creation of theoretical foundations for the synthesis of adaptive control systems. Several different methods of connection schemes of the control object for the adaptive system are presented. Consider is an algorithm for indirect measurement of gas turbine engine parameters based on its mathematical model. Moreover, here is a method for synthesizing an adaptive temperature controller.

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