Methodology and practical application of the automation system for unmanned spacecraft design

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Abstract. The problem of automation of design of automatic spacecraft structures taking into account their dynamic characteristics are considered. According to the results of the research, the procedure of unification of the method of automatic formation of stiffness and inertia matrices of complex spatial structure is proposed. The procedure based on the transfer functions method allows to determine the level of loads of a certain type. The proposed approach shows the best results in bench tests of automatic spacecraft structures and can be used to calculate complex mechanical systems of machines and assemblies for various purposes.

1. Introduction

The development of algorithms for solving design problems [1, 2] is only a link in the chain of problems, the solution of which will turn the computer into an effective design tool.

Automation of design work is associated with the implementation of the following requirements [3]: methods must comply with the design and technological characteristics of the design object; input and output parameters must comply with the current regulatory and technological documentation of the industry; the capabilities of the technical base that provides automation must be taken into account; methods must be easy to operate.

The formulation and implementation of operational requirements for the design subsystem are associated with the greatest difficulties. This is because [4], the designer is not always clear about automation capabilities, and CAD developers are not familiar enough with the specifics of the designer. This situation leads to a not clear understanding of the designer's place in the computer-aided design.

In work [5] the "integrated" systems allowing: to automate the whole chain of design operations taking into account possibilities of the designer and the computer; to contain a set of the alternative algorithms providing the solution effective on speed (at the set accuracy) for various specific tasks; to expand and improve the system; to provide convenient exchange of information, both internal (between blocks), and external; to have continuous control of the work of the system are offered.

2. Formulation of the problem

A large amount of input information takes considerable time [6] to collect, to prepare, to load and control data. The imperfection of placement programs with a long account time and without consideration of all functional requirements for placement, results in spending much calendar time to solve the problem. This disadvantage can be compensated by the introduction of active dialogue.

In the domestic and foreign literature, the main attention is paid to the methods of development of design automation systems from the development of the structure to the gradual program detailing - "from top to bottom" [7]. These methods are certainly promising and have a number of advantages, but require [8] a stable and developed technical base, qualified developers and proven detailed formalization of design tasks. At the same time, in many design organizations there is a big reserve for the solution of separate design tasks (in the majority – settlement [3]) with use of the developed
packages of the applied programs [9]. This reserve can be successfully used in the development of computer-aided design subsystems as component blocks [10].

Thus, at the initial stage of CAD creation, the method of "bottom-up" systems development is historically and logically justified [4, 7].

3. Theory

The existing approach [11] requires a long period of time to create a subsystem, but has a number of advantages. The most significant of them is the low probability of errors in the formulation of the problem and the choice of the model, the possibility of training qualified personnel in the process of implementing the software. To reduce the process time it is proposed to use the method of geometric placement of elements when creating a subsystem of computer-aided design (table 1).

**Table 1** Stages of creation of a subsystem for automated geometric layout of the elements

| Stage | The driving contradiction | A Goal | Means of achieving the goal | The way achieving the goals |
|-------|---------------------------|--------|-----------------------------|----------------------------|
| 1     | Layout quality - reduced designing period | To automate the creating of the layout. | The introduction of computers, development of programming and optimization techniques. The development of methods for solving location problems. | Development of algorithm and program for layout. Reducing the task by choosing the order of placement and pre-orientation elements. |
| 2     | The limited resources of the computer are a large number of users. | To increase the speed of layout programs. To reduce the testing efforts and documentation. | The introduction of external computer devices (displays and plotters), the development of algorithms for computer graphics. | Development of algorithms and programs for control and input of the drawing layout. |
| 3     | Coasts for automation | To increase the use of subsystem in the design. To reduce the work for documentation | The introduction of graphical displays, the development of a standard mathematical software (operating systems), the development of methods of placement and computer graphics. Experience in the development of the software package. | The expansion of the range of solved tasks. The development of alternative algorithms for the solution of similar tasks. Development of programs of data input. Development of standard modules. |

The algorithms of dynamic calculation methods described in this section are implemented as independent programs of narrow purpose, each of those can be translated, compiled and written to an external medium [10].

Programs were made with using standard mathematical software and can be implemented in the form of an application programs package with different sequence of their execution depending on the customer's requests.

The constructed algorithms can be used for dynamic computers calculations and greatly simplify them. Stiffness, inertia and damping properties of the system are determined on the base of individual elements characteristics, subsystems and substructures by the same automatic operations of matrix algebra.

The input information includes topological, geometric and mechanical characteristics. Under the topological one we understand information about the relationship between the elements of the system, without specifying the orientation in space and without determining their physical properties. Geometric characteristics define the relative coordinates of the connection points of the elements, their Euler angles and dimensions. Mechanical properties are the physical properties of the elements: material density, elastic modulus, shock absorber stiffness (damping), etc. Thus, the output information is: recorded in the form of two numerical arrays, the stiffness and the inertia matrices of the system.
Then the main task of the software implementation is the automatic formation of the stiffness and inertia matrices of the complex mechanical system design (figure 1).

**Figure 1.** A block diagram of the calculation programs.

4. Results
The paper proposes a unification methodology for the method of automatic formation of stiffness and inertia matrices of complex spatial structure. The initial information is divided into three groups of parameters characterizing the topological, geometric and mechanical properties of the system.

The interrelation of structural elements is defined in extremely compressed form by means of a graph that represents a set of numbered parts (vertices) [10].

In the computer, the graph is represented as "topological arrays" - the vector of the number of links and the vector of links.

The link vector of the i-th node $\bar{S}_i = (S_{i1}, S_{i2}, ..., S_{in})$ contains the numbers of the nodes connected by the i-node.

The vector of the number of links $\bar{V} = (\bar{V}_1, \bar{V}_2, ..., \bar{V}_n)$ is composed of n integers $l_i$ (n is the number of nodes), indicating the number of links of each node.

A set of n vectors $\bar{S}_i$ is composed as a vector of connections: $[\Sigma] = (\sigma_1, \sigma_2, ..., \sigma_n)^T$. 
The transformation of matrices of stiffness, inertia and damping of structural elements from the local coordinate system in the General one is carried out on block, since this operation is similar [9].

The geometry of the structure is determined by the orientation of the elements with the corners \( \psi, \nu, \varphi \), consecutive rotations around the axes \( x, y, z \) - General coordinate system of the structure to their coincidence with the local coordinate system \( x', y', z' \) factors and the relative points of connection with other elements \( r_x, r_y, r_z \).

Matrices of stiffness, inertia and damping of structural elements are calculated in a local coordinate system for specified mechanical properties, the algorithm is described in [10].

The described method of forming the matrix is relatively simple, easy to implement on a PC and does not require a large memory. It allows to vary the parameters of elements of a mechanical system with optimization of dynamic characteristics of the structure.

Matrices are used to calculate the spectrum of natural vibrations and forced vibrations of a research design.

The transformation of the stiffness and inertia matrices to a common coordinate system for the dynamic model is shown in [10]. The source data for calculating are the bars of the frame, solid body and shock absorbers.

Input, storage and output devices for text and graphic information are used to solve layout problems [11]. Mathematical tool is a set of standard and special programs that provide information processing and design calculations. Information tools are designed for the accumulation, storage and transmission of data. The Central part of the information tools is a database, which is a set of interrelated data stored together [6]. Structural independence and independence on programs that use data allow to expand the database quantitatively (data accumulation) and qualitatively (capacity building at the expense of new applications). These specified properties allow us to identify ways to provide them within the subsystem, determine the functions of the components of the AMS and its composition (table 2). As we can see in then table 2, the core consists of (figure 2): database (with software control and broadcast), critical modules (comprising machine model forming blocks, control, check constraints, valid search decisions), the auxiliary module (provides preparation information for the subsequent design), reducing the module (allowing to reduce the calculation time), the output information (which includes blocks the formation of images and documents).

### Table 2 The composition and functions of the automated subsystem design.

| Given properties of the subsystem | Ways of implementation of the specified properties | The appropriate modules ASD | The functions carried out within framework the subsystem |
|----------------------------------|---------------------------------------------|-----------------------------|-----------------------------------------------------|
| 1. The adequacy of the object and the design process | 1. The choice of project objectives 2. The formalization of functions, objectives and constraints 3. The development of a computer model of the object | 1. Critical modules (units: forming machine model, control, check constraints, valid search decisions) 2. Auxiliary modules 3. Database (together with control units and transmitters). | 1. Getting results that are acceptable in form and precision of geometric objects, constraints, optimality 2. Preparation of information for the subsequent design 3. Storage of information 4. Convenient exchange of information (including documentation and dialogue) 5. Reducing the dimensionality of the task |
| 2. Ergonomics | 4. The choice of solution method 5. Processing of the results calculation 6. The development of input and output model 7. Development of methods of information exchange 8. Automation of the input and output of information 9. Control data 10. Test programs 11. Introduction of alternative algorithms and programs 12. Reduction of machine time calculation | 4. The modules display information (together with blocks the formation of images and documents) 5. Reducing modules | |
| 3. Reliability | | | |
| 4. Efficiency | | | |
5. Summary and conclusions

The detailed structure of subsystems allows us to make it open. In particular, the subsystem, the result of the placement of geometric bodies depends on the method of solving the problem. In some cases, with the same order of bodies placement one method provides a solution, while the another one does not provide a solution in the field of permissible locations. This feature of the problem can be used to ensure the reliability of the system [3].

In the case when one of the program modules does not provide a solution (the inability to find accommodation in the field of acceptable solutions, detection of errors in the program, etc.), switching to an alternative program module can lead to an acceptable result. The possibilities of duplicating software modules are illustrated in the diagram (figure 3).
Figure 3. The scheme of duplication of software modules: a - methods of testing the vertical aiming angle (VAA); b - methods of search of accommodation (HFDP - The hodograph of the vector function of dense placement).

Software for receiving graphical documents should contain a program: select views, sections, dimensions, drawing two-dimensional images; the removal of hidden lines; constructing dimension lines and labels; the reduction of idle passes; the drawing (figure 4).

Figure 4. The scheme of algorithm of a choice of compartment types.
Construction of two-dimensional images is a projecting of devices ribs and forming a shell on the appropriate coordinate plane [5]. Output parameters of the program are vertex coordinate tuples and signs of a broken line forming the drawing. Thus, algorithm output information is a list of vertex coordinates forming the visible outline lines. The major difficulty in making such programs is to place labels and dimension lines in the free field.

6. Summary and conclusions
The technique based on the method of transfer functions allows to determine the level of loads acting on the structure.

The conducted research shows that this approach gives the best results in solving the problem of bench tests of automatic spacecraft structures and can be used to calculate complex mechanical systems of machines and assemblies for various purposes.

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