Automation of the development of electrodynamic objects based on the dual approach

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Abstract. This paper considers an approach that demonstrates the features of creating complex electrodynamic systems. In practice, the creation of such objects is associated with a decrease in the levels of electromagnetic radiation, control of the direction of propagation of electromagnetic waves. The main properties of the generated automated system for assessing the quality of the electrodynamic characteristics of objects are considered. Suggestions are given on its structural diagram, the contours of the operation control and control of the restructuring of electrodynamic objects are shown. The created system for assessing the quality of electrodynamic characteristics can be useful in the design of a wide class of technical systems.

1. Introduction

Various electrodynamic objects are included in a wide class of technical devices. From the point of view of practice, developers strive to solve problems related to the control of the distribution of scattered electromagnetic fields. Computer-aided design (CAD) systems are used to develop electrodynamic systems that consist of a large number of objects [1, 2].

As an object of research, this paper discusses a system for assessing the quality of characteristics of complex electrodynamic objects. Since there can be many options for building a system, it is necessary to use optimization approaches [3, 4]. It is proposed to apply a method associated with consistently applied criteria [5]. Optimization of various components of design solutions will take place with a focus on the final solution. The purpose of the paper is to describe the characteristics of such a system, its structure. During the development of the system, the principle of dual control is used.

2. The features of the system for evaluating electrodynamic characteristics

Based on the goal, the object of research is a system for controlling the characteristics of complex electrodynamic objects. It is considered as a nuclear subsystem in a large control system of electrodynamic characteristics in the q-th direction in a given class of objects. The system is used to control the characteristics of different classes of electrodynamic objects, which is multilevel. Control systems for the characteristics of an electrodynamic object in individual directions within a given class are considered as a basic control level.

An automated system that allows evaluating the characteristics of electrodynamic objects in the q-th
direction within a given class is a system within which, with the involvement of modern information technologies and computer facilities, automation was carried out for all basic procedures for evaluating characteristics [6, 7].

In the course of implementing control procedures, we focus on the principle of duality. It makes it possible to substantiate the structure of dual control systems for the characteristics of complex electrodynamic objects, and the features of systems for assessing the characteristics of individual elements that make up such objects, within a given direction according to the corresponding characteristics.

Figure 1 shows a block diagram of such a dual control system for a basic electrodynamic object.

![Figure 1. Illustration of a control system for electrodynamic objects, consisting of two loops.](image)

The block diagram shows that the system for evaluating characteristics along the $q$-th direction in a given class determines the core of the regulator of the functioning loop. It is based on the set of estimation subsystems that are associated with the estimation operators $\{H_0, H_1, ..., H_B\}$.

In figure 1 the system is given associated to the work of characteristic control loop $\{CCL\}_q$ and the control loop of the change of characteristics (CLC) when the formation of object is carried out. It has the ability to update the means to achieve the goal. This is also due to the fact that the means of characteristics of electrodynamic objects are changing – $M_q^{(i)}$.

The principle of duality of control according to the basic control systems of the characteristics of electrodynamic objects will determine what will be duality according to the criteria of control efficiency. $J_1$ is a criterion related to the efficiency [8] of the electrodynamic system; $J_2$ is a criterion associated with the efficiency of changes in the electrodynamic system.

In our research, it is important, first of all, the criterion that is associated with the efficiency of the system in relation to basic electrodynamic objects. If we consider the deterministic simplified approach, then it is represented as follows:
\[ J^{(i)}_{\text{q}}(A^{(i)}_{\text{q}}) = \{ f^{(i)}_{\text{q}}(Y^{(i)}_{\text{q}}, A^{(i)}_{\text{q}}) \geq f^{\text{set}}(A^{(i)}_{\text{q}}), \gamma = 1, Y_{\text{q}}(A^{(i)}_{\text{q}}) \} \] (1)

It takes into account that there are results of measurements \( Z^{(i)}_{\text{q}} \) of the parameters of the characteristics created for the \( i \)-th electrodynamic object (without taking into account the influence of many means of achieving goals - \( X^{(i)}_{\text{q}} \)).

We correlate the content of the criterion for the efficiency of the basic control system with the fact that all inequalities in (1) will be fulfilled. At the same time, there are fixed results of evaluating the characteristics of the \( i \)-th electrodynamic object for all stages of its formation.

Let us explain these inequalities. The way in which the function \( f^{(i)}_{\text{q}}(\bullet) \) is written, as well as the number of inequalities \( \gamma_{\text{q}}(A^{(i)}_{\text{q}}) \) will affect the requirements for electrodynamic objects at the \( l \)-th stage in the \( q \)-th direction for the \( A^{(i)}_{\text{q}} \)-th purpose of changing the object.

If we analyze the circuit in figure 1, based on the set of operators \(-\{H^{(i)}_{\text{q}}\}\), then it is required to analyze the criterion for assessing the quality of creation - \( J^{(i)}_{\text{q}} \). It is considered as a measure of how well the characteristic (function \( f^{(i)}_{\text{q}}(\bullet) \)) created for the \( i \)-th object at the \( l \)-th stage of development corresponds to the one that is required (function \( f^{\text{set}}(A^{(i)}_{\text{q}}) \)) for all requirements for the elements of the object.

That is, we believe that \( J^{(i)}_{\text{q}} \) is considered in the form of a multidimensional and multiparametric construction [9, 10].

The analyzed system for evaluating characteristics should allow calculating the criterion for evaluating quality \( J^{(i)}_{\text{q}} \) by a set \( J^{(i)}_{\text{q}} \) of elements of electrodynamic objects.

3. Description of the solution to the problem in the design of a system for assessing the quality of the electrodynamic characteristics of objects

The analyzed electrodynamic objects during the design are considered in the form of complex systems, which requires the involvement of computer resources.

The structure of the description of the electrodynamic object \( <\text{SDEO}>_{\text{q}} \) during design is considered as a prototype of the system:

\[ PRA_{\text{inv}}\{S_{\text{inv}}, K_{\text{inv}}, P_{\text{inv}}\} \] (2)

In the final description of \( <\text{SDEO}>_{\text{q}} \) as a design result is considered as a design solution \( PR \):

\[ PRA_{\text{inv}}\{S, K, P\} \] (3)

In the specified solution, \( S \) is a structure, \( K \) is a parameter, \( P \) is considered as an implementation of the system project.

Computer-aided design of \( <\text{SDEO}>_{\text{q}} \) is associated with the implementation of the formation process, based on the description (2) the final description \( PR \), which is described by (3).

It is necessary to take into account during the development that there are two loops in the system for controlling the characteristics of electrodynamic objects.

Allocate \( <\text{SDEO}>_{\text{q}} \) - for the operation control loop, as well as \( <\text{SDEO}>_{\text{q}} \) for the control loop of the restructuring of an electrodynamic object. In the design solution (3), two components are distinguished:

\[ PR = \{PR_{f}, PR_{p}\} \] (4)

In the expression \( PR_{f} \) - the design decision \( <\text{SDEO}>_{q} \), which is associated with the control loop of the object operation;
PR_q - the design solution <SDEO>_q, which is associated with the control loop of restructuring object.

In each of the contours, which are associated with management, two criteria are involved that are associated with the object under research <SDEO>_q: a criterion showing the quality of the object <SDEO>_q and a criterion showing the complexity of creating an object <SDEO>_q.

In the first of the analyzed contours <SDC EC>_q there are such criteria:

- the criterion associated with the quality of the object <SDEO>_q - shows the probability that the error in assessing the quality of object creation in the q-th direction will fall into the required area - \( P_{\Phi_0} \) (the goal for the work contour - \( A^\text{Gen}_{q} \) ) is considered in type of quality assessment, it can be related to the relevant standards);
- the criterion associated with the complexity of the formation of the object <SDEO>_q - \( J_{3q}(PR_{q_0}) \). It shows the costs of assembling and creating it [11, 12].

Two criteria are required in the contour associated with the control of the restructuring of the object <SDC EC>_q.

The first one shows the quality of the object <SDEO>_q - \( J_{2q}(PR_{q_0}) \). It shows the likelihood that an error in assessing the quality of creating an electrodynamic object in the q-th direction will fall into the required area - \( P_{r} \) while taking into account a new quality standard - \( A^\text{Gen}_{q} \). We consider it as the best when compared with \( A^\text{Gen}_{q_0} \).

The second criterion is related to the complexity of creating the object <SDEO>_q - \( J_{1q}(PR_{q_0}) \). It shows the corresponding required costs.

There are certain requirements: and, which are related to the values of the designated criteria for the quality of the generated objects <SDEO>_q. They are considered from the point of view of constraints on the worst values of the analyzed characteristics.

Let us show the key features of the computer-aided design problem <SDEO>_q.

It is required to determine \( PR = \{PR_{q_0}, PR_{q_1}\} \) which will satisfy the following conditions:

\[
\begin{align*}
J_{1q}(PR_{q_0}) &\geq J^T_{1q}, & J_{2q}(PR_{q_0}) &\geq J^T_{2q}, \\
J_{3q}(PR_{q_0}) &\leq J^T_{3q}, & J_{4q}(PR_{q_0}) &\leq J^T_{4q}.
\end{align*}
\]

As an approach that allows solving the design problem, we propose to use the optimization method according to consistently applied criteria (equivalent, heterogeneous and contradictory):

\[
\begin{align*}
J_{1q}(PR_{q_0}) &\rightarrow PR_{q_0} \in M_{q_0} \max, \\
J_{2q}(PR_{q_0}) &\rightarrow PR_{q_0} \in M_{q_0} \max, \\
J_{3q}(PR_{q_0}) &\rightarrow PR_{q_0} \in M_{q_0} \max, \\
J_{4q}(PR_{q_0}) &\rightarrow PR_{q_0} \in M_{q_0} \max.
\end{align*}
\]

In the above expressions \( M_{q_0} \) is considered as a set of admissible options \( PR_{q_0} - <SDEO>_q_{q_0} \). In this case, the quality criterion of the formed object will be no worse than the \( PR \) in those versions that were created before; \( M_{q_1} \) - set of admissible options - <SDEO>_q_{q_0}. 


When the automated design of electrodynamic objects $\langle SDEO \rangle_q$ is carried out, then one-criterion optimization problems are repeatedly solved, in which there is a discrete argument $PR$ in expressions (6)-(9).

In practice, a dialogue between a person and a computer is realized. Based on the initial description of the electrodynamic object $\langle SDEO \rangle_q$, based on the primary data, the final description of the object will be formed, corresponding to (3) It satisfies certain requirements related to the values of the quality indicators of the generated electrodynamic object $J_{q_1}(PR_{q_1})$, $J_{q_2}(PR_{q_2})$, $J_{q_3}(PR_{q_3})$, $J_{q_4}(PR_{q_4})$. This description will be optimal in the sense of Pareto.

The process aimed at automated design $\langle SDEO \rangle_q$ is based on the following steps: decomposition - decision - coordination.

This process will be iterative. Due to the application of decomposition, the design process will be split into several stages. They are aimed at solving particular problems. A "tree" of goals and criteria is being formed.

To ensure the design goal, which is presented in expressions (6)-(9), it is important to agree on particular goals and criteria for individual stages and tasks. In this case, it is necessary to take into account the general criteria for the optimality of the formed objects in terms of the quality and complexity of creation.

4. Performance analysis results

Let us give an example of the developed approaches to control the characteristics of a complex electrodynamic object. The structure of such an object is shown in figure 2. The object is made of metal. There is a dielectric layer with a thickness of $d_2$. The known parameters are as follows: $L_1 = 16\lambda$, $L_2 = 5\lambda$, $L_3 = 3.5\lambda$, $d_1 = 1.7\lambda$, $L_4 = 2.5\lambda$. Characteristics of metal-dielectric material is $\varepsilon = 0.1-0.3j$, $\mu = 0.2-0.6j$. It is necessary to determine the values of the dimensions $L_5$ and $d_2$.

![Figure 2](image)

Figure 2. Illustration of an electrodynamic object that is analyzed in the control system.

As a quality requirement, there is a condition that in the sector of observation angles $0^\circ < \varphi < 10^\circ$ the value of radar cross section (RCS) is not more than 25 dB. As a method for calculating electromagnetic
characteristics, we used the method of integral equations. The design goal is associated with the creation of an object with the smallest possible mass. During the implementation of the constructed algorithm, two possible options were found: 1) \( L_5 = 1.1 \lambda, \ d_2 = 1.2 \lambda \), 2) \( L_5 = 2.6 \lambda, \ d_2 = 1.75 \lambda \). In the expressions \( \lambda \) is the wavelength of electromagnetic wave. Based on the design goal, the first option is required.

5. Conclusion
The paper demonstrates the possibility of constructing an automated system that makes it possible to assess the quality of characteristics of complex electrodynamic systems. The structure of such a system is given. The peculiarities of the formulation and solution of the problem associated with assessing the quality of electrodynamic characteristics are shown. When solving the design problem, it is proposed to use the optimization method with consistently applied criteria.

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