Scientific and Methodological Foundations of Decomposition and Analysis of the Interaction of Processes in the Life Cycle of High-Tech Integrated Control Systems

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***Abstract*—This article provides proves of the refined formulation of the problem of multiprocessor simulation of core and opposing processes' interaction in the life cycle of the control system. For this, decomposition of the end-to-end process in the life cycle of control system is executed; The following processes are separated: organizational processes that reflect a relation of controlling bodies regardless of means of control, organizational-technical processes that reflect relation of controlling bodies considering means of control, and technological processes that reflect relation of means of control. Such approach to the representation of the structure of processes can also be applied to the study of opposing processes. Interaction at the process level is considered in relation to the main attributes of the processes: the inputs and outputs of the processes, process control, and the resources involved for its implementation. It is proposed that the complex multi-process model of a high-tech control system be based on the scheme of interaction of processes in the life cycle and the basic model of interaction of the core and opposing processes within each type of process, which basically uses the unified attributes of the typical process. In this case, the basic model is presented based on unified object-oriented modules, reflecting the operation of the control system in the form of multi-directional interaction of the elements of the end-to-end process.**

I. INTRODUCTION

In accordance with modern views of system engineering, aimed at promoting developers' approaches to the design of high-tech systems using information and telecommunication technologies (ITT), the procedure for using process methods as part of a systems approach to a design of a wide range of systems, complexes and hardware is mainly determined and is regulated by international and national standards harmonized with them.

The same time, unified approach of system engineering to design of complex systems based on ITT not necessarily provides required quality of technological solutions for automated integrated control systems (ICS) design, because it's limited to implementation and development of business processes only and does not work on processes in design solutions.

In addition, business processes are normally considered, only within the production stage limited by the framework of enterprises. At the same time, part of the life cycle of the product, related to creation and design stage, and substantiating technical requirements for it, stays outside of scope of the researched business processes. Such activities are also business processes and are usually carried out by the customer. Within the framework of the existing quality management system, this part of the life cycle of management systems is not regulated in mutual relation with the production zone one an enterprise.

Therefore, determining the ways of expanding the capabilities of modern systems engineering techniques in relation to such systems is an actual scientific task. Developing process approach to the studies on control systems, proposes an extension of the scope of application of the process approach method, with the inclusion of the part of control systems lifecycle into quality management systems. Following that, the article proposes an expanded classification of the processes in the life cycle of control systems as high-tech development objects based on the end-to-end decomposition

The article proposes to consider a new direction in the development of the process approach to life cycle analysis, which is based on the decomposition of the end-to-end process in the life cycle of systems, analyzing possible options for interaction at the level of core and opposing processes and justification of a rational integration of ICS components on a process basis of interaction of core and opposing processes in a control system lifecycle. Research of the process basis of simulating the interaction of such processes is aimed at identification of the most significant links between such, in order to ensure interoperability at the process level when creating integrated systems, contrary to the traditional approach of ensuring interoperability at technical and semantic levels only. An important feature of the refined process approach is the expansion of the classification of groups of processes in the ICS life cycle as high-tech development objects.

From a scientific and methodological point of view, in the context of a rapid development of basic control techniques, it seems appropriate to proceed to the analysis of processes in the life cycle of control systems with the representation of end-to-

end process as a network process structure of heterogeneous processes that are compiled to their full group. On this basis, the description of the scheme of interaction of processes in the life cycle of control systems and the structure of the basic multi-process model of the control system are presented.

II. Development and scope expansion of process approach methods

Systems engineering presumes harmonization of a number of approaches to the design of complex systems in a single complex; among the approaches:

- systematic approach that determines the purpose of the system, its boundaries and elements;
- process approach that determines the functioning and the main factors, the impact of which leads to a change in the properties of the system;
- assessment of the maturity of processes in the life cycle of systems.

The following main conditions and factors determine the need to clarify the approaches to the study of promising automated ICS and their elements:

- the use of a systematic approach to the design of complex systems has revealed in practice the limitations in such systemic parameters as certainty, consistency, integrity of systems as objects of development and development;
- relationship of external and internal factors influencing on the object, the processes they launch within the object, leading to a change in the properties of the object, causing changes in the processes in the system of objects, should be considered;
- functional, process and other methods of modern management should be used together.

The discovery of the principle of division of labor, that consists of defining the list of functions performed in the course of production activities and justifying the need for their separate implementation, served as the basis for the first industrial revolution in the 18th century. This served as the basis for the formation and further development of a functional approach to the management of organizations and production control. Along with this approach, at the beginning of the 20th century, alternative methods were being developed by Henry Fayol in the framework of the general theory of administration, and Walter Shewhart in the direction of statistical process control [1, 2]. Thus, the essentials for process management approach were founded. With this approach, the desired result is achieved more efficiently when activities and related resources are managed as processes, and the identification, understanding and management of interrelated processes as the systems, contributes to the effectiveness and efficiency of the organization in achieving its goals.

During the 20th century, the views of management professionals on the basic methods and description of the process approach were widely developed. For example [2-6], the general and special characteristics of modern methods of the process approach, the methodology of process modeling and proposals for their development are given. It is important to note that in these and other works, the main areas of application and development of the process approach methods are related to the business process area considered as part of the improvement of the product quality management system.

The comprehensive development of a wide range of modern management methods indicates that in the transition period to the sixth technological age in the world economy, the conditions for their use are changing. As noted in [7], the use of a systematic approach to the subject of complex systems is associated with such systemic limitations as insufficient definition of the subject area, inconsistency of the intended purpose of the systems and complexes being developed and conditions for their use, integrity in determining their composition. Thus, the goal of complex development of functional and process methods in a systematic approach and defining the scope of application of process methods acquires new aspects of relevance associated with the development of guidelines for determining the structure of the end-to-end process in the life cycle of automated ICS, for identifying and analyzing the directions of interaction of its components.

Guided by the main provisions of the process approach, taking into account the retrospective of its development, on the one hand, the needs for studying and developing the process basis for creating and applying ITT in designing ICS, on the other hand, it seems appropriate to expand the application of the process approach in the following areas, as demonstrated at Fig. 1:

- development of a quality management system at industrial enterprises based on the methods of the process approach, including the customer's organizational structures (departments) in the overall quality assurance process, defining the structure and interconnection of organizational (business) processes in the responsibility of the customer's structural departments
- expanding the scope of application of the process approach beyond the organizational processes (business processes):
    - planning and organization of the end-to-end process throughout the life cycle of high-tech control systems (from the formation of the organizational-technical, system and technological structure at the level of basic research to the organization and ensuring their full support at the operational stage);
    - designing automated ICS based on a multi-process model, that takes into account the types of processes and groups of processes for each of the types.

In the future, the integrated application of process approach methods to the design, implementation, application and development of automated ICS will allow:

- to form an end-to-end process throughout their life cycle, including, ultimately, a full group of processes, analyzing the interaction of which will allow us to establish the most significant interrelationships between them;
- on a process basis, to conduct a search for directions of improving processes in the life cycle of automated ICS.

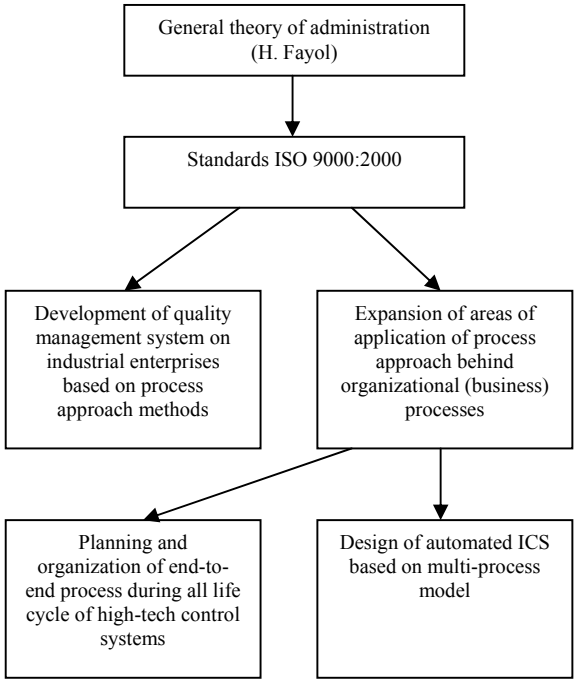

Fig. 1. Retrospective of process approach and proposals on main areas of improvement and application

III. Structure of processes in control system lifecycle

Considering the limitations of the systems approach [7], caused by incomplete certainty, inconsistency and integrity of the tasks, conditions of application and the needs of users of promising ICS, the areas of improvement of control systems are determined by the following main features:

- the ambiguity of their purpose and conditions of use, associated with intensive integration processes as a part of various kinds of multi-functional systems;
- inconsistency of their tasks, caused by the conflict of the core and opposing processes, both at design and operation stages;
- resource constraints at all stages of the life cycle.

Considering the above, it is reasonable to apply modern methods of process approach to meet the constrains [8]. The paper [9] presents qualitatively new approach to the development of the methodology for the design of integrated control system as a complex of bodies, points and means of control based on process approach. At the same time, the papers use new methodological base for the application of methods of process approach, contrary to widely known tricks for improving business processes, limited mainly by quality management system in the production sphere.

It should be noted that the widespread use of process approach methods applied to the theory and practice of business processes as part of the development of a quality management system in Russian enterprises is elaborated in [8-19] and in several international standards, for example

- ISO 9000: 2005 (Quality management systems. Fundamentals and vocabulary);
- ISO 9000: 2008 (Quality management systems. Requirements), ISO 9004: 2009 (Management for the sustainable success of an organization - Approach based on quality management);
- ISO/TC 176/SC 2/N 544R3, ISO 9000 implementation and support package: Guide to the concept and application of the process approach to management systems (Release 3,15.10.2008),
- other standards, that national standards are harmonized with.

At the same time, the process approach is applied mainly in the production sphere.

The end-to-end process in the ICS life cycle is decomposed with the allocation of such groups of processes as *core* processes that contribute to the achievement of the goals of the ICS, and *opposing* processes, while both groups include basic, supporting and auxiliary processes. Thus, the diversity of lifecycle processes structure determines the need for a comprehensive analysis of the directions of mutual influence on its elements' level. The specified groups of processes, from the prospective of the relation to control system elements, may be classified as follows, considering the proposals published in [9], [13]:

- in control bodies: *organizational (business) processes*, reflect a relation of controlling bodies regardless of means of control,
- in means of control (as a complex of automatization tools and telecommunication network): *technical-technological processes*, reflect relation on a level of means of control without involvement of human operator,
- in control points: *organizational-technical processes*, reflect relation of control bodies and managers using means of control, *organizational-information processes*, reflect relation of control bodies and managers using means of control over information resources, *organizational-cognitive processes*, reflect relation of control bodies and managers using means of control over knowledge resources.

Secondary classification of processes that characterize the relation of controls to each other using any management tools, information resources, knowledge resources, etc., can be expanded as technologies and algorithms of interaction between controls them improve. Such approach provides essential conditions for analyzing possible directions of relation of process components by its groups and types, and identification of direction of its significant and not-significant relation. This allows to justify a priority of developed technical and system solutions on optimization of process elements in the direction of its' interoperability.

Finally, the aggregation of process elements can be done with implementation of necessary measures to improve them in the life cycle of the ICS, considering it's interoperability at the level of process elements. This approach is aimed at the comprehensive provision of the functionality of the ICS due to development of network process structure, as they are:

- laid at an early stage of their life cycle when justifying during conducting fundamental research of the basic idea of forming their role in solving actual problems and meeting the basic needs of future users,

- developed at the level of systems solutions in the framework of applied research,
- implemented in the form of standard hardware and software and design solutions during development work,
- tested and evaluated in the process of experimental testing of the systems,
- manifest and maintained at the operation stage.

IV. SCHEME OF INTERACTION OF PROCESSES IN ICS LIFE CYCLE

The important role of the early stages of ICS lifecycle, as high-tech systems, is confirmed by the fact that the expansion of quantity and quality of new technologies also defines the scale of threats and hazards that accompany technological progress in the field of practical application and development of informational, cognitive, and telecommunication technologies. In this regard, it seems appropriate to consider a generalized mechanism of the influence of external factors on the condition of the control system and its components. As such, using the described [9, 13, 20] approach to description of relationship of external factors influencing on an object, the processes launched by them within the object, the scheme of their relationship can be presented as follows (see Fig. 2):

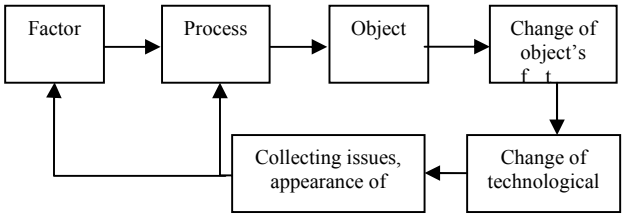

Fig. 2. General flow of relation of factors, processes and features of objects

The specific factor of the external conditions of functioning of object control system runs organizational process in the form of wording additional requirements for its objects, or changing the conditions of its operation, as a result of which, the functional properties of the control system change at the organizational-technical level or at the technical-technological level. Analysis and implementation of these requirement should be assessed and carried out considering the nature of their influence on the organizational process. For example, the telecommunication basis of the control system, being a key element of the control system, which largely determines its structure and topology, mainly aims to provide technical-technological support to the organization and practical implementation of organizational-technical and organizational processes in control system. The telecommunication basis of the control system should be considered as an object under the complex influence of the above factor. The example of three kinds of factors of different nature illustrates the relation of factors, the processes they launch, which manifest themselves in interrelation, and lead to change of the attributes of telecommunication basis of control system, which ultimately lead to changes in in the properties of the control system. This relation multi-directional. Fig. 3 shows a generalized scheme of interaction between core (basic) and opposing processes on a process basis [9].

It shows the direction of interaction according to the main attributes (input/output, control impact, resources):

- according to the same process attributes (inputs and outputs of processes, control actions on processes and resources for the implementation of processes), relation of processes can be considered as almost a real-time relation, which is the worst case in terms of minimizing negative impact on the main process;
- according to different attributes of the processes. It requires an analysis of how fast and intensive the opposing process influences on of the core process;
- combined interaction.

Considering possible interaction, the worst and most significant interactions are identified and ranged. Then, the necessary measures to neutralize threats are justified.

Modelling the features of interaction of attributes and processes is reasonable to realize based on scheme of object-oriented modules with indication of possible directions of its mutual influence and simulation of interaction procedures of interaction by parameters of core and opposing procedures.

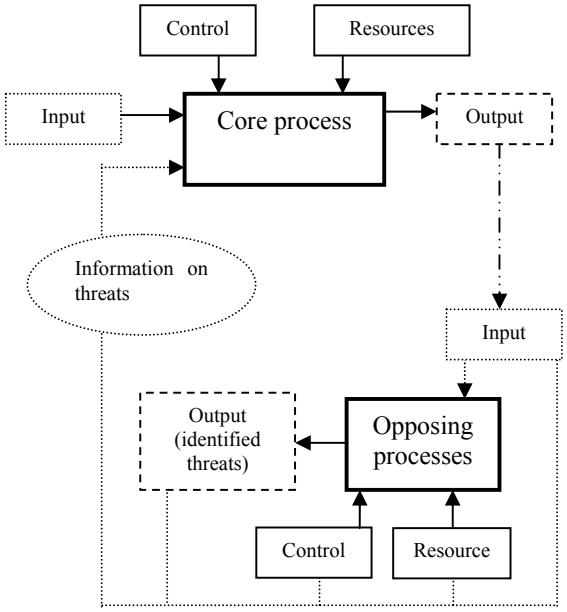

Fig. 3. Generalized scheme of relation of core and opposing processes in control system life-cycle

Generalized scheme of interaction of core and opposing processes, shown on Fig. 3, is applicable for all processes described on Fig. 2

V. STRUCTURE OF BASE MULTI-PROCESS CONTROL SYSTEM MODEL

Based on generalized scheme of interaction of core and opposing processes (see Fig. 3) and creating object-oriented modules that simulate relation of groups of processes, the structure of multi-process model of end-to-end processes in lifecycle of control system is developed (see fig. 4). This model is based on simulation of:

- building core and opposing processes,

- interaction of these processes based on it's attributes.

Each module reflects elements of the multi-process structure of the core and opposing process. The respective attributes are presented as:

- Generators of transacts simulating the inputs of the core (G_{iC0}, G_{iC1}…G_{iCk}) and opposing (G_{iX0}, G_{iX1}…G_{iXk}) processes,
- Generators of transacts simulating the control actions on target (G_{cC0}…G_{cCn}) and opposing (G_{cXp}) processes,
- Generator of transacts simulating the use of resources for the implementation of targeted (G_{rC1}…G_{rCm}) and target (G_{rX1}…G_{rXq}) processes.

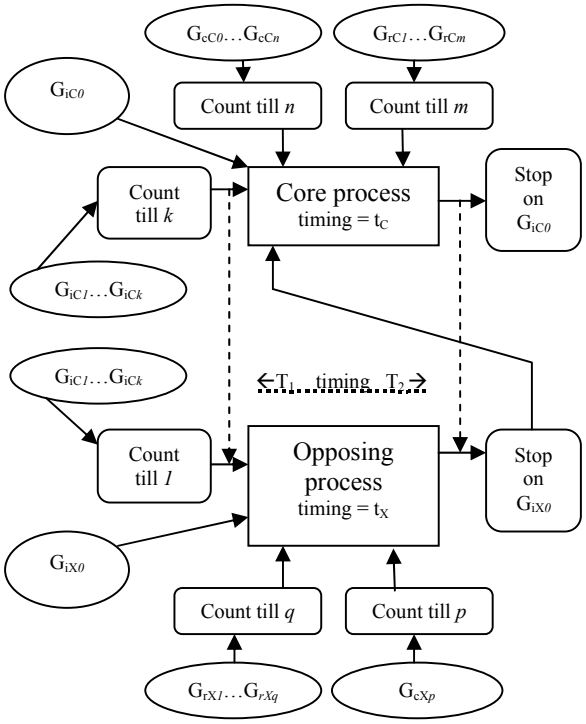

Fig. 4. Structural scheme of base multi-process model

Realization of core and opposing processes is carried out considering delay t_C and t_X respectively. The channels of interaction of core and opposing processes is characterized by delay T_1 and T_2. Each block *G* creates transacts with the set of attributes, that simulate:

- input parameters of processes (the density of incoming components that form full set of input data for process realization, priorities usual for these components);
- parameters of actions that control realization of the process;
- parameters of resources required for realization of the process.

Such approach for process realization is unified and can be applied for simulating core and opposing processes.

Simulation of the process of passing transaction through the corresponding blocks of time delay, priority maintenance, assembly of the copies of the original transaction, is the essence of multi-process modeling of the complex process of interaction between the core and opposing processes. The main results of their modeling are estimated based on functions of distribution of the probability of service time of a transaction in the composition of their flow simulating the main process.

Other results that characterize the degree of compensation for the negative impact of opposing processes are derived in the form of probability-timing characteristics of the process of servicing transacts that simulate the functioning of opposing processes. For program realization of base multi-process model it is reasonable to use such discrete system simulation language as GPSS.

Based on multi-process modeling of the core and opposing processes, it is possible to determine the limits of adjusting the core processes and substantiate proposals for expanding the possibilities for monitoring and controlling the parameters of the opposing processes.

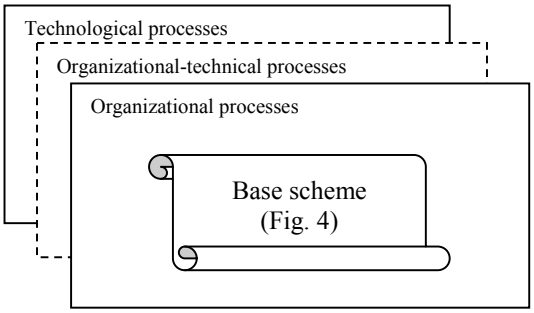

Fig. 5. Structural scheme of advanced multi-process control system model

It seems reasonable to describe each process shown on Fig 2 based on base model of core and opposing processes shown on Fig. 4. Each pair of core/opposing processes in this advanced model will be defined by its own set of parameters (input/output, attributes etc.). The advanced multi-processed module of interaction of core and opposing processes it shown on Fig. 5. It shows interaction of technological, organizational-technical, and technological core and opposing processes.

Initially, the complex simulation of three groups of processes identified during decomposition of ICS lifecycle (organizational, organizational-technical, and technological), is reasonable to organize separately by process. At this stage, it's important to identify ensemble of parameters of G-transacts generators for each kind of processes. After obtaining results of simulation for each kind of processes, it is required to perform an analysis and assessment of potential inter-process integration.

After this, development of proposed advanced model will be done considering mutual relation of core and opposing processes taking into account relation of heterogenous factors, shown in fig. 5, and proving inter-relation of G-transacts' generators group for simulation of three kinds of processes within the full set of processes.

VI. Conclusion

The proposed approach to decomposition of the end-to-end process in the lifecycle of the ICS with separating within ICS the organizational, organizational-technical, and technological processes, is aimed to prove essential conditions for their integration, considering identic structure of core and opposing

processes within the each one. The target of multi-process simulation of interaction of core and opposing processes in the lifecycle of the ICS, is set based on a definition of base scheme of interaction of core and opposing processes, which was used a s a basis for multi-process model of integrated system. Interaction on a process level is research considering base process attributes: input and output of the processes, managing the process, and sources for managing the process. The complex multi-process model of high-end control system is based on the scheme of interaction of processes in lifecycle and base model of interaction of core and opposing processes within each kind of processes, which is based on unified attributes of typical process. The base model is presented base on unified object-oriented modules that reflect control system operation as a multi-targeted interaction of the elements of end-to-end process.

The proposed approach to multi-process modelling of the end-to-end process in the lifecycle of the ICS as a high-tech system, provides the following basic features:

A. on a qualitatively new basis, conduct an analysis of the conditions for the implementation of core processes, considering opposing processes; substantiate proposals for the qualitative development of management system elements taking into account the definition of process attributes as part of their full group and possible directions of mutual influence of processes considered at the attribute level
B. securing it from negative factors in a life-cycle,
C. integrated development of the components of the end-to-end process and usage of possibilities for improvement for each of them,
D. justification of the process basis for integration of new functional components into control systems.

Base and advanced structure of multi-process simulation of ICS can used as a basis for development of new ways of securing interoperability of control system elements, considering network process structure in its life-cycle.

Proposals for expanding the scope of the process approach and developing its methods in relation to the activities of the customer's structural departments can be used as the basis for the development of regulatory and procedural documents governing the customer's activity.

VII. ACKONOWLEDGMENT

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