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ENSURING OF FUNCTIONAL STABILITY OF DIFFICULT DYNAMIC SYSTEMS AS ONE OF URGENT SCIENTIFIC TASKS OF MODERN THEORY OF AUTOMATIC CONTROL

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Abstract. *In the article the functional stability of complex systems are considered. Mathematical formalization of property of functional stability is presented. Promising directions of research in this area are also described.*

Keywords: survivability, criteria, control, technical system, functional stability

ZAPEWNIENIE FUNKCJONALNEJ STABILNOŚCI ZŁOŻONYCH UKŁADÓW DYNAMICZNYCH JAKO JEDEN Z AKTUALNYCH PROBLEMÓW NAUKOWYCH NOWOCZESNEJ TEORII STEROWANIA

Streszczenie. *W artykule przedstawiono rozważania dotyczące funkcjonalnie stabilnych systemów złożonych. Przedstawiono matematyczną formalizację funkcjonalnej stabilności obiektu.. Opisano również najbardziej obiecujące obszary badań w tej dziedzinie.*

Słowa kluczowe: przeżywalność, kryteria, sterowanie, system techniczny, stabilność funkcjonalna

Introduction

Today it is known plenty of publications in the area functionally of steady control systems [1-20]. In connection with that necessity of analysis of received results and their judgement in the common context of development of cybernetics arose. To modern control systems ability requirement is presented to execute its functions after the occurrence of malfunctions, possibly with the worst specifications. Private decisions about giving problem are known: construction of redundant information-measuring systems, tolerant computing systems, adaptive control systems.

1. Task statement

At present it is known that properties of dynamic control systems are characterised by following concepts:

- reliability is property of the object which consists in the ability to preserve in time in installed limits of the value of signs and parameters characterising those properties of the object which defines his ability to execute required functions in given modes and conditions,
- survivability is property of the object consisting in keeping serviceability at the impact of affecting means and off-design conditions of operation,
- safety is property of the object which consists in ability to prevent such changes of its conditions and properties which would be dangerous for people and environments.

Today it's important properly to diagnose events and to understand the logic of their development in time. It allows to accept beforehand the appropriate measures and to develop algorithm of anti-emergency and restoring control. Under anti-emergency control, we will understand control, the purpose of which consists in prevention of development of emergency events arising in the control system. Restoring control is a control, the purpose of which consists in returning to the condition of serviceability, serviceability or correctness of control system operation.

Functional stability is considered as property of dynamic system consisting in ability to execute at least installed minimum volume of its functions at failures in information, computational and energy parts of the system, as well as at impacts of external indignation.

The realisation of functional stability can be reached by introduction to the control system of various forms of redundancy (of structural, functional, information, etc.) and operator's readiness to control of controlled device at the occurrence of failures and malfunctions. It's important in due time to find out began malfunctioning origins and to prevent the inevitability of accident or destruction of the controlled device.

The reasons of occurrence of non regular (emergency) situations can be different, for example:

1. Infringements in the channel of measurement. These infringements can be caused by various types of failures of gauges of information-measuring system or interferences in communication lines.
2. Infringements arising during realisation of algorithms of control themselves. So, at work of computer failures in the processor or the cells of storage device are possible.
3. Infringements during control. These infringements are connected with damages of control elements or actuating devices.

If not to provide beforehand opportunity of occurrence, non-regular (emergency) situations, then the controlled device cannot reach tasks in view, purposes. Therefore urgent task for difficult control systems is the task of synthesis of control at occurrence of possible listed infringements.

2. Features of supplying functional stability of difficult dynamic systems

For the first time concept "functional stability" and basic bases of the supplying of functional stability were presented in publications devoted to control of difficult independent objects [1-4]. Under the functional stability of the system her property is understood to preserve ability to carry out its functions, tasks, purposes. These functions are defined by standard requirements. At the same time to system external indignation influence. At system operation failures, malfunctions, failures can arise.

It was installed that the basic condition of supplying of the given property is opportunity of resources redistribution inside the control system.

In traditional systems of automatic control of dynamic objects (Figure 1) the appropriate control channels are provided (as a part of the gauges, calculators and actuators).

The technological base of the supplying of functional stability is integration of the resources of the system and their redistribution [5]. At the same time, information-measuring subsystem will include all sources of the information, computing system - all calculators, and energy subsystem - all actuators and energy sources (Figure 2).

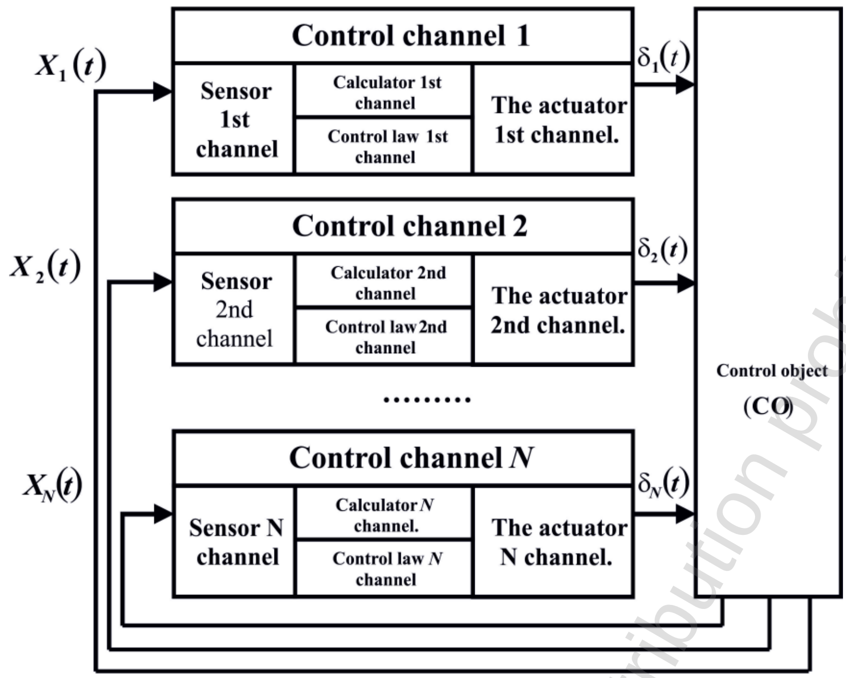

Fig. 1. The structure of traditional systems of automatic control of dynamic objects

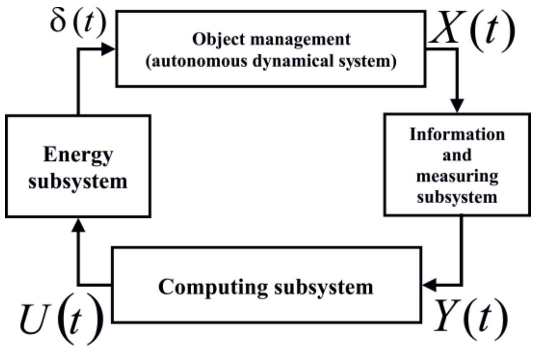

Fig. 2. The structure of on-board information-controlling complex

3. Mathematical formalization of property of functional stability

We will consider control system (Figure 2) in which the controlled device is described by the equation in the form of Lanzhevena.

$$\dot{X}(t) = A(t) \cdot X(t) + \delta(t) + \xi(t) + \gamma(t) \,. \tag{1}$$

Information-measuring subsystem - the equation of supervision:

$$Y(t) = H(t) \cdot X(t) + \eta(t) + \gamma(t) \,, \tag{2}$$

where there is a *X(t)* – *n*-dimensional vector of condition of the system, *U(t)* – *m*-dimensional vector of control, *Y(t)* – *l*-dimensional vector of measurements, *A(t)* – dynamic system matrix of dimension $n \times n$, *H(t)* – matrix system measurements of dimension $l \times m$, *γ(t)* – *n*-dimensional random vector, value of which quantitatively characterizes action of failure to system, $\gamma_0(t)$ – the value of the vector *γ(t)*, functioning appropriate to normal mode, $\gamma_i(t)$ – the appropriate of *i*- failure, *ξ(t)* – random the vector of Gauss indignation of condition of the system with zero vector of average and correlation matrix

$$\xi(t) \in \Omega_{\xi} : M[\xi(t)] = 0; \quad M\left[\xi(t) \cdot \xi^T(t')\right] = Q(t)\delta(t - t') \tag{3}$$

η(t) – random *l*-dimensional vector Gaussian interferences of measurements with zero vector of average and correlation matrix

$$\eta(t) \in \Omega_{\eta} : M[\eta(t)] = 0; \quad M\left[\eta(t) \cdot \eta^T(t')\right] = R(t)\delta(t - t') \tag{4}$$

Computational and energy the subsystems are presented by the equations:

$$U(t) = u(Y, t) \tag{5}$$

$$\delta(t) = B(t)U(t) + \gamma(t) \tag{6}$$

B(t) - transition matrix of control of $n \times m$ dimension.

The criterion of quality of control is represented as

$$I\left(X(t), U(t) / \gamma(t)\right) = = M\left(\int_{t_0}^{t_k} X^T(t) \cdot \beta \cdot X(t) dt + \int_{t_0}^{t_k} U^T(t) \cdot C^{-1} \cdot U(t) dt \right) \tag{7}$$

Management, providing at least the expectation of a quadratic quality criterion (7) for the selected model failures subject to the restrictions on the range of permissible state and control, will be functionally stable under the conditions of:

$$\left| I\left(X(t_0), U(t_0) / H_0(t_0)\right) - I\left(X(t_0), U(t_0) / H_i(t_0)\right) \right| < \varepsilon \,, \tag{8}$$

$$\lim_{t \to \infty} \left| I\left(X(t), U(t) / H_0(t)\right) - I\left(X(t), U(t) / H_i(t)\right) \right| < \delta(\varepsilon) \,, \tag{9}$$

The inequalities (8) and (9) represent the mathematical formalization of properties of the functional stability control system (1-6). If the initial time t_0 failure leads to a deterioration in the quality management system I (X, U) on the value of ε, the functional and sustainable management some time to restore the quality of the system (the amount of degradation of performance will not exceed the value δ(ε).

Thus, the resistance can be regarded as a functional mathematical functional stability. This approach is fundamentally different from the consideration of the properties of the dynamic stability of the system (the stability of the phase coordinates of the control object).

Ensuring functional stability of dynamical systems involves different approaches compared with the classical theory of automatic control [6–8]. In classical control theory to solve the problem of optimization "in the small". In this case, control is determined by the conditions of optimization of transients for the selected criteria.

The task of ensuring functional stability when abnormal, emergency (failures) in the system can be reduced to the problem of adaptive control "in the large". It is provided in the control system, redistribution of resources (energy, information, computing). This will achieve the control objectives.

In [9–12] shows the relationship of concepts: the "functional stability", "reliability", "vitality", "fault tolerance". It is shown that the traditional methods of improving the reliability, survivability and resiliency of technical systems aimed at reducing the number of possible failures and irregularities. Methods to ensure functional stability aimed at ensuring the implementation of the most important tasks of the control system in case of violation in the control system has already taken place. The method of synthesis of functional, sustainable management based on the principle of separation, which involves the sequential execution of two procedures: observation (assessment) and management.

Thus, the features of the method of synthesis of functional stability of dynamical systems are that they do not provide for the need to identify and detect the causes of failures or damage [13-16]. For the formation of a special retort (reducing) the control is important, not the cause but the consequence of manifestations of failure or damage to the control system.

4. Technology to ensure functional stability is consistently performing the following procedures

Procedure 1. Organization of the control of the entire control system and identify the factors (conditions) normal functioning.

Procedure 2. Identification procedure failure or the detection of a failed control system (subsystems, complex, node, element).

Procedure 3. Switching-off of identifying element of total control system.

Procedure 4. Redistribution of control system resources (information, computation, energy) so that system preserved ability to execute given functions.

The transition process in functional and stable system is regarded as the time interval from the start of detection of failure before you finish the reallocation of resources of a complex system.

By analogy with the dynamic stability criteria (e.g., criteria Vyshnegradsky, Hurwitz, Nyquist, Mikhailova, Lyapunov) proposed criteria for functional stability.

So, for a dynamical system for which possible failures in the form of an abrupt change in the structure, may be offered a graph of functional stability criterion.

We consider the graph $\Gamma=\{S,J\}$, where S - the set of vertices $S=\{x_i, y_j, u_k\}$, $i=[1,\dots, n]$, $j=[1,\dots, m]$, corresponding to the components of the vectors X,Y,U; J - the set of arcs corresponding to the presence of a functional link between the components of the $J=\{(X_i,Y_j),(Y_j, U_k),(U_k,X_i)\}$.

As considering failures correspond change of functional communication between the components of vectors X,Y,U, then the dynamic system can be functionally steady, if at failure way A=($X_i,\dots, U_k$) including all components of vectors X and U exists.

For distributed information and control systems described in the form of an undirected graph $G(V, E)$, $v_i \in V$, $e_{ij} \in E$, $i,j=1,\dots,n$, with the adjacent matrix:

$$A = ||a_{ij}||, i, j = 1..n, a_{ij} = \begin{cases} 1, & by \quad e_{ij} \in E; \\ 0, & by \quad e_{ij} \notin E. \end{cases} \qquad (10)$$

where plenty of the tops V corresponds plenty of units of switching of dimension, and plenty of ribs E - plenty of communication lines between switching units, was offered other criterion. The system will be functionally steady, if between any pair of units of switching at least one transmission of information route is found.

Feature of giving criterion is that opportunity emerges to evaluate quantitatively a functional stability of distributed information-controlling systems on the grounds of simple external signs.

5. Algorithm of detection and the fender of failures in functionally steady information-controlling complex

For detection and founder of failures in the system are formed the images-primary standards of the consequences of emergency situations which are caused by failures in the control system. Images-primary standards are preserved in the memory (Fig. 3) and are compared with the images of real (current) condition. By results of comparison of images conclusion of quality of system operation is accepted. For each case of failure control is formed to prevent negative consequences of this failure.

The use of functional and sustainable systems. Initially, the methods used to ensure functional stability to improve the technical capabilities of complex technical systems that operate in extreme conditions (such as aerospace systems). Further development of information technology has led to the emergence of new complex systems. Now it is possible to ensure the proper functioning of systems in terms of unlikely but have very serious consequences of abnormal, emergency situations. Examples of such systems are: system emulsifying, chemical and petrochemical complexes. Components of such systems are scattered in some areas include means of automated information processing and management. On the distribution of information and control systems adversely affect different factors: internal and external. Internal factors is a failure, failures, errors corporate subscribers. External factors - adverse environmental impact. Therefore, ensuring the functional stability of distributed information and control systems is also an urgent task.

Feature of offered algorithm consists in that, communicating synthesis task functionally of steady system is split into private tasks: synthesis of failures detection algorithms and synthesis of failures fender algorithms.

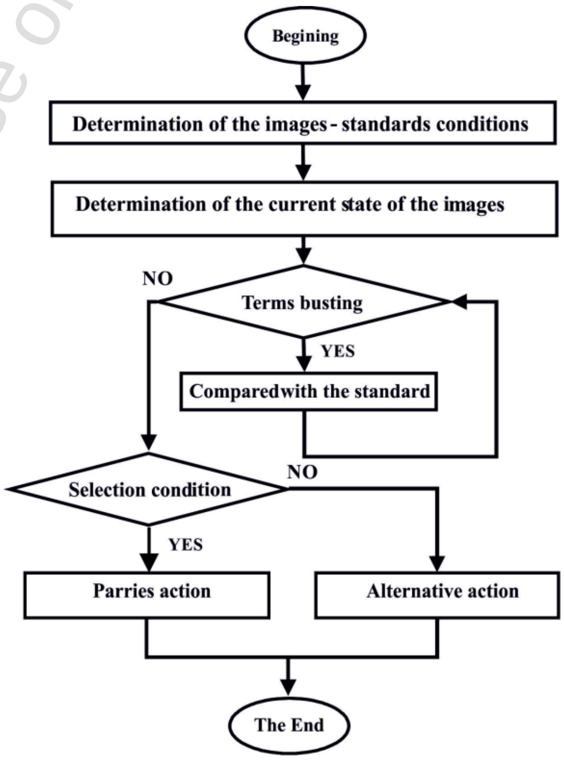

Fig. 3. Algorithm of detection and founder of the consequences of failures of functionally-steady information-controlling complex

In [10, 13] it is shown that the methods provide observability, controllability and identifiability of dynamic objects are not suitable for distributed information management systems. Therefore, research is needed to determine the criteria, indicators, signs of functional stability.

The problem of ensuring functional stability is important for monitoring technological hazards objects. Introduction of redundancy (duplicate elements) increases the system cost. It does not guarantee the quality improvement of the system. On the synthesis of the optimal structure of functional redundancy ecologically sustainable systems of monitoring papers [18–19].

A promising new area of research is to provide a functional stability of vehicles (both ground and air). The research problem – to ensure their normal functioning in case of possible equipment failures, communication channels. This will significantly improve the safety of vehicles.

As a promising area of research is to provide a functional stability ergatic (man-machine) systems. In these systems, the control element is a human operator. The task of ensuring the stability of functional ergonomics, systems can be reduced to the following procedures: formalization and description of a person in a closed loop control; distribution of functions between the human operator and hardware-software.

6. Conclusions

Functional theory of sustainable systems is the result of a systematic approach to solving the problem of improving the safety of complex control systems. In this case, functional stability is a property which is essentially distinct from the reliability, stability and resiliency.

Methods to ensure functional stability aimed at better utilization of technical resources complex technical systems. In this case, the hardware and software are not the passive role assigned to perform a rigid program and active reallocation of resources to achieve these goals.

The task of ensuring functional stability can be considered as one of the most pressing scientific challenges of modern control theory of complex systems.

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