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STUDY OF THE ELECTROMAGNETIC RESISTANCE OF AN UNMANNED AERIAL VEHICLE UNDER THE ELECTROSTATIC DISCHARGES INFLUENCE

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A B S T R A C T

The paper proposes an approach to predicting the electromagnetic resistance of an unmanned aerial vehicle (UAV) when exposed to an electrostatic discharge. The approach is based on the study of the electromagnetic environment and electromagnetic interference in the interface communication lines of the UAV onboard equipment. The effect of a discharge of static electricity from an engine blade on a UAV fuselage made of a composite material is considered. From the results of the study of the electromagnetic environment in the intra-fuselage space, it can be seen that the strength of the electromagnetic field at the calculation points reaches sufficiently large values, therefore, the electromagnetic compatibility of the UAV onboard equipment may deteriorate. The predicted levels of electromagnetic interference in the interface communication lines will also lead to a malfunction of the onboard equipment of the UAV. Technical measures are proposed that will ensure the electromagnetic stability of the UAV when exposed to a discharge of static electricity.

1. INTRODUCTION

The development of technical systems is due to their introduction into all spheres of human activity and is characterized by intelligence, automation, information content, as well as tougher requirements for reliability, quality of operation, functional safety and electromagnetic compatibility. Violation of the functioning of technical systems as part of the UAV as a result of electromagnetic interactions and influences (i.e. electromagnetic compatibility) is characterized by the terms: sweat of finances, time and life (Balyuk, Kechiev & Stepanov, 2007; Gaynutdinov & Chermoshentsev, 2019). Thus, the violation of the electromagnetic compatibility of technical systems will lead to a violation of the quality of the functioning of the object of their operation.

This paper considers an aspect of the problem of electromagnetic compatibility, determined by electromagnetic influences, namely the electromagnetic resistance of the UAV and the noise immunity of its

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technical systems. The electromagnetic resistance of the UAV is understood as its ability to maintain the specified quality of functioning under the conditions of external electromagnetic influence not related to the principle of functioning of its technical systems. So the electromagnetic resistance of the UAV is determined by the ability to perform the specified functions with the required quality in a given electromagnetic environment formed by external electromagnetic influences.

The relevance of the study of the electromagnetic stability of UAVs under external electromagnetic influences is due to the following facts (Kirillov, 2004; & Chermoshencev & Gaynutdinov, 2015):

- increasing the automation and intellectualization level of the UAV, due to the various types integration of radio-electronic and electronic systems in the closed fuselage space, complicates the electromagnetic environment;
- the use of electronics to control actuators makes these systems susceptible to external electromagnetic influences;
- the complication of the design of the UAV due to the use of composite (carbon fiber, fiberglass, etc.) materials not only complicates the solution of the problem of electromagnetic resistance, but also does not correct the first level of shielding of onboard system during external electromagnetic influences.

Depending on the material, coating, air humidity and wind speed, the fuselage and tail of the UAV may accumulate static electricity. It should be noted the increased possibility of accumulation of static electricity for UAVs made of composite material, which is due to the difficulty of draining the charge into the atmosphere due to the lack of proper conductivity of composite materials (Gaynutdinov & Chermoshentsev, 2016).

Russian (Gizatullin, 2012; Imyanitov, 1970; Potapov, 1995) and foreign scientists and specialists (Garcia-Hallo et al, 2016; Honda, 1999; Likar et al, 2011) made a great contribution to the study of static electrification of aircraft. At the same time, there are no reliable physical dependencies that make it possible to assess the level of electrification of an object, as well as reliable statistical data on its values. Existing data only speaks of the electrification voltage range.

The greatest danger of static electricity is due to its discharges. A discharge of static electricity creates spatial electromagnetic interference electric and magnetic fields of the near zone and electromagnetic fields of the far zone. These interferences can disrupt the quality functioning of the onboard equipment of the UAV.

It should be noted a large number of works aimed at studying the noise immunity of technical systems under the influence of static electricity discharges (Gizatullin, 2012; Komyagin, 2016; & Kechiev & Pozhidaev, 2008). At the same time, the issues of the impact of static electricity discharges on the UAV electronic equipment have not been adequately reflected in the scientific and technical literature. These issues are of greatest interest when composite materials are used in the design of UAVs.

The purpose of this work is to study the electromagnetic resistance of the UAV when exposed to static electricity discharges based on predicting the electromagnetic situation in the intra-fuselage space and the level of electromagnetic interference in its antenna-feeder paths and interface communication lines of the UAV onboard equipment.

2. METHODS AND MODELS FOR RESEARCH

2.1 Research Methods

Studies of the effect of static electricity discharges on UAV onboard equipment can be carried out at three levels of detail (Gaynutdinov & Chermoshentsev, 2018).

At the first level, a study of the electromagnetic environment in the inner space of the UAV fuselage is carried out under the influence of static electricity discharges. The electromagnetic field strength is calculated in the fuselage specific points, which can later be compared with the levels of electronic meance noise immunity.

At the second level, a study of electromagnetic interference in the interface communication lines, communication lines of the UAV power supply network and metallization under the influence of static electricity discharges is carried out. This is how the levels of electromagnetic interference are calculated, which are primarily characterized by duration and amplitude. These EMI values can be compared to the immunity levels of the devices at the respective input/output ports when exposed to static electricity.

At the third level of detail, a study of the noise immunity of a particular type of onboard equipment is carried out by studying electromagnetic interference in interface coupling paths and printed circuit boards when exposed to static electricity discharges in the UAV. So the parameters of electromagnetic interference in the coupling paths of on-board equipment are compared with the elements noise immunity levels.

The conducted studies allow us to propose the following sequence of actions for predicting the electromagnetic resistance of the UAV when exposed to static electricity discharges:

1) Analysis of UAV parameters and onboard equipment. The geometric and electrophysical parameters of the UAV are specified.
2) Development of models for predicting the impact of static electricity discharges. A simulation electrodynamic model of the UAV is being developed. The type and method of electromagnetic influence, parameters of influence are set.
3) Forecasting the levels of the electromagnetic environment (for the first level of study detail) and electromagnetic disturbances (for the second level of study detail).
4) Evaluation of the quality of the on-board equipment functioning under the influence of static electricity discharges. At this stage, the levels of electromagnetic disturbances on the ports of the devices are compared with the levels of immunity of these ports.

It is possible to predict the electromagnetic resistance of UAVs by methods based on analytical calculations, mathematical modeling of electromagnetic processes and experimental studies.

Experimental studies of the impact of static electricity discharges do not allow predicting the electromagnetic resistance of the UAV, experimental research methods are applied only when the object has already been manufactured and is undergoing testing. Analytical calculations do not allow taking into account the peculiarities of the impact of static electricity discharges on the UAV. The most promising method for studying the impact of static electricity discharges is seen precisely in the application of methods for mathematical modeling of electromagnetic processes based on the use of software implementations of numerical methods. This approach seems to be the most effective method for predicting the impact of static electricity. For these purposes, commercial (CST Microwave Studio, FEKO) and free software products (Fu, Xie, & Zhang, 2008) can be used, which allow modeling some EMC problems of technical systems. In simulation programs, as a rule, grid methods are used: the finite difference method in the time and frequency domain, the method of moments, the finite element method, the TLM method, the finite integral method (Chermoshencev & Gaynutdinov, 2015). The studies conducted by the authors R. R. Gaynutdinov and S. F. Chermoshentsev (2017) and comparison of the results of predicting noise immunity using an approach based on electromagnetic modeling, when studying other problems of external electromagnetic influences with experimental data, show discrepancies of no more than 15%, with a complete and correct description of the study object.

2.2 Influence Models

An analysis of the literature (Potapov, 1995) on the impact of static electricity discharges on UAVs allows us to distinguish three types of discharge current:

- discharges of static electricity from the operator during maintenance of the UAV;
- discharges of static electricity from the carrier of the UAV during its transportation.
- discharges of static electricity associated with the operation of the UAV.

The paper studies the impact of a discharge of static electricity from the UAV engine blade. Research is carried out for a discharge current level of 300A, which corresponds to the maximum known levels (Komyagin, 2016).

The discharge current pulse is given by the following expression:

$$I(t) = \frac{U_0}{1 \cdot 10^9 \cdot L_n}[\exp(-2 \cdot 10^7 \cdot t) - \exp(-9{,}8 \cdot 10^8 \cdot t)] \quad (1)$$

where U_0 is the potential of the electrified object, L_n is the inductance of the electrified object, t is the time.

In the work, UAV studies, the fuselage and plumage which is made of a composite material, are carried out. Research is carried out on the first level of detail for electronic and electrical equipment and on the second level for UAV radio-electronic equipment. A UAV with the following parameters is considered: wingspan 3180 mm, length - 3100 mm; fuselage height and width - 380 mm, thickness of material 5 mm, material type layered composite (carbon fiber). The parameters of the fuselage material are described by the Debye formula (parameters at a frequency of 1000 MHz: electrical conductivity - 1.5 S/m; dielectric constant - 7.5) (figure 1).

When predicting the impact of a discharge of static electricity, the placement of on-board electronic meance in the inner fuselage space of the UAV is accurately taken into account. This fact makes it possible to achieve accuracy in the electromagnetic field strength distribution calculations in the UAV intrafuselage space, as well as possible resonance effects. When modeling the impact of a static electricity discharge, the onboard equipment is represented by closed parallelepipeds, repeating the exact geometric dimensions of the onboard equipment corresponding blocks. The onboard equipment blocks materials correspond to the passport characteristics (figure 2).

In work the distribution of the electric and magnetic field strengths over the UAV is calculated. The strength of the electromagnetic field created by the impact of a discharge of static electricity is also calculated at the points shown in figure 3.

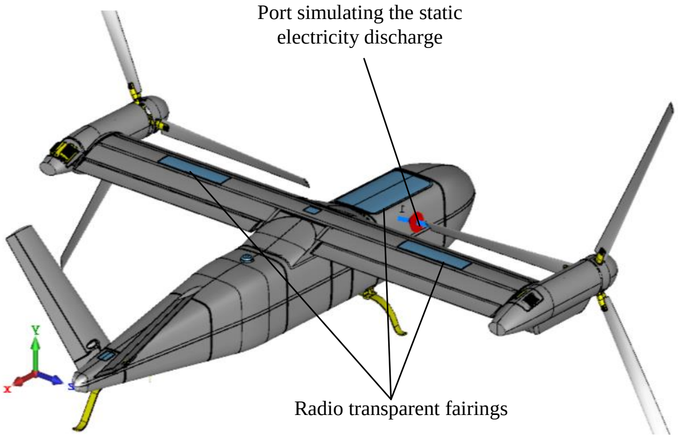


Figure 1. Graphical representation of simulation model the static electricity discharge impact a UAV (Compiled by the authors)

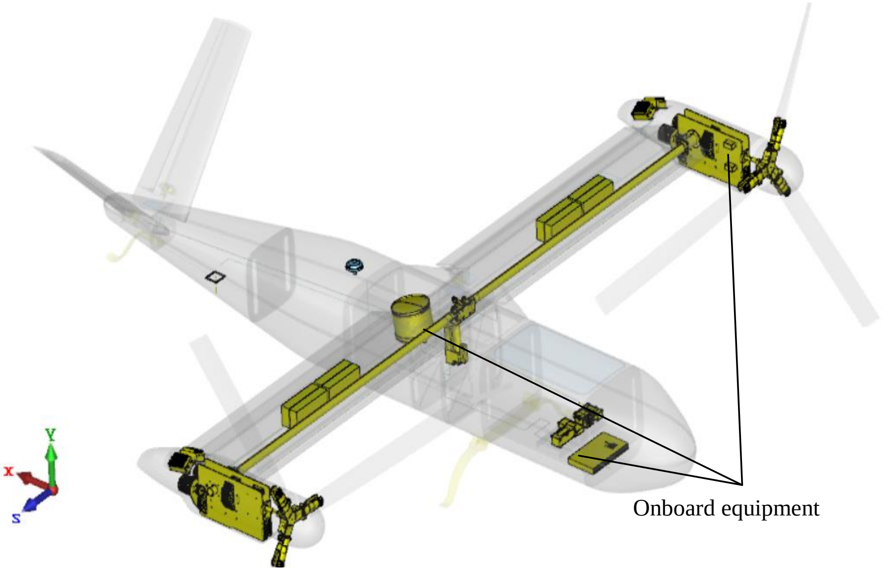


Figure 2. Onboard equipment placement in the UAV (Compiled by the authors)

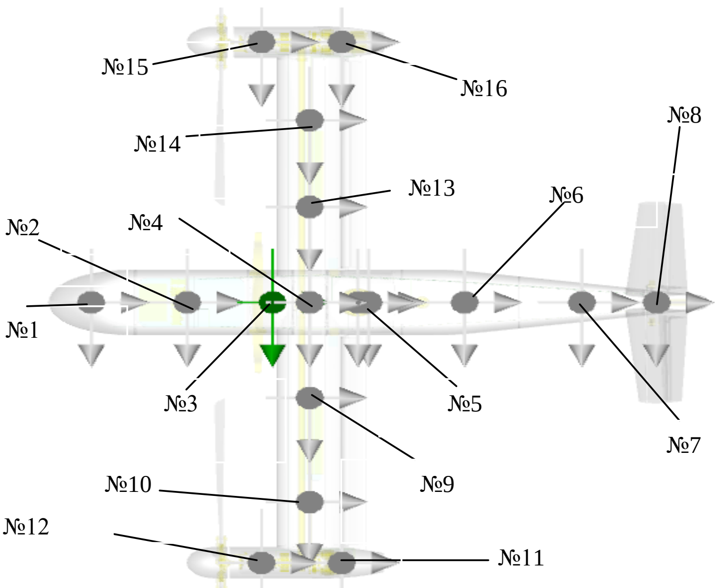


Figure 3. Points for calculating the electric field strength in the intrafuselage space of the UAV

In this work, the electromagnetic disturbances prediction in the circuits of the following interface coupling paths is carried out:

- in the RS-485 interface, length - 9354 mm (FTP cable 4-cat5E);
- in two RS-232 interface coupling paths, length 1863 mm and 1320 mm (FTP cable 4-cat5E) (figure 4).

Electromagnetic disturbances in the circuits of the RS-232 interface coupling paths are calculated with an equivalent load of 120 Ohm. In the case of the RS-485 interface, in addition to the terminations, a 120 Ohm load is connected in parallel to the coupling paths at each connection point of peripheral controllers.

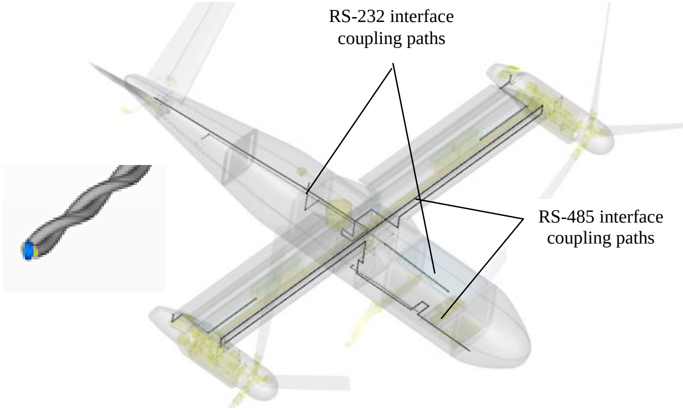


Figure 4. Interfaces coupling paths trace

When modeling the electromagnetic environment and electromagnetic disturbances in interface communication lines of the UAV intra-fuselage space under the influence of a discharge of static electricity from the engine blade, the electro physical and geometric parameters of the UAV are accurately taken into account. The radio-transparent fairings location and their dimensions are also taken into account. When conducting studies of the impact of a discharge of static electricity, the location of the antennas of electronic equipment and their parameters are accurately taken into account.

3. RESULTS

3.1 Electromagnetic environment in the fuselage

When static electricity is discharged from the engine blade in the UAV intrafuselage space, a complex electromagnetic environment is observed, while the maximum values of the electric (figure 5) and magnetic (figure 6) fields are observed at the place by electrostatic strike.

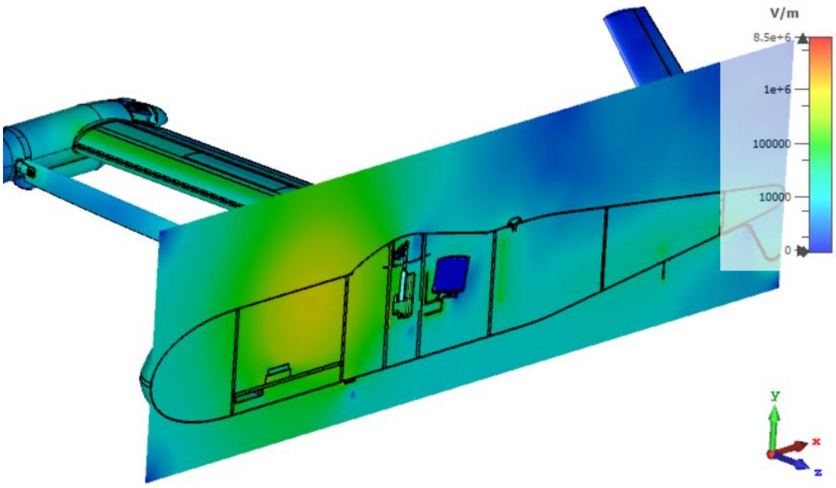


Figure 5. Electric field strength distribution by the UAV a general view

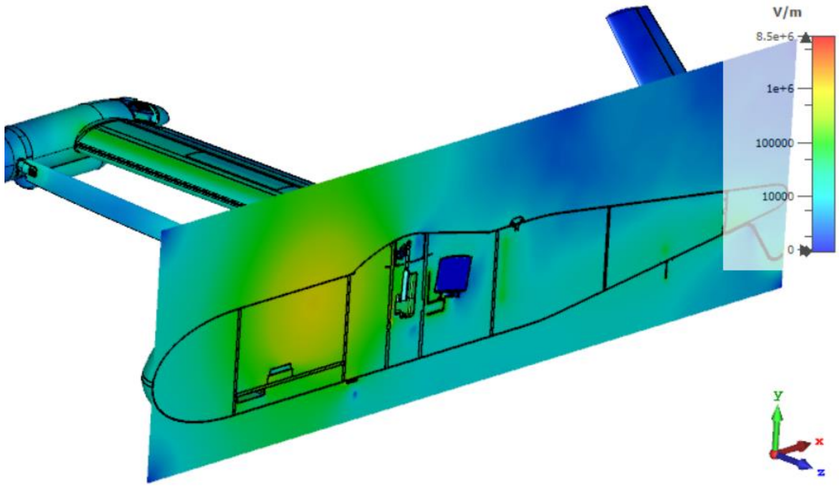


Figure 6. Magnetic field strength distribution by the UAV a general view

The summary electromagnetic field strength values, calculated at the corresponding points (figure 3) of the intra-fuselage space of the UAV, are shown in figure 7.

The calculation points were in the centers of the compartments formed by frames as also in places where electronic equipment is installed.

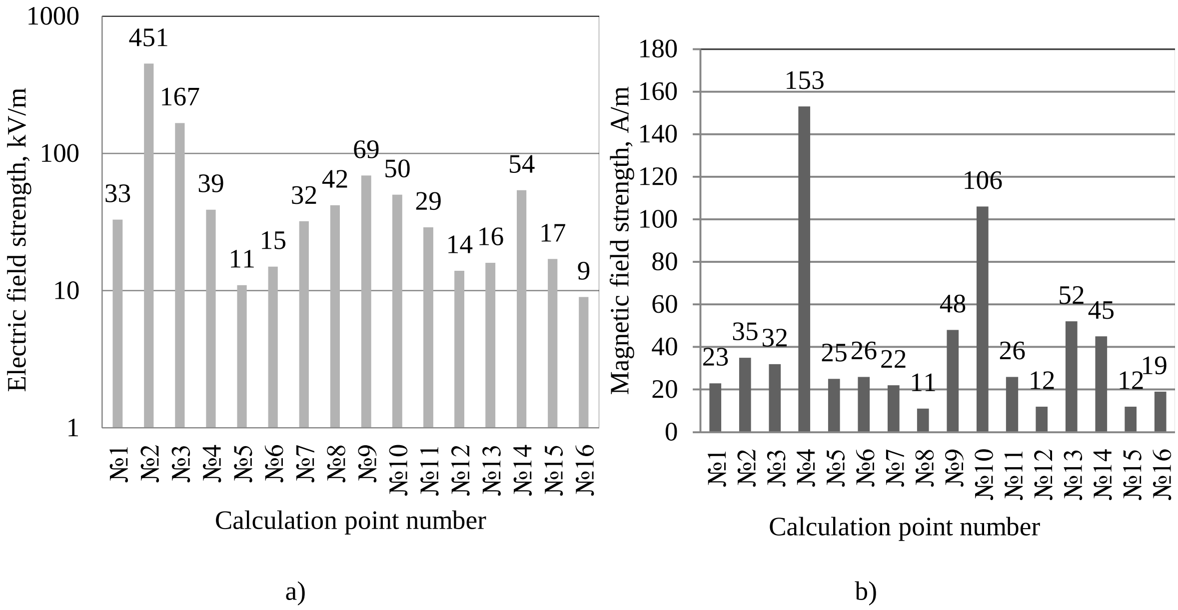


Figure 7. Summary results (a - electric field strength, b - magnetic field strength)

The maximum values of the electric field strength by influence an electrostatic stoke in UAV are observed at points No. 2 and No. 3, which is due to the proximity of these points to the impact epicenter. The highest value of the electric field strength reaches 453 kV/m (figure 8a), and the waveform repeats the shape of the acting voltage pulse. It should be noted that at the other points of the calculation, the wave has a complex shape due to multiple reflections in the UAV inner fuselage space. The magnetic field strength highest value is observed at point No. 4, which is due to the direction of propagation of the fields directed around the point of impact. The level of the magnetic field strength at this point reaches 153 A/m (figure 8b), while the electromagnetic wave has a complex shape.

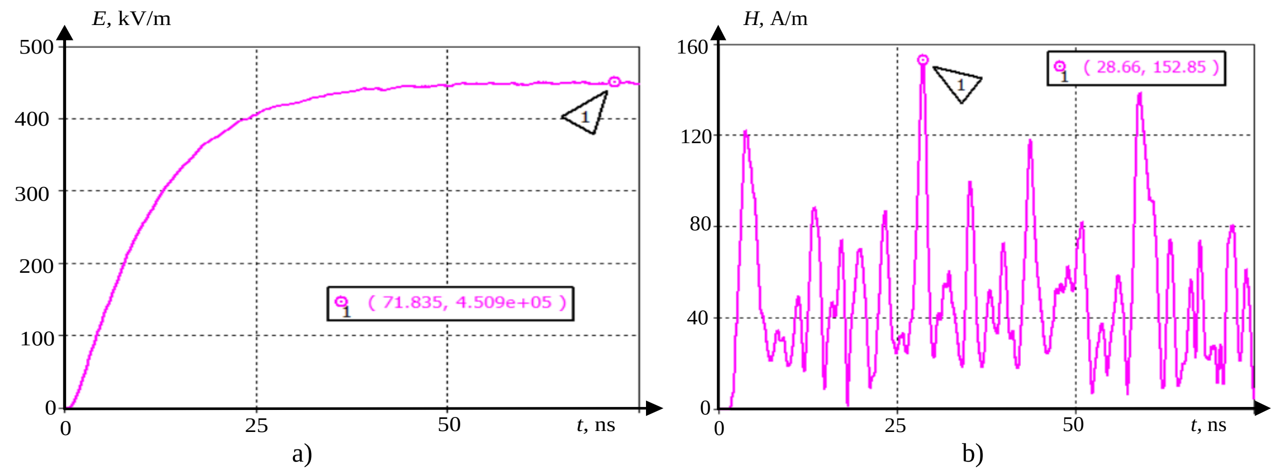


Figure 8. Electric field strength (a) and magnetic field strength (b) changing in the calculation point

The requirements of DO-160G/14G, mil 461 apply to all onboard equipment of aircraft, and depending on the operating conditions of the onboard equipment, the fuselage structure provides different requirements for resistance to electric field strength. So the most stringent requirements of these documents regulate tests with an exposure level of 7.2 kV / m of radio frequency electromagnetic interference with pulse modulation. Normative and technical documents requirements comparison with the electric field strength calculated values are shows that the levels of electric field strength in the UAV intrafuselage space during by influence electrostatic stoke in UAV reach high values and will lead to a violation of the UAV onboard equipment functioning.

3.2 Results of the electromagnetic disturbance study

Electromagnetic disturbance in the RS-485 interface coupling paths under the influence of a static electricity discharge is calculated at the connection points of peripheral controllers and at the line matching points (figure 9). The following points were chosen as control points: point No. 1 and No. 2 correspond at the line matching points; point No. 3 corresponds to the point of on-board equipment connection; point number No. 4 corresponds to the rescue system connection; points No. 5-9 correspond to the peripheral controller’s connection; points No. 1-5 connect on-board equipment to the interface inside the fuselage, and points No. 6-9 in the wings. The summary results of the study of electromagnetic disturbances in the RS-485 interface are shown in figure 8. In general, electromagnetic disturbances can be approximated by a damped sine wave, the frequency of electromagnetic disturbances fluctuation ranges from 60 MHz to 10 GHz, while the lower the electromagnetic disturbances amplitude, the longer and higher the oscillation frequency.

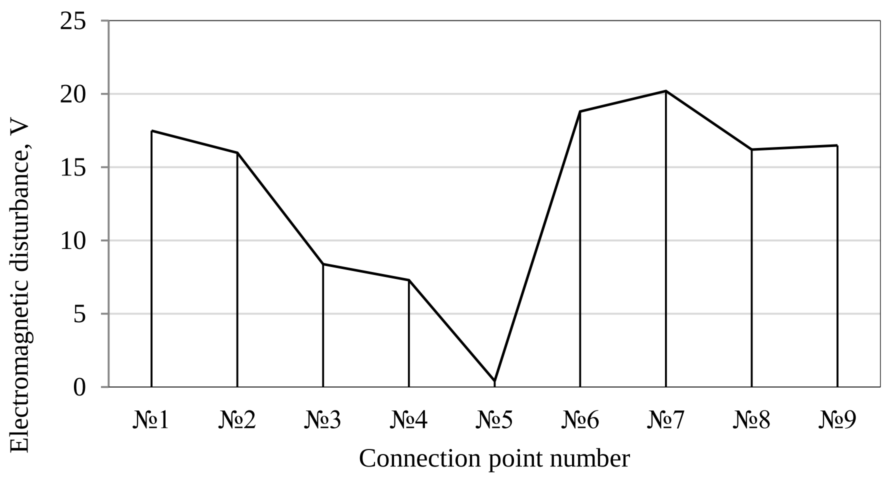
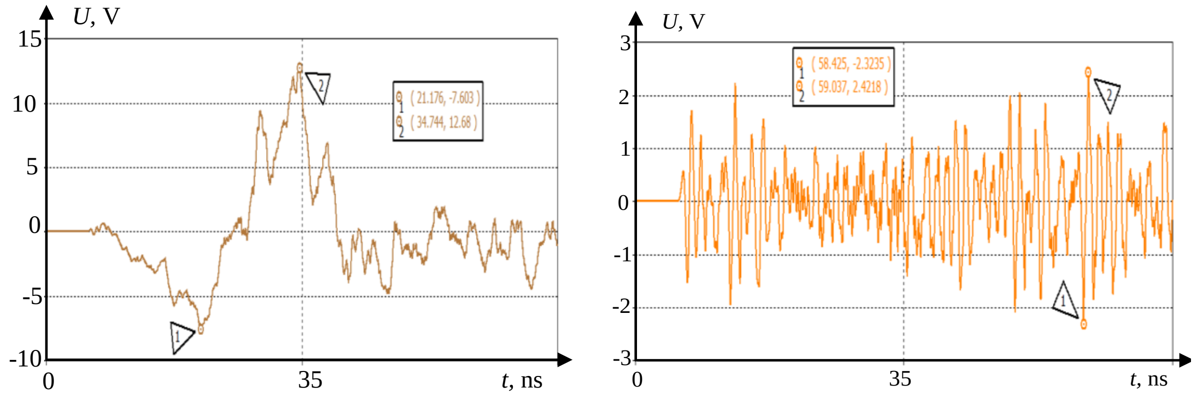


Figure 9. Electromagnetic disturbance research summary results

The study results show that the maximum values of electromagnetic disturbances in the RS-485 interface coupling paths reach values of 20 V and are observed at point No. 7. The frequency of electromagnetic disturbance fluctuations is 60 MHz. (figure 10a). The electromagnetic disturbance maximum levels are observed on the RS-232 interface coupling paths connecting the radio modem and the control system (length 1863 m) (figure 10b). Electromagnetic disturbance level research:

- in the interface coupling paths with a length of 1836 mm - 4.7 V, the electromagnetic disturbance frequency oscillations - 0.71 GHz;
- in the interface coupling paths with a length of 1320 mm - 3.5 V, the electromagnetic disturbance frequency oscillations - 0.3 GHz.



a) b)

Figure 10. Example of electromagnetic disturbance in the RS-485 (a) and RS-232 (b) interface coupling path

In accordance with the requirements of regulatory documents Do-160D (section 20) and Mil-461, the permissible electromagnetic interference levels in the interface communication lines reduced to the input of the onboard system should not exceed 81 dBμV in the frequency range up to one GHz (Department of defense interface standard, 2015; Federal Aviation Administration, 2009). When comparing the regulatory documents requirements of and calculated levels, the resulting electromagnetic interference in the interfaces exceeds the allowable ones and will lead to UAV onboard facilities failures. To eliminate the influence, it is necessary to apply constructive and circuitry methods to ensure electromagnetic compatibility. To ensure the electrostatic UAV onboard systems stability, it is necessary to provide communication lines shielding. If it is impossible to use shielding due to an increase in the object mass, it is advisable to use circuitry methods to ensure electromagnetic compatibility (Gaynutdinov, Suzdaltsev, & Chermoshentsev, 2020). So, to reduce electromagnetic interference in the RS-485 interface, it is advisable to use a band-stop filter for the frequency range from 50 MHz to 70 MHz, and in the case of the RS-485 interface, it is necessary to use a low-pass filter with a cutoff frequency of 0.6 GHz.

4. DISCUSSION

In the work, studies of the electromagnetic environment in the intrafuselage space of the UAV and electromagnetic interference in the interface communication lines were carried out. The impact of the discharge of static electricity formed on the engine blades into the UAV fuselage is investigated. To conduct research, software implementations of numerical methods are used. An electrodynamic model has been developed that allows, when conducting research, to take into account the exact electro physical and geometric parameters of the UAV. The presence of radio-transparent optics, the location of on-board equipment, and the routing of interface communication lines along the UAV are also taken into account. The results of the study show the possibility of violation of the electromagnetic stability of the UAV when exposed to static electricity discharges. Thus, the levels of electromagnetic field strength and electromagnetic interference in communication lines exceed the requirements of regulatory and technical documents.

5. CONCLUSION

The main conclusions of the work are as follows:

1) An approach to the study of electromagnetic disturbances in UAV communication lines under the influence of static electricity discharges from the engine blades is proposed.
2) UAV simulation models have been developed that make it possible to predict the electromagnetic environment in the internal space and electromagnetic disturbance in the interface coupling paths when exposed to static electricity discharges. In this case, the geometric, structural and electro physical parameters of the UAV are precisely taken into account.
3) From the results of the research, it can be seen that a complex electromagnetic environment is observed in the intra-fuselage space of the UAV, and the strength of the electromagnetic

field at the points of calculation reaches quite large values. The obtained values of the electric field strength exceed the requirements of regulatory and technical documents, and, therefore, there may be a deterioration in the electromagnetic compatibility of onboard equipment.

4) The study results of electromagnetic disturbance in UAV interface coupling paths under the static electricity discharges influence are obtained. The study results show that the electromagnetic disturbance values in UAV coupling paths can reach quite dangerous values (up to 20 volts for the example under consideration) for the onboard equipment high-quality functioning.
5) Recommendations are proposed to meet the requirements for onboard equipment electromagnetic resistance based on the circuitry and design methods use.

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