Simulation installation space of the vehicle to solve the problems of component layout, electrical wiring and wire routing

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Abstract. The presented work is devoted to modeling the mounting space of a vehicle onboard electrical equipment complexes for solving the problems of assembling elements, wiring of electrical circuits and routing of wires. A model of the mounting space of the onboard electrical equipment complex has been developed. Various modifications of on-board electrical equipment of modern vehicles under various restrictions are considered and investigated.

1. Introduction
Onboard electrical equipment complexes of modern vehicles (cars, airplanes, helicopters, etc.), according to systemic features, allow them to be classified as complex systems. According to [1] and the analysis carried out, the onboard electrical equipment of modern vehicles is characterized by the following features [2-4]:
- a large number of interconnected systems, which include a generation system, an electric power distribution system, systems of equipment complexes, etc. Subsystems can also be distinguished as part of these systems, etc.;
- multidimensionality due to the large number of connections between systems: connections for power supply, functional connections between equipment complexes, blocking circuits, etc. They lead to numerous restrictions in the choice of solutions, to the need to adjust technical design specifications and agree on decisions made;
- a multi-level structure (and depending on the circuit, design, installation features, there is a variety of such structures);
- schematic and structural integration of many systems characterized by different nature and physical essence (for example, radio equipment and other equipment);
- multi-mode operation of its individual elements, subsystems, systems and the complex as a whole;
a large mass and length of wire connections, a significant spread in the capacities of electricity receivers;
a clearly defined life cycle, the main stages of which are the development of technical design specifications, substantiation of the main characteristics, design, manufacture as part of a prototype product, testing and fine-tuning of prototypes, serial production, operation and intended use, withdrawal from operation.

On the other hand, the design of onboard electrical equipment complexes of modern vehicles is currently impossible without the use of software systems CAD, CAM, CAE, CALS (PLM) technologies, which is due to the following reasons [5-6]:
- number of new models, modifications and complete sets of vehicles is constantly increasing;
- requirements for the quality of project documents and their compliance with international standards and regulations are increasing, which leads to a large number of engineering calculations;
- structure of onboard electrical equipment is constantly becoming more complex, which leads to an increase in the range and complication of drawings;
- volume of routine work of an engineer increases, therefore the prestige of his work decreases;
- there is an intensification of design work with a shortage of qualified designers, which leads to difficulties in the implementation of projects by traditional methods on time, an increase in errors in documentation.

Existing computer-aided design systems allow solving in a single design space the entire range of tasks for the creation of onboard electrical equipment for modern vehicles: from the development of circuit diagrams to the formation of harnesses and the release of all design documentation in electronic form. But most of them are means of graphic and informational support of the project process. The quality of design solutions here depends largely on the preparedness and experience of the engineer. The existing CAD systems do not solve the problems of optimization, analysis of the quality and reliability of the designed electrical complexes. To solve these problems, it is necessary to develop a mounting space of a vehicle, in which it will be possible to implement algorithms and specialized software for optimizing onboard electrical equipment complexes.

2. Model of the installation space of the onboard complex of the vehicle's electrical equipment
To solve the problems of topological and parametric synthesis of an onboard electrical equipment complex of a vehicle in a computer-aided design system, a real object must be matched with a mathematical model, which will allow formalizing and algorithmizing the design process [7].

The purpose of the mounting space model is to accurately reflect the actual mounting space when solving layout problems, electrical structures placing, electrical circuits wiring while interblock mounting, and electrical circuits routing.

In accordance with the characteristic features of the problems of topological and parametric synthesis, the mathematical model of the electrical circuit for connecting the elements should:
- set the belonging of the elements to the connections up to outputs;
- allow to accurately estimate the number of connections between elements and parts of the circuit;
- not to dictate the order of joining elements, i.e. reflect the factor of unknown connection of the elements' outputs within the same circuit.

In this case, the nature of the connection (input or output) is usually not essential, information is needed about the invariance of the elements' outputs, types, metric characteristics and topological properties of elements and connections.

An undirected lattice graph can be used as a mathematical model of the vehicle mounting space [8]. Each plane of the mounting space is divided into elementary platforms. Each platform corresponds to a vertex of the graph (Fig. 1), which is given by coordinates (s;t).

Two vertices are connected by an edge if a connection can be made between the corresponding elementary platforms, taking into account the metric parameters and topological properties of the elements or structural modules installed in the given mounting space [9].
We define the mathematical model of the space of a truck in the form of a weighted graph:

\[ G = (A, U) \]  

where \( A \) - set of vertices of a graph, \( U \) - multitude of edges.

Graph \( G \) describes a spatial lattice obtained as follows. An orthogonal mesh is applied in the section planes of the vehicle. The choice of the sampling step using the coefficient \( k \) depends on the problem being solved and, on the one hand, is determined by the simulation accuracy, and on the other hand, it is limited by the time of solution on a computer and the volume of its memory.\[10\].

On graph \( G = (A, U) \), you can set longitudinal and transverse routes, elements of onboard electrical equipment, restricted areas. The edges of the graph \( G = (A, U) \) are assigned a "weight" equal to the distance between the corresponding vertices of the points of the real space of the vehicle.

Let us select in the graph \( G \) the pieces \( G^{(i)} = (A^{(i)}, U^{(i)}), i = 1, z \) in which the sets of vertices \( A^{(i)} \subset A \) correspond to the points of the vehicle space located in the prohibited zones, and \( U^{(i)} \) are the subsets of those edges from \( U \) that are connected at least by one end to the vertices \( a_s \in A^{(i)} \), where \( z \) is the amount of pieces. Then the mathematical model of the vehicle mounting space can be represented in the form of a graph \( G_2 = (A_2, U_2) \subset G_1 \), where \( A_2 = A_1 \setminus \bigcup_{i=1}^{z} A^{(i)}, U_2 = U_1 \setminus \bigcup_{i=1}^{z} U^{(i)} \). Model \( G_2 \) is used to solve the problems of arrangement and placement of electrical structures.

In turn, in the graph \( G_2 \) we will form pieces \( G^{(j)}_2 = (A^{(j)}_2, U^{(j)}_2), j = 1, t \), in which the sets of vertices \( A^{(j)}_2 \subset A_2 \) describe the areas occupied by electrical equipment, that is, electrical structures, blocks, etc., and \( U^{(j)}_2 \subset U_2 \) are the sets of edges connected with at least one end to the vertices \( a_q \in A^{(j)}_2 \). Then you can select a part of the mounting space of the vehicle, where external wiring is performed between the terminals of the elements of electrical equipment (Fig. 2).

Also, in the existing model of the vehicle mounting space, it can be noted:
- in three-dimensional space, the configuration of the shortest connecting lines is also represented by a tree;
- tree branches are a set of straight line segments;
- tree branches grow in directions parallel to the x, y, z coordinate axes;
- distance between two points is determined by the formula (orthogonal metric):

\[
d_{ij} = \left| x_i - x_j \right| + \left| y_i - y_j \right| + \left| z_i - z_j \right|
\]  

(2)
Figure 2. Vehicle mounting space with permitted and prohibited zones

3. Results and discussion

According to the general algorithm for the synthesis of onboard electrical equipment and the developed model of the mounting space, methods were proposed for placing structural units, electrical circuits wiring while interblock mounting, forming and routing harnesses.

Let us consider an example of the implementation of the algorithm for the layout and placement of the onboard electrical equipment of an unmanned aerial vehicle on the model of the mounting space. Fig. 3 shows the electrical schematic diagram of the distribution system of an unmanned aerial vehicle (UAV), where $A1...A192$ - protection device; $K1...K192$ - electromagnetic relay; $P1...P5$ - consumer of electrical energy; $Bus L$ – bus of left side of the UAV; $Bus R$ – bus of right side of the UAV. A flexible
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approach to describing the mounting space in the form of graph models can be used for various vehicles and other autonomous objects.

Fig 4 shows the placement of the electrical components without structural layout nodes. It is necessary to layout the elements (protection devices) in the structural node PB1 and PB2, and the elements (electromagnetic relay) in the structural unit SB1 and SB2, and place them according to the new conditions.

![Figure 4. Electrical schematic diagram of the UAV distribution systems](image)

To arrange these elements in constructive nodes, we use the algorithm described in the article [7]. First, we define with elements that cannot be in one subcircuit and with prohibited elements. Fig. 5 shows the layout of the elements of the electrical equipment of an unmanned aerial vehicle after applying the algorithm described.

![Figure 5. Electrical schematic diagram of the UAV distribution systems](image)

4. Conclusion
According to the proposed mounting space of the onboard electrical equipment of the vehicle, a pilot design of electrical complexes for an unmanned aerial vehicle was carried out. The developed algorithms and software products were investigated on a number of modified electrical systems of an unmanned aerial vehicle under various restrictions.

The introduction into industrial operation made it possible to significantly reduce the design time for the onboard electrical equipment of the vehicle by 8-12% as a result of reducing the calculation time and labor intensity during the design. The proposed algorithms and techniques have increased the reliability of calculations due to the elimination of mechanical errors of manual design, promptly make changes to documents, relieve engineers from routine work. Thus, the earliest possible practical results, technical and economic effect are achieved.

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