Methodology of Complex Objects Structural Dynamics Proactive Management and Control Theory and Its Application

Boris Sokolov[1,2](✉), Vyacheslav Zelentsov[1], Nikolay Mustafin[1], and Vadim Burakov[1]

[1] St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences, Saint Petersburg, Russia
sokolov_boris@inbox.ru, v.a.zelentsov@gmail.com, nikolay.mustafin@gmail.com, v.v.burakov@gmail.com
[2] St. Petersburg State University of Aerospace Instrumentation, Saint Petersburg, Russia

Abstract. Methodological and methodical fundamentals of the complex objects (CO) proactive management and control theory based on the fundamental results obtained in the interdisciplinary field of system knowledge are proposed. The paper provides information on the developed innovative multiple-model complexes, combined methods, algorithms and techniques for solving various classes of problems of operational, structural and functional synthesis and management of the development of the regarded classes of CO. The tasks of controlling the structural dynamics of CO belong to the structural and functional synthesis class of problems and the formation of appropriate programs for managing and control of their development. The main difficulty and a special feature of the solution of the regarded problems is as follows. Determination of optimal control programs for the basic elements and subsystems of CO can be performed only after all functions and algorithms of information processing and control that should be implemented in these elements and subsystems are known. In its turn, the distribution of functions and algorithms by the elements and subsystems of CO depends on the structure and parameters of the control laws of these elements and subsystems. The difficulty of resolving this controversial situation is ex-acerbated by the fact that under the influence of various reasons, the composition and structure of the CO at different stages of their lifecycle changes over time. The given examples of solving practical problems for such subject areas as spacecrafts, logistics, and industrial production.

Keywords: Complex objects · Proactive management and control theory · Multiple-model complexes · Combine methods · Algorithms · Structure dynamic control

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1 Introduction

The main subject of our research is complex objects (CO). By complex objects we mean such objects that should be studied using polytypic models and combined methods. In some instances, investigations of complex objects require multiple methodological approaches, many theories and disciplines, and interdisciplinary researches. Different aspects of complexity can be considered for distinguishing between a complex system and a simple one, for example: structure complexity, operational complexity, complexity of the choice of behavior, complexity of development [1–3, 10, 16, 18].

Classic examples of CO are: control objects for various classes of moving objects, such as surface and air transport, ships, space and launch vehicles, etc.; geographically distributed heterogeneous networks, flexible computerized manufacturing [2–6, 13, 18].

One of the main features of modern CO is the changeability of their parameters and structures caused by objective and subjective reasons at different stages of the CO life cycle. In other words, in practice we always come across the CO structure dynamics [10].

Under the existing conditions, the CO potentialities for increment (stabilization) or degradation (reducing) makes it necessary to perform the CO structure management and control (including the management and control of reconfiguration of structures). There are many possible variants of CO structure dynamics management and control. For example, they can be [5–7, 11–18]: *alteration of CO functioning means and objectives; alteration of the order of observation tasks and control tasks solving; redistribution of functions, problems, and control algorithms between CO levels; reserve resources control; control of motion of CO elements and subsystems; reconfiguration of CO structures*.

According to the contents of the structure-dynamics management and control problems, they belong under the class of the CO structure, i.e., functional synthesis problems and problems of program construction providing for the CO development.

As applied to CO, we distinguish the following main types of structures: the structure of CO goals, functions and tasks; organization structure; technical structure; topological structure; structure of special software and mathematical tools; technology structure (the structure of CO control technology).

By structure dynamics management and control we mean a process of control inputs producing and implementing for the CO transition from the current macro-state to a given one [10]. So, in our paper, we propose a new applied theory of CO structure dynamics management and control (SDMC).

2 Results

The main aim of our research is to prove the need of integrated modeling for parallel structural-functional synthesis of CO under dynamic conditions. Moreover, the main idea of our approach is to use fundamental results of structural-dynamic management and control theory [10] for multiple-model description of CO functioning and research.

2.1 Methodology

During our research we describe the main classes of CO integrated modeling tasks. For these aims, we use SDMC theory. Methodological basics of this theory include: the methodologies of generalized system analysis and the modern optimal control theory for CO with reconfigurable structures [2–6, 13, 18]. Moreover, these basics are related with the concepts of proactive control of their structure dynamics, the concept of complex preemptive modeling of the specified objects and their functioning processes, concepts of integration of knowledge, information and data, as well as the concept of model (rather than algorithm) priority when constructing relevant proactive monitoring and controlling systems. Our research has shown that these concepts have received implementation in a number of principles. Those are: the principle of non-terminal decisions, diversity absorption, hierarchical compensation, and complementarity; the principle of self-recursive description and modeling of the research objects; the homeostatic balance of interaction, overcoming the separation principle; the principles of multiple-model and multi-criteria approaches;, the principles taken as a basis for onthology creation, the principles of decomposition and aggregation; the principle of a rational multi-criteria compromise providing unavoidable threshold information and time limitations [8, 9, 11–16].

2.2 Methodology

As provided by the concept of CO multiple-model description, the proposed general model includes particular dynamic models: the dynamic model of CO motion control (Mg model); dynamic model of CO channel control (Mk model); dynamic model of CO operations control (Mo model); dynamic model of CO flows control (Mn model); dynamic model of CO resource control (Mp model); dynamic model of CO operation parameters control (Me model); dynamic model of CO structure dynamic control (Mc model); dynamic model of CO auxiliary operation control ($M\nu$ model) [6, 7, 10]. Figure 1 illustrates a possible interconnection of the models.

CO structure-dynamic control problem has some specific features in comparison with classic optimal control problems. *The first feature* is that the right parts of the differential equations undergo discontinuity at the beginning of interaction zones. The considered problems can be regarded as control problems with intermediate conditions. *The second feature* is the multi-criteria nature of the problems. *The third feature* is concerned with the influence of uncertainty factors. *The fourth feature* is the form of time-spatial, technical, and technological non-linear conditions that are mainly considered in control constraints and boundary conditions. On the whole, the constructed model is a non-linear non-stationary finite-dimensional differential system with a reconfigurable structure. Different variants of model aggregation were proposed. These variants produce a task of model quality selection that is the task of model complexity reduction. Decision-makers can select an appropriate level of model thoroughness in the interactive mode. The level of thoroughness depends on the input data, external conditions, and required level of solution validity.

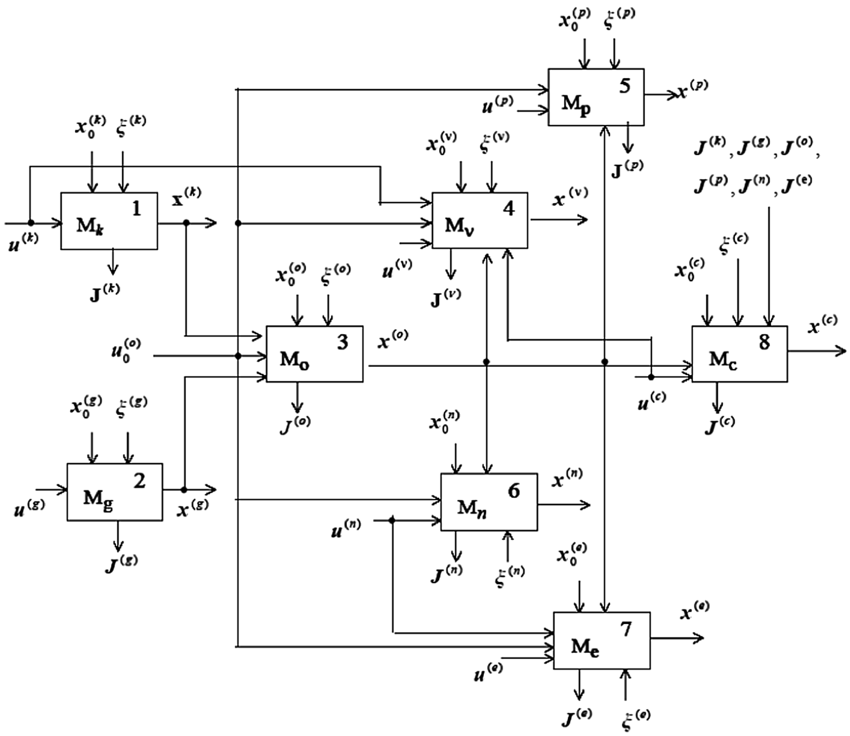

Fig. 1. Structural-dynamics management and control multiple-model description of complex objects

The proposed interpretation of CO structure dynamics control processes provides the advantages of modern optimal control theory for CO analysis and synthesis. Procedures of structure-dynamics problem-solving depend on the variants of transition and output functions (operators) implementation. Various approaches, methods, algorithms and procedures of coordinated choice through complexes of heterogeneous models have been developed by now.

As results of our investigations, the main phases and steps of a program-construction procedure for optimal structure-dynamics control in CO were proposed.

At the first phase, forming (generation) of allowable multi-structural macro-states is performed. In other words, a structure-functional synthesis of a new CO make-up should be fulfilled in accordance with an actual or forecast situation. Here, the *first-phase* problems come to CO structure-functional synthesis.

At the second phase, a single multi-structural macro-state is selected, and adaptive plans (programs) of CO transition to the selected macro-state are constructed. These plans should specify transition programs, as well as programs of stable CO operation in intermediate multi-structural macro-states. *The second phase* of program construction is aimed at solving multi-level multi-stage optimization problems.

One of the main opportunities of the proposed method of CO SDMC program construction is that besides the vector of program control, we receive a preferable multi-structural macro-state of CO at the end point. This is the state of CO reliable operation in the current (forecast) situation.

A method of multi-optional prediction of multi-structural macro-states of GSB MGDO based on the construction and approximation of attainability domains of the logic and dynamic models describing the structural dynamics of these objects was developed. In addition, it was shown that the orthogonal projection of the goal set (a set of required values of quality indicators of proactive control over CO) on the specified attainability set evidently allows to receive a set of non-dominated alternatives (Pareto set) in the virtual space of system and technical parameters characterizing multi-structural macro-state of CO. This result is based on the theorem proved by Professor L.A. Petrosyan in1982. In the course of research, it was also found that this set can be considered as a set of non-terminal decisions, the capacity of which allows to judge about the potentials of the CO control system (in other words, structural controllability of this category of objects).

2.3 First Prototype

The multiple-model description of CO structure-dynamics management and control processes is the base of integrated analytical-simulation technologies and simulation systems. Figure 2 illustrates the general structure of a simulation system, which was used for CO structure-dynamics control simulation. We assume the simulation system to be a specially organized complex. This complex consists of the following elements: simulation models (the hierarchy of models); analytical models (the hierarchy of models) for a simplified (aggregated) description of objects studied; informational subsystem that is a system of data bases (known as ledge bases); control-and-coordination system for interrelation and joint use of previous elements and interaction with the user (decision-maker).

The components of the simulation system were the main parts of the developed program prototypes in the course of our investigation. The processes of CO structure-dynamics control are hierarchical, multi-stage, and multi-task ones. The structure of simulation system (SIS) models conforms the features of control processes. There are three groups of models in SIS: models of CO CS and OS functioning (subsystem I of SIS); models of evaluation (observation) and analysis of structural states and CO CS structure-dynamics (subsystem II of SIS); decision-making models for control processes in CO CS (subsystem III of SIS). The subsystem of models for CO CS and OS functioning includes: models of CO functioning, models of CO classes functioning, and models of CO system functioning (subsystems 1, 2, 3 of SIS); models of CO interacting station (IS) functioning (subsystem 4 of SIS), models of functioning for control center (CC), central control station (CCS), and control station (CST) (subsystems 5, 6 of SIS); models of CO CS subsystems interaction and models of interaction between CO CS and OS (subsystem 7 of SIS); models of objects–in-service (OS) functioning (subsystem 8 of SIS); models of environmental impacts on CO CS (subsystem 9 of SIS); simulation models of CO CS goal directed applications under conditions of environmental impact (subsystem 10 of SIS).

In general, CO functioning includes informational, material, and energy interaction with OS, with other CO, and with the environment. Along with the interaction, the facility functioning, resource consumption (replenishment), and CO motion are to be considered via functioning models.

The subsystem of CO CS structure-dynamics evaluation (observation) models and analysis models includes: models and algorithms of evaluation (observation) and analysis of states of CO motion; facilities, interactions and resources (subsystem 11 of SIS); models and algorithms of evaluation (observation) and analysis of SO states (subsystem 12 of SIS); models and algorithms of situation evaluation and analysis (subsystem 13 of SIS).

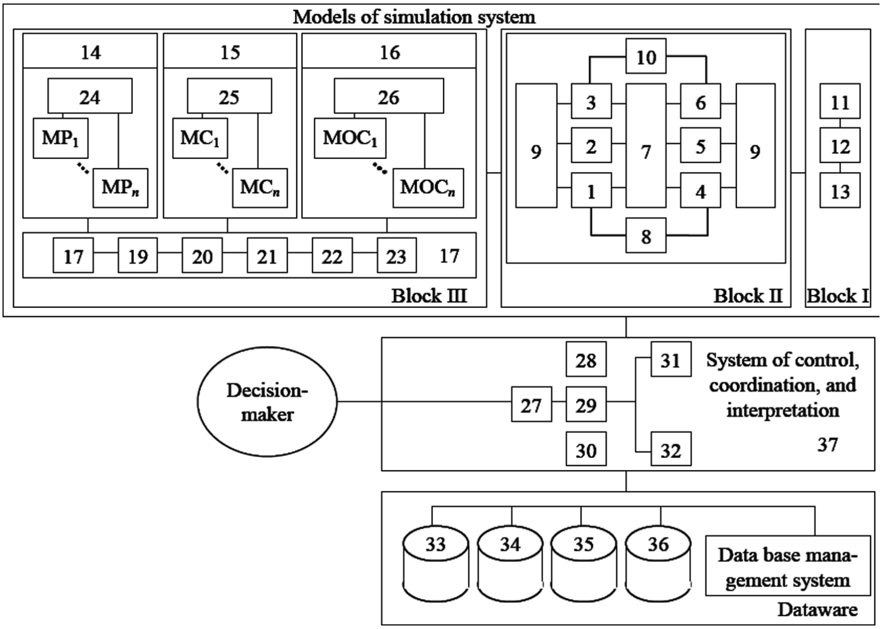

Fig. 2. Structure of simulation system

The subsystem of decision-making models includes: models and algorithms of CO and CO CS long-range and operational planning (sub-system 14 of SIS); models and algorithms of control for CO CS topologic, organizational, technology, and technical structures; models and algorithms of control for CO CS structures of software and dataware tools structures (subsystems 16, 17, 18, 19, 20, 21 of SIS); models and algorithms of correction for CO CS long-range and operational plans (subsystem 15 of SIS); models and algorithms of coordination for functioning of CO CS subsystems at stages of planning, correction, and operational control (subsystem 15 of SIS) (subsystems 24, 25, 26 of SIS); models and algorithms of operational control in CO CS (subsystem 16 of SIS).

In Fig. 2, the following notations where used: MP1, . . ., MPn; MC1, . . ., MCn; MOC1, . . ., MOCn are the models of planning, correction, and operational control for CO of (1, . . ., n) types correspondingly. Figure 2 also shows the system of control, coordination and interpretation containing user interface and general control subsystem (27 subsystem of SIS), local systems of control and coordination (28 subsystem of SIS), subsystem of data processing, analysis, and interpretation for planning, control and modeling (30 subsystem of SIS), subsystem of modeling scenarios formalization (31 subsystem of SIS), subsystem of software para-metric and structural adaptation (32 subsystem of SIS), subsystem of recommendations producing for decision-making and modeling (29 sub-system of SIS).

The data-ware includes data bases for CO states (33 subsystem), for CO CS states and general situation (35 subsystem), for SO states (34 subsystem), and data bases for analytical and simulation models of decision-making and of CO CS functioning (36 subsystem).

The main feature of integrated modeling is the coordination of different models constructed via formal or non-formal decomposition of tasks. Various approaches, methods, algorithms and procedures of a coordinated choice through complexes of heterogeneous models have been by now developed [7, 8].

3 Conclusion

Methodological and methodical basis of CO structure-dynamics management and control theory have been developed by now. This theory can be widely used in practice. It has an interdisciplinary basis provided by the classic control theory, operations research, artificial intelligence, systems theory and systems analysis.

The presented multiple-model complex, as compared with known analogues, have several advantages. It simplifies decision-making in CO structure-dynamics management and control, because it allows seeking for alternatives in finite dimensional spaces rather than in discrete ones. The complex permits to reduce dimensionality of CO structure-functional synthesis problems to be solved in a real-time operation mode. Moreover, the proposed approach to the problem of CO structural dynamics management control enables:

- common goals of CO functioning to be directly linked with those implemented in CO control process;
- a reasonable decision and selection (choice) of adequate consequences of problems solved and operations fulfilled are related to structural dynamics to be created (in other words, to synthesize and develop a CO control method);
- a compromise distribution (trade-off) of a restricted resources appropriated for a structural dynamics management and control to be found voluntarily.

A more detailed information about CO structure dynamics management and control theory implementation in different applied areas is placed on the web site http://litsam.ru.

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