

# THE DESCRIPTION OF DYNAMIC SPACECRAFT CHARGING USING MODERN COMPUTER TOOLS

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## Abstract

The peculiarity of spacecraft charging dynamic processes on GEO is determined by the mechanism of suppression of an secondary electron emission by a retarding electrical field and sharply differing timescales of charging processes, including fast change of external conditions (plasma, sunlight, spacecraft orientation). For numerical simulation of development of spacecraft charging processes in time the automatic multistep Gear method specially intended for the decision of "stiff" systems of the ordinal differential equations is used in this work.

The increase of performance modern PC has allowed to use this method for spacecraft models with number of elements more than 1000. The tests show high stability and accuracy of the used methods even at influence of spacecraft model sampling degree. This algorithm is realized in the new version of spacecraft charging tool "Coulomb", constructed as the WWW client - server.

The tools includes the interactive builder of spacecraft models and 3D display system of the information and results of accounts, material properties and space plasma parameter databases, tools for solution of electrostatic and dynamic problems, and scenario manager tool.

The tool use HTML browsers with VRML by plug-in, WWW Apache server with PHP and MySQL extensions, which allows using it in local and remote access mode. The described technique is applied to the of spacecraft charging analysis on a GEO and HEO under various conditions: in the eclipse and in the sunlight, slow or fast rotation spacecraft in sunlight, movement of a shadow on a surface spacecraft, and also at time variation of plasma parameters. The results of spacecraft charging calculation are presented.

## Introduction

By consideration of spacecraft (SC) charging processes which are taking place on geostationary (GEO) or high elliptic (HEO) orbits in conditions of illumination by Sun, and also at sharp changes of the characteristics of an environment, for example at pass of GEO SC through a shadow of the Earth during a spring and autumn equinox, extremely important the realization of the analysis of development of charging processes in time, i.e. decision of dynamic tasks is.

## Dynamic spacecraft charging solution method

Proceeding from physical and mathematical model of GEO and HEO SC charging, described in [1], the change in time of potential in some point of a dielectric surface of SC, concerning potential of a SC metal structure is described by the following equation:

$$\frac{\partial}{\partial t}(U_k(t) - U_c(t)) = \frac{d}{\epsilon} 4\pi j_{total,k}(t),$$

where:  $U_i(t)$  - potential of a dielectric surface,  $U_c(t)$  - potential of the SC structure,  $d$  - thickness of dielectric material,  $\epsilon$  - dielectric permeability,  $j_{total,i}(t)$  - density of a complete current, flowing on a SC surface in point  $i$ .

The basic components giving the contribution to a complete current are the primary currents of plasma, secondary emission currents, bulk conductivity current, and photoelectron current.

As is known, photocurrent, leaving a SC surface, considerably exceeds other currents, however because of small photoelectron energies are small, a retarding electrical field near to a surface [2] effectively suppresses the photocurrent. As a rule, such suppression of a photocurrent simulates by a multiplier dependent on normal component of the electric field on a surface that results in photocurrent sharp changes at small variations of potential.

Other factor determining dynamics SC charging is differing on some orders of characteristic scales of times.

The solution of this task for a complex SC can be carried out only by numerical methods. The system of the ordinary nonlinear differential equations is:

$$\frac{\partial}{\partial t} U_k(t) = \sum_l G_{kl} j_{total,l}(t)$$

This system is "stiff" for considered case of SC charging and consequently requires special methods for the solution. As have shown trial accounts, in this case the GEAR method program [3]. This program includes implicit multistep methods (up to 6 points), iterative predictor algorithms, and automatic choice of a step with the task and error control.

### **Space environment calculations tool**

This software is a set of tools for SC model creation and calculations of spacecrafts interaction with space environment. Different utilities and calculation modules are combined into a WWW server. It includes database management system, tools for charging and radiation calculations along with the 3D spacecraft model building graphics user interface. System ideology is based on the client-server architecture, where all operations with data are performed on the server side and data representation is controlled by of the client side with the help of an ordinary WWW browser. Such model is useful in companies with distributed network of developers and users, it is easy to manage the system and reduces the efforts of administrators and provide effective system security.

- **Object model representation**

Object (SC model) data is stored in the database as a tree-like structure of units and details descriptions. Details are represented by the set of simple bodies like cone, cylinder etc., placed in space and grouped together in units. Each detail or unit have many specific properties, such as materials characteristics, colors and some textual information for clear model representation. Object editor allows to edit details/units data or copy details or a full model data from one location in the tree to another. Also, user can get a list of all created models for better navigation. There are several separated databases in the system, used in one common database management interface. Database tables are: list of materials descriptions, space environment descriptions database, a list of task, performed by the user, object data, specific environment conditions (particles fluxes) database etc. Databases allow using the system in collaborative work of a group of people using user authentication mechanism. Only registered users can use system resources.

- **3D Model builder**

The builder incorporates the system of graphics representation of the model in plane format (PNG image) or VRML (optional) if the client side has VRML support. Object data is represented as an ordinary HTML page with graphics. Special library tools are used to create plane graphics files and VRML files. Color for each detail on the image of the body can be selected separately. 4 views are proposed to the user. The user can determine image browsing parameters, so, there is the possibility to change the size of the selected view or rotate the object model of image in the view. Model data is taken from the object database with corresponding view dimensions. Model builder is the core module of the system and looks like a control center. So, the process of the model creation can be controlled from the main builder window.

- **Calculations**

Calculation tools are represented by the set of mathematical models dealing with the space crafts charging problem solution and absorbed dose calculations that are of under development for many years and are suited and optimized for work under the WWW server control. The scripting language controls all tools. Contributed data is generated by separated scripts, which are connected with the database management system. Calculations are organized as tasks, registered in the database. So, user can remind any task, view or change task data and perform new calculations. Each task uses its own directory for temporary and results files storage, and can be automatically created by the system. Updating when the task is finished, automatically loading the results of of calculations.

- **Results representation**

Results of calculations are represented in a simple HTML form with plane graphics in PNG format and can be printed as an ordinary report. Also, VRML model of the object is available for browsers with VRML support. All results are stored on the server side. Special system WWW-based file manager can be used to manage data in the server-side user directory, which is created during the user registration.

- **System implementation**

System is based on the MySQL database engine. The database management system interface is written on the modern PHP engine with gd extensions for on-the-fly graphics production. System works under the control of Apache web server on the Unix-like operating system (Linux). Security is provided with the user authentication mechanism. The traffic, transferred via the Secure Socket Level browser and server interfaces provide security connection to the server over Internet.

Core system functions are based on the PHP scripts, which are used for data manipulation, database access control, graphics processing and session management. Calculation modules are written on C and Fortran languages, providing optimal performance for described problem solution tasks.

Calculation modules can be updated without any influence on the main system structure and modules.

## Calculation results

The developed technique was applied to account dynamic SC charging processes. As simple SC model is the cylinder, and model real SC is of the complex shape.

In fig. 1 the dependences on time of potentials of two elements located on opposite lateral surfaces the parties of the cylindrical SC are shown which rotate around of a longitudinal axis with the 24 hours period. The direction of illumination - is perpendicular of this axis. In this case the rotation rate is slow, and the time of an establishment of local balance of currents is essential less period of rotation. From figure it is visible, that the potentials of elements located on opposite lateral surfaces of the case, change in antiphase with the specified period. Besides on curves the local peaks appropriate to fast fluctuations of potential are observed. Last effect is connected that in this case model of the cylindrical case is constructed as polyhedrons. The occurrence of local peaks is explained by change of light exposure of separate sides.

The greatest difficulties are caused by a case of rather fast rotation, when the time of an establishment of local balance of currents is comparable to the period of rotation. In fig. 2 the example of dynamical charging rotating with the period 60 is shown from that of a cylindrical body simulated by polyhedron. The rather smooth changes, noticed in figure, of

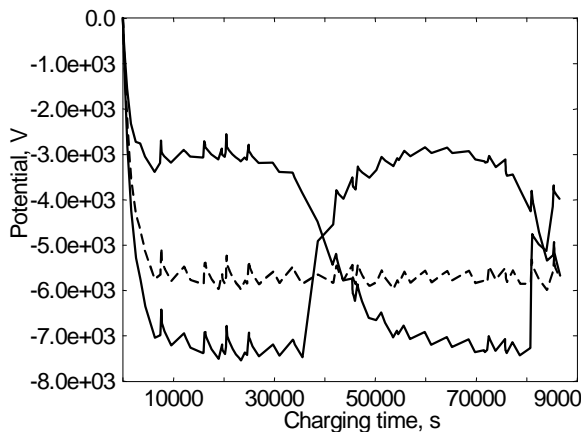


Fig. 1. Electric potential on the opposite sides of rotating cylinder (solid line) and potential on metal (dashed line) vs charging time in the case of the low rotation velocity

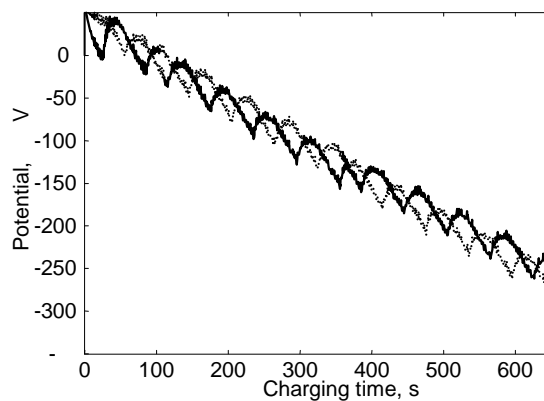


Fig. 2. Electric potential on the opposite sides of rotating cylinder vs charging time in the case of the high rotation velocity

potential correspond to the period of rotation, but also in this case fast fluctuations caused by change of light exposure of sides distinctly are visible. This example shows, that the developed technique of modeling of dynamic charging allows tracing fluctuations of potential of elements of a surface in a wide interval of times.

On Fig. 3-7 the results of SC charging calculation on GEO are shown. The model includes about 30 elementary surfaces and about 850 elementary triangles.

In fig. 3 the dependence on time of potentials of the chosen elements of the lighted and not shadowed elements, and also potential of the SC metal structure is shown. The initial stage of common charging lasts  $\sim 10$  sec, then occurs differential charging of the lighted and shadowed elements. Since SC has the complex shape, and some elements shadow each other. The change of potential in time though carries monotonous character, however are observed non-monotonous potential fluctuation at the lighting elements.

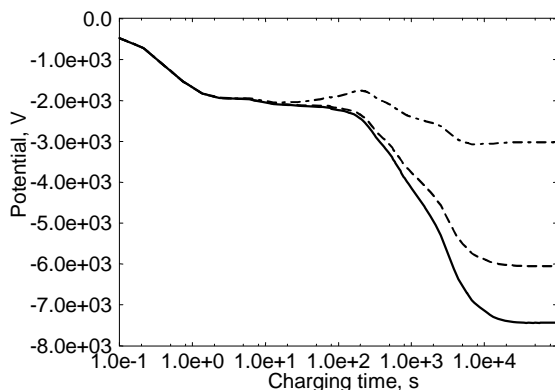


Fig. 3. Electric potential value of various spacecraft surface elements (solid line – dark side of the fuel tank, dotted line – lighted side of the tank, dashed line – potential on metal) vs. charging time

Thus differential charging is caused in the basic change of potential of the shadowed surface ( $dU \sim 5500$  V), and lighted surface all on  $\sim 500$  V.

In fig. 4 and fig. 5 the distributions of potential in SC vicinity for two moments are shown.

In fig. 4 the average stage of charging, and in fig. 5 a late stage of charging are shown. Let's note, that a configuration of an electrical field on the not covered party SC differ for a little these two cases, and on the lighting party the configuration of a field near to a SC surface has in an equilibrium condition much more expressed complex structure. The potential distribution is direct on a SC surface conveniently to investigate using 3D visualization computer methods.

Such of system of representation allows investigating details of distribution of potential Interactively to change a point of supervision, flying around SC, coming nearer and leaving from it.

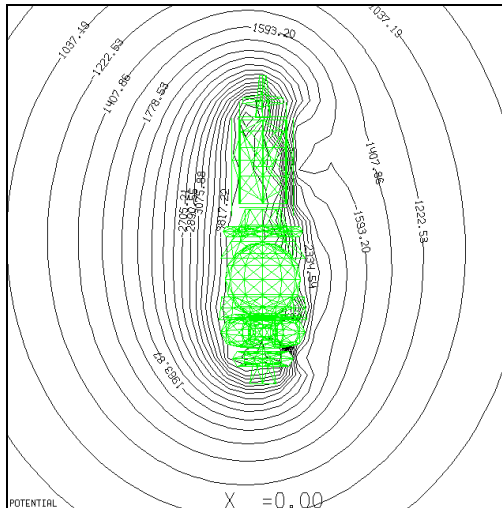


Fig. 4. Configuration of the electric field near the spacecraft on the intermediate charging process stage ( $t=10^3$  s)

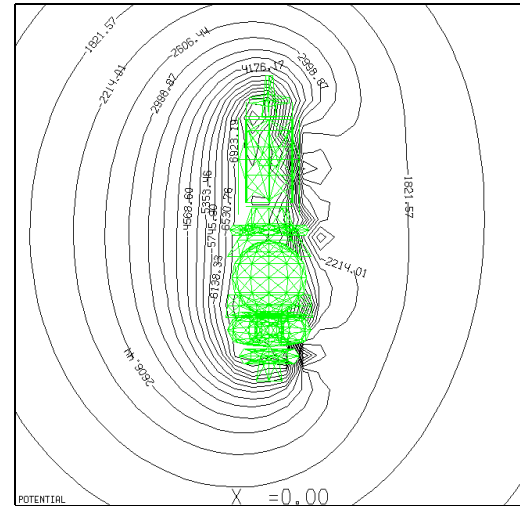


Fig. 5. Configuration of the electric field near the spacecraft on the final charging process stage (steady state)

In fig. 6 screenshot of representation of such results in VRML browser is submitted. The values of potential on a surface are shown by a color code on the screen of the computer and grayscale in hard copy.

In fig. 7 we illustrate dependence of characteristics of a ratio differential and common charging depending on size of a photocurrent. At small value of a photocurrent (the family of curves 1) is shown a short stage common charging (up to  $\sim 2000$  V), accompanying further differential charging. At a photocurrent considerably exceeding plasma current, the dynamic process is defined differential charging. Potentials of the not lighting elements on late stage of charging (equilibrium condition) aspire to each other, while potentials of the SC case in these two cases differ approximately in 3 times.

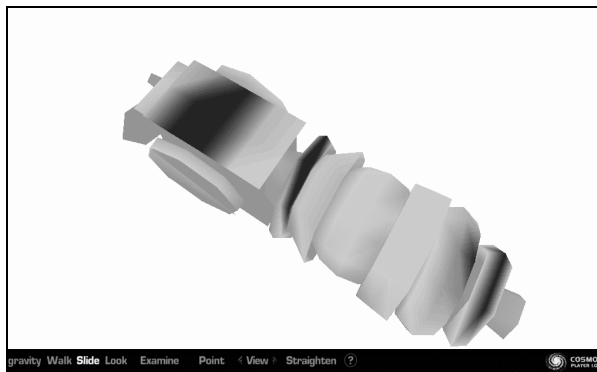


Fig. 6. Screenshot of the 3D visualization of potential distribution on the spacecraft surface on the final charging process stage (steady state): dark grey – low potential, light grey - high potential

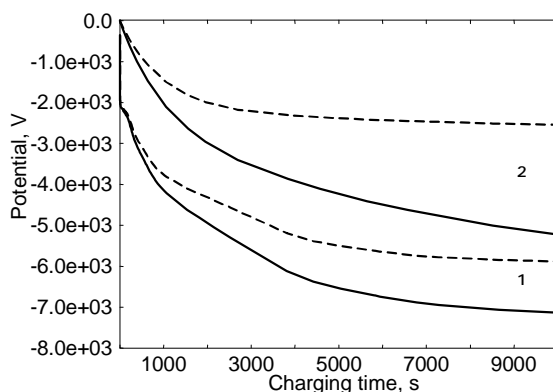


Fig. 7. Electric potential of various spacecraft surface elements (solid line – dark side of the fuel tank, dashed line – potential on metal) vs charging time in two cases: 1 -  $j_{\text{phot}} < j_e$ , 2 -  $j_{\text{phot}} > j_e$

## Conclusion

Thus, developed and tested a method on various simple and real tasks a technique of the solution dynamic charging problem, based on a Gear algorithm, can be used for the analysis of non-stationary SC charging, caused by the various reasons and having various temporary scales.

The developed user interface allows conveniently to describe a soluble task and SC model, and also to display the entrance and target information, including 3D visualization.

## References

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