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**MODELING OF SPACECRAFT ELECTRICAL POWER SUPPLY FOR
TRANSIENTS CURRENTS AND VOLTAGES CALCULATIONS AFTER
ELECTROSTATIC DISCHARGE IMPACT**

Master's Programme Spacecraft system design

The abstract of the Master's Thesis

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The thesis work is done at the “Applied physics and space technology” department of Federal State Autonomous Educational Institution of Higher Professional Education «Siberian Federal University».

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INTRODUCTION

Topicality of the work. Driven by plasma flows spacecraft (SC) acquires certain electric charge and, electrical potential relative to the surrounding plasma.

Different parts of the SC surface can be charged differently: because of the different external factors influence on these sites, differences in electrophysical properties of covering materials. And, so called, differential charging, wherein between the certain parts of a SC surface an electrical voltage arises. In some cases the arising potentials can be measured in kilovolts and may lead to electrical discharges on the SC and solar arrays (SA) surface.

SA represents a planar structure. The positive and negative outputs are mutually spaced. After electrical interface mounting a considerable part of it may remain unshielded. Decoupler SA equipment is in close proximity to the unshielded cabling. Whereas from the SA output connectors to the energy convert complex (ECC) input connectors the cabling has solid shielding.

From this perspective, these unshielded parts of SA cabling, that are in close proximity to the dielectric surface of solar cells protective glasses, are the most probable objects, which may be electrostatic discharge - stress-exposed (ESD). This exposure may lead to degradation or failure of the electrical radio component (ERC), which are part of the spacecraft electric power supply (EPS).

Object of the research is the EPS of "Express-AM5" SC.

Subject of the research are transient voltage and current processes in SC EPS.

The aim of the research is to evaluate the transient voltage and current processes impact, that arise in SC EPS when subjected to ESD, on unshielded SA electrical interface.

In course of the research it is necessary to evaluate the impact at different points of the EPS electrical circuit. The most concern are the processes at the ECC inputs and outputs.

Based on the results of the evaluation a decision of feasibility of introducing ESD parry equipment implementation.

Scientific novelty. All results of the dissertation work are new.

The place of the dissertation execution was on-board SC EPS department of JSC Reshetnev "ISS".

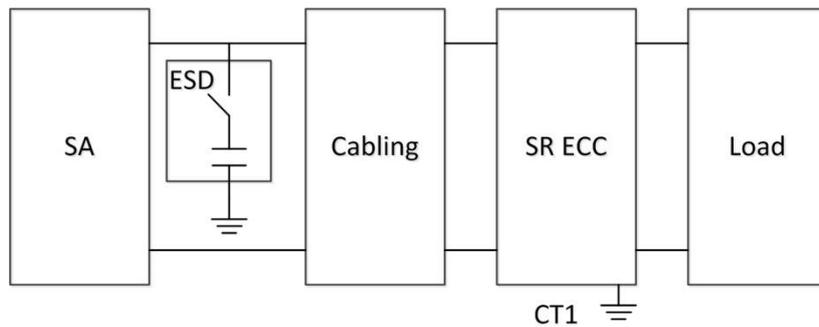
International internship - Institute of Aeronautics and Space , Toulouse , France.

BASIC SUMMARY

In the introduction of the work the topicality of the thesis theme has been substantiated, formulated the research objective and highlighted the practical significance of the results.

In the first chapter the SC EPS block diagram and determination of the equivalent circuit for each block are presented.

Cut SC EPS view is shown on the block diagram (Figure 1).



ESD - electrostatic discharge simulation circuit,
 CT1 - terminal for return ECC bus –SC frame communication,
 SR ECC –shunt regulator of energy convert complex
 Figure 1 - SC EPS block diagram

To determine the amplitude of the transient current and voltage processes in different circuit points and the impact level on ERC of on-board equipment and cabling it is required to perform a mathematical simulation of the ESD impact on the EPS circuit.

To achieve this objective, the following challenge were set and solved:

- defined the equivalent electrical circuits of EPS components (shown on Figure 1);
- simulated the operation of equivalent electrical circuits for each component from block diagram as shown on Figure 1 in dynamic simulation system;
- determined the impact levels on the concerned electrical circuit points (ECC inputs and outputs, ECC units, decoupler SA equipment);

Theoretically conductive elements of SC were selected as the most probably points for ESD impact.

A negative electric charge accumulating on the solar cells protective glasses surface of SA may cause electrostatic effects on the following conductive SC elements:

- on unshielded positive bus or return bus of SA cable;
- on SC case through the magnetospheric plasma.

ESD impact on these points was considered in this research.

The first chapter result is equivalent electrical circuit for the considered part of SC EPS (see Figure 1).

The second chapter presents the results of transient voltage and current processes simulating for the circuit elements and their analysis. Protect schemes application to reduce the amplitude of the EPS impact transients was evaluated.

For transient voltage and current processes simulating for the circuit elements after the ESD impact dynamic simulation system Simulink of software MATLAB 7.10 was used.

The simulation results analysis has demonstrated the excess of accepted values on voltages and currents for ECC ERC. Maximum transient processes occur when unshielded positive bus of SA cable are exposes to ESD. In this case, the SA output voltage ranges from minus 2400 V to plus 1210 V, the current reaches a value of 118 A. At the ECC shunt regulator (SR) voltage ranges from minus 1880 V to plus

200 V. The most considerable weight of the impact on the ECC bear he input SR ECC diodes. The reverse voltage on the input diodes reaches 655 V that may lead to a diode breakdown.

To reduce the impact on ERC of on-board equipment and cabling the following options of the following simple protection schemes were offered:

- have a diode between the positive bus of SA cabling and SC frame toward the positive bus at the ECC SR input;
- have a diode between the return bus of SA cabling and SC frame at the ECC SR input. In this case installations in forward and reverse polarity were considered;
- introduce elements into the scheme at the ECC SR input that change magnetic coupling between the positive and negative buses (transformer) .

The influence on the level ESD impact after the introduction of the magnetic coupling with diodes protection schemes was also evaluated.

The analysis of the obtained results of the protection schemes influence to reduce the transient amplitude in case of ESD impact on unshielded SA bus demonstrated the following:

- a decrease of the amplitude of the impact on the cabling and the ECC SR input almost in all cases of protection schemes applications;
- the best results on decreasing were the amplitude were achieved by introducing of the magnetic coupling together with the diodes into the circuit. The polarity of the diode between the return bus and the SC frame did not matter;
- the effect of protection schemes on the ranges of voltage changing of other circuit points is insignificant.

CONCLUSIONS AND RECOMMENDATIONS

The first experience of mathematical simulating of the ESD impact on the SA – ECC power circuit have led to unexpected results. On the one hand, a real technical samples demonstrate in-flight work without interruptions and degradation. On the other hand, a real simulation showed the current and, especially, voltage effects on power circuits elements, which values are significantly higher than the permissible limits to ensure their normal operation.

This discrepancy may be due to a combination of the following factors :

- mathematical description of the items is not fully equivalent in the physical characteristics of the SA – cabling – ECC circuit objects;
- specified levels of ESD impacts significantly exceed levels of actual impacts;
- actual ESD impact levels do not lead to catastrophic failure due to elements design resources;
- power circuit elements loose their functionality during the ESD impact and restore it after. In addition to that this on-board equipment failure is not observed due to ECC filtering properties and the short impact duration.

In this situation, it seems feasible to perform further analytical and experimental research of this phenomenon. This research requires to be carried out to the following plan and directions:

1) Analytical research:

- a joint parameters and structure analysis of elements mathematical models;
- a joint parameters and levels analysis of ESD mathematical models;
- develop proposals to clarify the parameters and structure of mathematical models and additional computational experiments.

The result of the work should be mapping out initial data for the experiment and corrected model.

2) Experimental research:

Necessary experimental equipment is available i.e.:

- representative SA test panel for the experiment;
- the layout of the ECC input circuits;
- power cabling;
- ESD generator and measurement equipment.

If necessary, protection schemes layouts may be assembled. It is offered to carry out the tests in the SC on-board EPS Laboratory of JSC "ISS".

The outcome of the experimental research should be:

- measured impact parameters;
- refined and verified model;
- proposals on adding, if necessary, extra protection schemes against ESD impact.

If a decision about necessity of protection schemes including is accepted, it's need to determine a protection device placement.

During the internship at Thales Alenia Space (Toulouse, France) Spacecraft complex design knowledge were obtained. Visiting SC manufacture and testing shops allowed to have a scientific discussion with French colleagues on the dissertation topic.

LIST OF WORKS PUBLISHED IN WHICH SIGNIFICANT THESIS

1. Kiselev, P.V. Development of the program and estimation procedure for electrical power convert equipment technical rate of spacecraft electrical power subsystem to compare the different electrical power convert equipment for maximum efficiency of spacecraft electric power subsystem / Intelligence and science: proceedings XIII Intern. young. scientific. conf. / Min. Ed. A.V Khnykin; Zheleznogorsk SFU branch. - Zheleznogorsk, 2013. - P. 30-32.

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3. Pochebut D.V., Kiselev P.V. Modeling of spacecraft electrical power supply for transients currents and voltages calculations after electrostatic discharge impact / Intelligence and science: proceedings Rus. XIV. young. scientific. conf. with int. uch. / Min. Ed. A.V. Khnykin; Zheleznogorsk SFU branch. - Zheleznogorsk, 2014. - P. 138-139.

4. Pochebut D.V., Kiselev P.V. Modeling of spacecraft electrical power supply for transients currents and voltages calculations after electrostatic discharge impact // Science City Research. 2014. № 2. P. 8-12.