UDC 519.711(045)
DOI:10.18372/1990-5548.75.17556

[1]**M. Ya. Ostroverkhov,**
[2]**A. M. Silvestrov,**
[3]**V. I. Chibelis,**
[4]**V. Yu. Lobodzynskyi,**
[5]**L. Yu. Spinul**

APPLICATION OF THE CONSISTENCY PRINCIPLE OF IDENTIFICATION AND CONTROL SUBSYSTEMS IN ADAPTIVE SYSTEMS

[1,2,3,4,5]Department of Theoretical Electrical Engineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute," Kyiv, Ukraine
E-mails: [1]n.ostroverkhov@hotmail.com, [2]silvestrovanton@gmail.com, [3]toe209@gmail.com, [4]vadim_lv@bigmir.net, [5]spinul20@gmail.com

***Abstract*—*The methodology of creating functionally reliable adaptive optimal systems of automatic control of objects, which have naturally existing characteristics of nonstationarity, nonlinearity, nonautonomy has been considered. This methodology is based on the principle of consistency of identification and control systems in the task of designing an adaptive control system when filtering is focused on optimality of identification, identification – on optimal control and control on the main indicator of optimality of the system. When the apriori information is limited, the global extremum is achieved on the basis of a multi-step relaxation process of optimization of each of the filtering, identification and control subsystems based on the accumulation of a posteriori information. Functional reliability and optimality is achieved by building an object identification subsystem focused on the management quality indicator. The workability of the considered principle was verified when solving the problem of optimal adaptive control of the roll channel of the missile and the problem of adaptive speed-optimal control along the real object roll channel by an optimally stabilized system.*

Index Terms—Identification; adaptation; goal orientation; optimization; functional reliability; automatic control.

I. INTRODUCTION

A mathematically perfect theory of optimal control of dynamic objects often loses its perfection because of the closeness of the mathematical model (MM) (based on which the optimal controller is synthesized) to the real object (RO). Therefore, non-optimal and worse quasi-optimal algorithms which are less sensitive to nonisomorphism of MM and RO are often used in practice. Let's take robust [1] as an example. Based on the fundamental laws of the material world (the law of the general interconnection of everything with everything, the inseparability of matter and motion, etc.), it can be argued that there is no such thing as:

- completely autonomous (isolated from the environment of finite-dimensional objects);
- physical constants (as opposed to mathematical constants);
- ideal stationarity of RO modes and parameters;
- two or more absolutely identical ROs and, accordingly, their parameters, etc.

Even in the simplest RO a conductor with electric current I, resistance R and voltage U is the mathematical model of communication obtained according to Ohm's law $U = I \cdot R, \quad R = \text{const}$ may be only approximate due to the fact that according to the Joule–Lenz law, heat Q is released in the conductor (RO) proportional to the square of the current I, and the temperature of the conductor dynamically depends on Q, which in its turn depends on the resistance R. So, the nonlinear nonstationary (generic) model [2] of the form:

$$U = R\left(\theta^{\circ}\left(Q\left(I^2,t\right)\right)\right)\cdot I$$

is more accurate.

Therefore, any MM can only approximately reproduce the behavior of the RO in a limited space-time domain. The more accurate the MM, the more efficiently it can be used to construct the management of the RO. Among a wide range of MM and identification methods we should accept those best solving the main (prior to identification) task of optimal management of the RO.

II. STATEMENT OF PROBLEM AND ALGORITHM OF THEIR SOLUTION

Taking into account the properties of real-world objects, the automatic control system (ACS) of the RO will be considered as a subsystem of a multi-level hierarchical system (MLHS). At the upper (relative to ACS) level of MLHS in the space of significant variables, the main indicator of MLHS quality is optimized

$$X^*(t)=\underset{\{X(t)\}}{\arg\operatorname{extr}}\,\Lambda\,. \tag{1}$$

The optimal $X^*(t)$, as an extremal for Λ, is ensured by the optimal according to its indicator $I(X,U,t)$ ACS RO

$$U^*(t)=\underset{\{U(t)\}}{\arg\operatorname{extr}}\,\mathrm{I}\,, \tag{2}$$

where the optimal controlling influence $U^*(t)$ is calculated according to MM RO. The structure Σ and vector β of the parameters of MM of RO are determined by the identification subsystem according to the indicator J of the proximity of variables MM and RO

$$\left(\Sigma^*,\beta^*\right)=\underset{\{\Sigma,\beta\}}{\arg\operatorname{extr}}\,J\,. \tag{3}$$

At the same time $\left(\Sigma^*,\beta^*\right)$ depend on J_{F} the filter quality indicator $\left(\Sigma_{\mathrm{F}},\beta_{\mathrm{F}}\right)$ of the random errors and obstacles in measurements $X_{\mathrm{F}}(t)$, variables $X(t),U(t)$.

In a correctly constructed IS, the indicators $\Lambda,I,J,J_{\mathrm{F}}$ are mutually agreed upon:

• filtering is focused on optimal identification of MM RO;

• identification – for the optimal management of RO by MM;

• RO management by MM – on the main indicator of IS optimality:

$$\Lambda^*=\underset{X}{\operatorname{extr}}\Lambda\,\Big|\,I^*=\underset{U}{\operatorname{extr}}I\,\Big|\,J^*=\underset{(\Sigma,\beta)}{\operatorname{extr}}J\,\Big|\,J^*_{\Phi}=\underset{(\Sigma_{\Phi},\beta_{\Phi})}{\operatorname{extr}}J_{\Phi}\,. \tag{4}$$

At each level of IS (4), the task of optimizing one's own indicator can be strictly formalized. But for the real achievement of the absolute extremum Λ^*, taking into account the costs of its search, it is necessary to ensure the decomposition of optimizations by IS levels with the mandatory condition of mutual agreement of the criteria (in the absence of contradictions between them).

Indicators are consistent if their extrema in the space of variable subsystems of the lower level coincide, the first variations in the extremum zone are almost zero, and the second are similar:

$$\delta^2\Lambda\left(U^*+\delta U\right)\sim\delta^2 I\left(U^*+\delta U\right), \tag{5}$$

$$\delta^2 I\left(\beta^*+\delta\beta\right)\sim\delta^2 J\left(\beta^*+\delta\beta\right), \tag{6}$$

$$\delta^2 J\left(\beta^*_{\Phi}+\delta\beta_{\Phi}\right)\sim\delta^2 J_{\Phi}\left(\beta^*_{\Phi}+\delta\beta_{\Phi}\right). \tag{7}$$

With a limited priori information, the global extremum $\Lambda\left(X,U,\Sigma,\beta,\Sigma_{\mathrm{F}},\beta_{\mathrm{F}}\right)$ is achieved on the basis of a multi-step relaxation process (4) of optimization (1), (2), (3) of each of the IC subsystems (4) based on the accumulation of a posteriori information.

III. THE ALGORITHM FOR IMPLEMENTATION OF THE CONSISTENCY CONDITION (5-7) INDICATORS

First iteration. Based on a priori information about RO, subsystems (1–3) and their indicators $\Lambda(X)$, $I(X,U)$, $J\left(X,X_{\mathrm{M}},\Sigma,\beta\right)$, $J_{\mathrm{F}}\left(X,X_{\mathrm{F}},\Sigma_{\mathrm{F}},\beta_{\mathrm{F}}\right)$ taking into account the principle of rational complication [3], according to which quality should precede the complexity of subsystems, at the first step of the multi-step optimization process, the simplest subsystems are selected that satisfy the a priori data.

For example, the simplest a priori MM RO of cause $x_i^*(t), i=\overline{1,n}$ – effect $y^*(t)$ relationship is linear stationary

$$y^*(t)=\sum_{i=1}^{n}\beta_i x_i^*(t)\,, \tag{8}$$

A filtering subsystem from a measurement mixture $x_i(t), y(t)$ of exact values $x_i^*(t), y^*(t)$ and random errors $N_{x_i(t)}, N_{y(t)}$, taking into account a priori information about smoothness (low frequency) $x_i^*(t), y^*(t)$ and higher frequency $N_{x_i(t)}, N_{y(t)}$, as well as taking into account linearity (8) and focus on the identification problem (3), instead of optimal (for example, Wiener) filters , uses the same linear filter for low-pass l variables W_{F}

$$W_{\mathrm{F}}\left\{y^*(t)\right\}=\sum_{i=1}^{n}\beta_i W_{\mathrm{F}}\left\{x_i^*(t)\right\}. \tag{9}$$

Therefore, in (8), (9) there will be the same coefficients β_i.

A priori information about the frequency band separation of useful component signals and errors makes it possible to select W_F in a such way that the errors $\hat{x}_i(t), \hat{y}(t)$ in the filtered variables $\hat{x}_i(t), \hat{y}(t)$ would be almost suppressed, and the variables $\hat{x}_i(t)$ retain the basis for correct determination by the simplest method – the method of least squares (LSM) of estimates of the vector of MM parameters (8)

$$\hat{\beta} = \left(\hat{X}^T \hat{X}\right)^{-1} \hat{X}\hat{Y}. \tag{10}$$

Next, according to MM (8) with an estimate, the simplest subsystem (2) of controlling of the RO variables is organized, which achieves a rough approximation of the extremum $\Lambda(X)$.

The second and subsequent iterations of the multi-step process consist (if a posteriori information is obtained) in specifying all elements of the hierarchical system (4) by harmonizing their indicators (5), (6), (7). The easiest way to do this is by computer modeling using optimal planning of the experiment [4] with the aim of constructing similar variations (5), (6), (7) as scattering ellipsoids in the zone of extrema of the corresponding functionals:

$$(\delta U)^{\mathrm{T}} \left.\frac{\partial^2 \Lambda}{\partial U \partial U^{\mathrm{T}}}\right|_{\Lambda^*} \cdot \delta U = (\delta U)^{\mathrm{T}} A_1 \delta U, \tag{11}$$

$$(\delta\beta)^{\mathrm{T}} \left.\frac{\partial^2 I}{\partial\beta \partial\beta^{\mathrm{T}}}\right|_{I^*} \cdot \delta\beta = (\delta\beta)^{\mathrm{T}} A_2 \delta\beta, \tag{12}$$

$$(\delta\beta_{\mathrm{F}})^{\mathrm{T}} \left.\frac{\partial^2 J}{\partial\beta_{\mathrm{F}} \partial\beta_{\mathrm{F}}^{\mathrm{T}}}\right|_{J^*} \cdot \delta\beta_{\mathrm{F}} = (\delta\beta_{\mathrm{F}})^{\mathrm{T}} A_3 \delta\beta_{\mathrm{F}}, \tag{13}$$

where $A_3 = K_1 A_2,\ A_2 = K_2 A_1$.

The matrices A_1, A_2, A_3 are formed by selecting the structures and parameters of the corresponding subsystems (1), (2), (3).

IV. A Bayesian Approach to the Reconciliation of Indicators of the Quality of Management I and the Identification

The most general indicator of the quality of management in a statistical formulation will be the Bayesian indicator of average costs, as a function of the estimation of the vector $\hat{\beta}$ of parameters of MM RO

$$R(\hat{\beta}) = \int_{\beta^*} \int_X \delta I^*(\hat{\beta}, \beta^*) \cdot P(X/\beta^*) \cdot P(\beta^*) dX d\beta^*. \tag{14}$$

Here $P(X/\beta^*), P(\beta^*)$ are corresponded to the density of the distribution. From the Bayes identity [5]

$$P(X/\beta^*) \cdot P(\beta^*) = P(\beta^*/X) \cdot P(X)$$

it follows that

$$R(\hat{\beta}) = \int_X P(X) dX \int_{\beta^*} \delta I^*(\hat{\beta}, \beta^*) \cdot P(\beta^*/X) \cdot P(\beta^*) d\beta^*, \tag{15}$$

where $P(X) = \int_{\beta^*} P(X, \beta^*) d\beta^*$.

So, we will get the optimal $\hat{\beta}$ estimate of MM RO under the condition

$$\frac{\partial}{\partial\hat{\beta}} \int_{\beta^*} \delta I^*(\hat{\beta}, \beta^*) \cdot P(\beta^*/X) d\beta^* \equiv 0, \tag{16}$$

where

$$P(\beta^*/X) = P(X/\beta^*) \cdot P(\beta^*) / P(X). \tag{17}$$

From where, since $\delta\hat{\beta} = \hat{\beta} - \beta^*$ and taking into consideration that

$$\int_{\beta^*} \frac{\partial^2 I^*}{\partial\hat{\beta} \partial\beta^T} \delta\beta \cdot P(\beta^*/X) d\beta^* = 0, \tag{18}$$

we will obtain, according to the indicator (15) of the average risk, the optimal estimate of the vector $\hat{\beta}$ targeted to the main indicator $I(X, U)$ of the management of quality of coordination

$$\hat{\beta} = \left[\int_{\beta^*} \frac{\partial^2 I^*}{\partial\hat{\beta} \partial\hat{\beta}^{\mathrm{T}}} \cdot P(\beta^*/X) d\beta^*\right]^{-1} \cdot \left[\int_{\beta^*} \frac{\partial^2 I^*}{\partial\hat{\beta} \partial\beta^{\mathrm{T}}} \beta^* \cdot P(\beta^*/X) d\beta^*\right]. \tag{19}$$

So, if in (14) there is a:

$$\delta I^* \approx \partial\hat{\beta}^{\mathrm{T}} \int_{\beta^*} \frac{\partial^2 I^*}{\partial\hat{\beta} \partial\hat{\beta}^{\mathrm{T}}} \delta\hat{\beta}. \tag{20}$$

Then, condition (20) is used as a functional to optimize the Opt method and its parameters α in the subsystem of identification

$$\alpha^* = \arg\min R(\hat{\beta}, \alpha). \tag{21}$$

Because of its absence, estimate (19) is reduced to an estimate by the maximum likelihood method, and for a normal distribution almost to an LSM estimate [6].

V. THE TASK OF THE OPTIMAL ADAPTIVE CONTROL OF THE MISSILE ROLL CHANNEL OF THE ROCKET

A. Statistically optimal stabilization of roll channel dynamics

The Criteria of the optimality

$$I = \frac{1}{2}\int_0^\infty \left(Cx^2(t) + Du^2(t)\right)dt \quad (22)$$

closed ACS with *P*-regulator (*K*-parameter of the PID controller) and RO with MM in the form of an integrator K_0/p with a time-varying coefficient K_0 (Fig. 1).

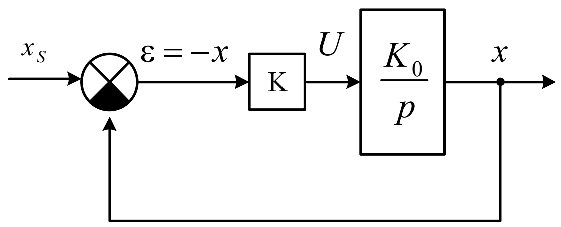

Fig.1. Parameter stabilization system

System equations (Fig. 1) provided that $x_S(t) = 0$

$$\frac{dx}{dt} = -\gamma x(t) = y(t), \quad (23)$$

where $\gamma = K \cdot K_0$.

So,

$$x(t) = x(0)e^{-\gamma t}, \quad (24)$$

where $x(0)$ has a normal law of distribution $M\{x(0)\} = 0, M\{x^2(0)\} = P_0 = \sigma_N$.

By substituting (24) into (22) and taking the derivative with respect to *K*, we obtain its optimal value

$$K^*(t) = \sqrt{\frac{C}{D}K_0(t)}. \quad (25)$$

Since $K_0(t)$ changes, so the subsystem of the identification must determine the coefficient according to $\gamma = K \cdot K_0$ and in accordance to (25), set the optimal PID controller in the ACS for stabilizing the system parameters (Fig. 1).

According to the integrated LSM [7], the indicator is minimized in subsystem (3). Denote $t_1 = t - \alpha, t_2 = t + \alpha$

$$J(\gamma,\alpha) = \int_0^T \left(y(t) - \gamma x(t)\right)\cdot\left[y(t_2) + y(t_1) - \gamma\left(x(t_2) + x(t_1)\right)\right]dt, \quad (26)$$

where α is a parameter of the integrated LSM.

The peculiarity of the rocket is that the speed $y(t)$ is measured quite accurately ($y(t) = \gamma x^*(t)$), and the roll angle $x(t)$ is measured with a random error $N(t)$:

$$x(t) = x^*(t) + N(t).$$

Estimate $\hat{\gamma}$ that minimizes (26):

$$\hat{\gamma} = \int_0^T \left[x(t)\left(y(t_2) + y(t_1)\right) + y(t)\left(x(t_2) + x(t_1)\right)\right]dt \Big/ 2\int_0^T x(t)\left(x(t_2) + x(t_1)\right)dt. \quad (27)$$

Moving on to estimates of the correlation functions that are symmetric with respect to the shift α, we obtain

$$\hat{\gamma} = \gamma\left[1 - \frac{\hat{R}_{NX^*}(\alpha) + \hat{R}_{NN}(\alpha)}{\hat{R}_{X^*X^*}(\alpha) + 2\hat{R}_{NX^*}(\alpha) + \hat{R}_{NN}(\alpha)}\right]. \quad (28)$$

The shift $\delta\hat{\gamma}$ of the grade $\hat{\gamma}$

$$\delta\hat{\gamma} = \frac{R_{NN}(\alpha)}{R_{X^*X^*}(\alpha) + R_{NN}(\alpha)}, \quad (29)$$

dispersion

$$\sigma^2_{\hat{\gamma}} = M\left\{\frac{\partial\hat{\gamma}}{\partial\Delta\hat{R}_{NN}}\cdot\Delta\hat{R}_{NN}\right\} = \gamma^2\left(\frac{R_{X^*X^*}(\alpha)\cdot\sigma_{R_{NN}}(\alpha)}{T\left[R_{X^*X^*}(\alpha) + R_{NN}(\alpha)\right]^2}\right), \quad (30)$$

where, taking into account (25) and (28)

$$R_{X^*X^*}(\alpha) = \frac{P_0}{1 - e^{2\gamma}}\cdot e^{3\alpha\gamma}, \quad (31)$$

$$R_{NN}(\alpha) = T\sigma_N^2\cdot e^{-r|\alpha|}. \quad (32)$$

Then

$$\delta\hat{\gamma} = \frac{1}{1 + \dfrac{P_0 \cdot e^{3\alpha\gamma + r|\alpha|}}{\left(1 - e^{2\gamma}\right) T \sigma_N^2}}, \tag{33}$$

$$\sigma_{\hat{\gamma}} \cong \frac{\sigma_{R_{NN}}(\alpha)}{T} = \frac{|\gamma|}{1 + Te^{3\alpha\gamma + r|\alpha|} \cdot \sigma_N^2 \dfrac{1 - e^{2\gamma}}{P_0}}. \tag{34}$$

Therefore, the average losses (15) will be

$$M\left\{I^*(\hat{\gamma})\right\} = \int_{-\infty}^{\infty} \frac{C + DK^2 P_0}{4\gamma} \cdot P(\hat{\gamma}) d\hat{\gamma}, \tag{35}$$

$$P(\gamma) = \frac{1}{\sigma_{\hat{\gamma}}\sqrt{2\pi}} e^{-\frac{\left[\hat{\gamma} - \left(\gamma^* + \delta\gamma\right)\right]^2}{2\sigma_{\hat{\gamma}}^2}}. \tag{36}$$

By substituting the corresponding numerical values $C = D = P_0 = \sigma_N = 1,$, $r = 0.4$ into (36), we obtain dependences $M\left\{I^*(\hat{\gamma})\right\}$ on the length T of the sample and on the parameters α (Fig. 2, a); optimal α^* from T and ratio r/γ (Fig. 2, b); extreme $\alpha^*(t)$ (Fig. 2, c).

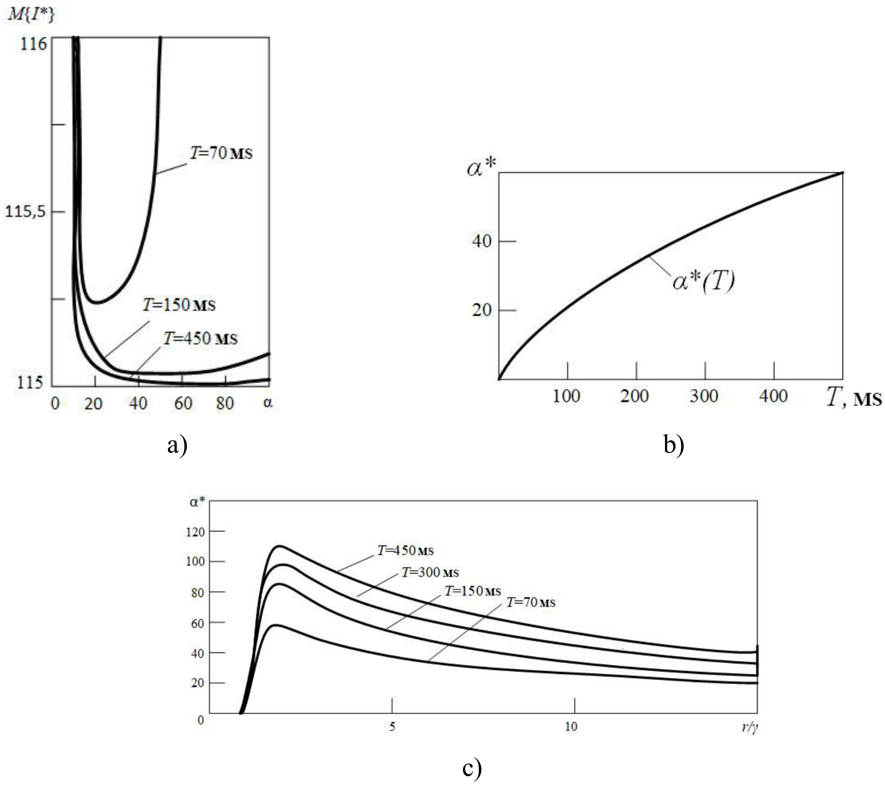

Fig. 2. Dependencies of the average losses on the shift α (a), the optimal value of the parameter α^* on the sample length (b), the family of extremes of the parameter α^* as a function of the sample length and the ratio of the indicators of the exponents of the correlation functions of the signal and disturbance

B. Adaptive speed-optimal control by an optimally stabilized system (Fig. 1)

The optimal speed control along the RO roll channel consists in the transfer of RO from $x(0) = 0$ to $x(t_{\min})$, where RO is understood as a first-order system (see Fig. 1) with an optimally stabilized parameter $\gamma = K \cdot K_0$.

$$\tau \frac{dx}{dt} + x(t) = K_1 U^*(t), \tag{37}$$

where $\tau = \left(K^* \cdot K_0\right)^{-1}, K_1 = \dfrac{x(t_{\min})}{U^*(t_{\min})}$.

The optimal control of the $U^*(t)$ and graphs $x^*(t)$, $\dfrac{dx^*}{dt}$ are shown in Fig. 3.

Considering the high sensitivity of the open-ended optimal control to the inaccuracy of the parameters τ, K_1, they should be specified by the identification subsystem according to the following algorithm:

1) For independent of K_1 evaluation τ, we divide the solution of equation (37) by its derivative:

$$Z(t)=\frac{x(t)}{\frac{dx}{dt}}=\frac{U_m K_1\left(1-e^{-\frac{t}{\tau}}\right)}{U_m K_1 \frac{1}{\tau} e^{-\frac{t}{\tau}}}=\tau\left[e^{\frac{t}{\tau}}-1\right]\approx t+\frac{t^2}{2\tau}. \quad (38)$$

Therefore, the estimation $\hat{\tau}(t)$ equal to

$$\hat{\tau}(t)=\frac{t^2}{2\left(Z(t)-t\right)}, \quad (39)$$

where $t>0$, $t_1<t_{\min}$, for example, $t_1=0.8t_{\min}$.

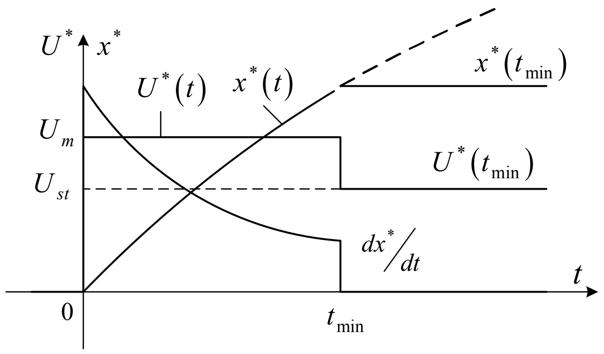

Fig. 3. Optimal control

2) As a τ, we take the exponentially weighted LSM estimate [6]. We will calculate the parameter $\hat{K}_1(t)$ by similarly averaging

$$\hat{K}_1(t)=\frac{x(t_{\min})}{U_m\left(1-e^{-\frac{t}{\tau}}\right)}. \quad (40)$$

Such a combination on the same interval of adaptive statistically optimal stabilization of RO dynamics at the expense of the PID controller and dual speed-optimal control guarantees the functional reliability of the ACS rocket at the roll angle x, as a non-stationary stochastic RO.

3) To ensure optimal rocket control in spatial motion [7], which is described by a three-dimensional system of equations in the Cauchy form

$$\frac{dX}{dt}=AX(t)+BU(t), \quad (41)$$

sequential active identification of the system (41) is performed by targeting test control influences $U(t)$ [9] to ensure consistency of control quality indicators I and identification J in the space of control influences $U(t)$ [9].

VI. CONCLUSION

Consistency of quality indicators of subsystems of different levels of the hierarchical system (3) allows designing functionally reliable adaptive optimal control systems of RO in conditions of non-stationarity and stochasticity of their characteristics.

REFERENCES

[1] F. Golnaraghi and B. Kuo, *Automatic Control Systems:* Tenth Edition. McGraw-Hill Education, 2017, 800 p.

[2] M. Ya. Ostroverkhov, A. M. Silvestrov, and O. M. Skrynnyk, *Systems and methods of identification of electrotechnical objects*: *monograph.* Kyiv: NAU, 2016, 323 p. [in Ukranian]

[3] V. V. Samsonov, A. M. Silvestrov, and L. Yu. Spinul, *Multiple adaptive system of identification*: *monograph*. Kyiv: National University of Food Technologies, 2018, 229 p.

[4] A. Özdemir [a]and M. Turkoz, "Development of a D-optimal design-based 0–1 mixed-integer nonlinear robust parameter design optimization model for finding optimum," *Computers & Industrial Engineering*, vol. 149, 2020. https://doi.org/10.1016/j.cie.2020.106742

[5] A. Zelner, "Bayesian analysis in econometrics," *Journal of Econometrics*, vol. 37, Issue 1, 1988, pp. 27–50. https://doi.org/10.1016/0304-4076(88)90072-3

[6] V. Dubovoi, R. Kvietnyi, O. Mykhalov, and A. Usov, *Modeling and optimization of systems*: *a textbook.* Vinnitsa: Edelweiss, 2017, 804 p. [in Ukranian]

[7] M. Ya. Ostroverkhov, A. M. Silvestrov, and G. I. Kryvoboka, *Identification of electrotechnical control objects: monograph.* Kyiv: National Technical University of Ukraine "Kyiv Politechnic Institute", 2020, 353 p. [in Ukranian]

[8] N. V. Kadam, "Practical Design of Flight Control Systems: Some Problems and their Solutions," *Defence Science Journal*, vol. 55, no. 3, 2005. https://doi.org/10.14429/dsj.55.1983

[9] Levchuk, G. Manko, V. Tryshkin, and V. Korsun, *Theory and practice of control objects identification*: *monograph.* Dnipro, Ukrainian State University of Chemical Technology, 2019, 203 p. [in Ukranian]

Received February 07, 2023

Ostroverkhov Mykola. Doctor of Engineering Science. Professor.
Department of Theoretical Electrical Engineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnical Institute," Kyiv, Ukraine.
Education: Kyiv Polytechnical Institute, Kyiv, Ukraine, (1985).
Research area: control methods of interconnected electromechanical systems in conditions of uncertainty of the mathematical model of objects.
Publication: 300.
E-mail: n.ostroverkhov@hotmail.com

Silvestrov Anton. Doctor of Engineering Science. Professor.
Department of Theoretical Electrical Engineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnical Institute," Kyiv, Ukraine.
Education: Kyiv Polytechnical Institute, Kyiv, Ukraine, (1969).
Research area: theory of identification of dynamic object.
Publication: 300.
E-mail: silvestrovanton@gmail.com

Chibelis Valeriy. Candidate of Science (Engineering). Associate Professor.
Department of Theoretical Electrical Engineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnical Institute," Kyiv, Ukraine.
Education: Kyiv Polytechnical Institute, Kyiv, Ukraine, (1978).
Research area: optimization of the new technology of industrial production of cables with solid polymer insulation for the improvement of ultra-high voltage power networks.
Publication: 250.
E-mail: toe209@gmail.com

Lobodzynskyi Vadym. Candidate of Science (Engineering). Associate Professor.
Department of Theoretical Electrical Engineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnical Institute," Kyiv, Ukraine.
Education: Kyiv Polytechnical Institute, Kyiv, Ukraine, (1978).
Research area: optimization of the new technology of industrial production of cables with solid polymer insulation for the improvement of ultra-high voltage power networks.
Publication: 80.
E-mail: vlobodzinskiy@gmail.com

Spinul Liudmyla. Candidate of Science (Engineering). Associate Professor.
Department of Theoretical Electrical Engineering, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnical Institute," Kyiv, Ukraine.
Education: Kyiv Polytechnical Institute, Kyiv, Ukraine, (1989).
Research area: theory of identification of dynamic object.
Publication: 130.
E-mail: spinul20@gmail.com

М. Я. Островерхов, А. М. Сільвестров, В. І. Чибеліс, В. Ю. Лободзинський, Л. Ю. Спінул. Застосування принципу узгодженості підсистем ідентифікації і керування в адаптивних системах

Розглянуто методологію створення функціонально надійних адаптивних оптимальних систем автоматичного керування об'єктами, які мають природно існуючі характеристики нестаціонарності, нелінійності, неавтономності. Ця методологія базується на принципі узгодженості систем ідентифікації і управління в задачі проектування адаптивної системи керування, коли фільтрація зорієнтована на оптимальність ідентифікації, ідентифікація – на оптимальне керування і керування на головний показник оптимальності системи. Функціональна надійність і оптимальність досягається шляхом побудови цілеспрямованої на показник якості керування підсистеми ідентифікації об'єкта. Працездатність розглянутого принципу перевірено при розв'язанні задачі оптимального адаптивного керування каналом крену ракети і в задачі адаптивного оптимального за швидкодією керування оптимально стабілізованою системою.
Ключові слова: ідентифікація; адаптація; ціле орієнтація; оптимізація; функціональна надійність; автоматичне керування.

Островерхов Микола Якович. Доктор технічних наук. Професор.
Кафедра теоретичної електротехніки, Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна.
Освіта: Київський політехнічний інститут, Київ, Україна, (1985).

Напрям наукової діяльності: Методи керування взаємозв'язаними електромеханічними системами в умовах невизначеності математичної моделі об'єкту.
Кількість публікацій: 300.
E-mail: n.ostroverkhov@hotmail.com

Сільвестров Антон Миколайович. Доктор технічних наук. Професор.
Кафедра теоретичної електротехніки, Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна.
Освіта: Київський політехнічний інститут, Київ, Україна, (1969).
Напрям наукової діяльності: теорія ідентифікації динамічних об'єктів.
Кількість публікацій: 300.
E-mail: silvestrovanton@gmail.com

Чибеліс Валерій Іванович. Кандидат технічних наук. Доцент.
Кафедра теоретичної електротехніки, Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна.
Освіта: Київський політехнічний інститут, Київ, Україна, (1978).
Напрям наукової діяльності: оптимізація нової технології промислового виготовлення кабелів з твердою полімерною ізоляцією для удосконалення енергетичних мереж надвисоких напруг.
Кількість публікацій: 250.
E-mail: toe209@gmail.com

Лободзинський Вадим Юрійович. Кандидат технічних наук. Доцент.
Кафедра теоретичної електротехніки, Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна.
Освіта: Київський політехнічний інститут, Київ, Україна, (1978).
Напрям наукової діяльності: оптимізація нової технології промислового виготовлення кабелів з твердою полімерною ізоляцією для удосконалення енергетичних мереж надвисоких напруг.
Кількість публікацій: 80.
E-mail: vlobodzinskiy@gmail.com

Спінул Людмила Юріївна. Кандидат технічних наук. Доцент.
Кафедра теоретичної електротехніки, Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського», Київ, Україна.
Освіта: Київський політехнічний інститут, Київ, Україна, (1989).
Напрям наукової діяльності: теорія ідентифікації динамічних об'єктів.
Кількість публікацій: 130.
E-mail: spinul20@gmail.com