MODELING OF SPACECRAFT CHARGING DYNAMICS USING COULOMB-2 CODE

Novikov, L.S.(1)(2), Makletsov, A.A.(1), Sinolits,V.V. (1)

(1)Skobeltsyn Institute of Nuclear Physics, Nuclear and Space Research Department, Lomonosov Moscow State University, Leninskie Gory, 1-2,Moscow 119992, Russian Federation
(2)National Research University Higher School of Economics,
Miasnitskaya Ulitsa 20, Moscow 101000, Russian Federation
e-mail: novikov@sinp.msu.ru

ABSTRACT

Description of spacecraft charging dynamic modeling technique which is used in COULOMB-2 code computations in the case of spacecraft surface complex shape is presented.

The spacecraft charging modeling is carried out by numerical solution of differential equations system describing time variation of local electric charge on each of discrete elements of the spacecraft surface.

Computation results obtained for spacecraft charging in hot magnetosphere plasma for several spacecraft design elements in time interval 20 - 10000 s are presented in the paper. The results are compared with similar ones obtained using the NASCAP-2к and MUSCAT codes.

1. INTRODUCTION

Modeling of spacecraft charging dynamic in geosynchronous orbit (GEO) is done in terms of numerical solution of differential equations describing variation in time of local electric charge on each of discrete elements of the spacecraft surface.

In the model, computation of the plasma particles primary currents is done using the Langmuir equations. Computation model includes secondary emission currents caused by primary electron ion currents, and photoelectron emission current.

Comparison of the computation results obtained for spacecraft charging in hot magnetosphere plasma in GEO with similar ones obtained using the NASCAP-2к [1] and MUSCAT [2] codes is done in terms of the *Min-Max* potential values and the spacecraft metal frame potential. The discrepancy is minimal for the frame potential, because the frame electric charge is a mean value arising due to many currents to the frame, so peculiarities of various approaches and models are not significant for this value.

2. MODEL

2.1. Geometry

In Coulomb-2, building of the spacecraft geometrical model with complex non-uniform surface is made using basic surfaces (primitives) and transformation procedures included in the SALOME graphic programs package [3]. The results below were obtained for the NASCAP spacecraft model [1] shown in Fig. 1.

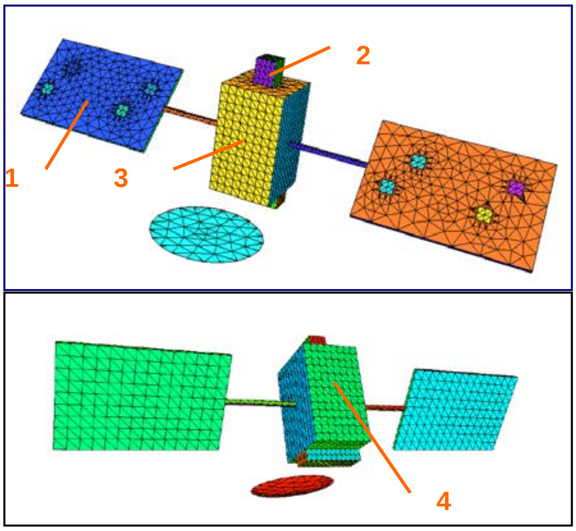

Figure 1. NASCAP spacecraft model. Electric potentials in points 1 – 4 as function of the charging time is shown in Results section

Principle equations of the spacecraft charging dynamics model COULOMB-2 are following:

$$\begin{cases} \dfrac{\partial \sigma_i^{(d)}}{\partial t} = j_i^{(pl)} + j_i^{(se)} + j_i^{(ph)} + j_i^{(cond)}; \quad i \in diel \\ \dfrac{\partial Q_m}{\partial t} = \sum\limits_{k \in met} S_k \left(j_k^{(pl)} + j_k^{(se)} + j_k^{(ph)} \right) - \sum\limits_{k \in diel} S_k j_k^{(cond)}, \end{cases} \qquad (1)$$

$$Q_m = \sum_{k \in diel,met} S_k \sigma_k^{(m)} \qquad (2)$$

where i is the surface element (triangle) number; $\sigma^{(d)}{}_i$, $\sigma^{(m)}{}_i$ are electric charge surface densities on dielectric and metal triangles (see *Electrostatics* section below); S_i is the area of the i-th surface element; $j^{(pl)}{}_i$, $j^{(se)}{}_i$, $j^{(ph)}{}_i$ and $j^{(cond)}{}_i$ is the plasma current density, secondary emission current density, photoemission current density and current density between the dielectric surface element and the spacecraft metal ground on the i-th surface element correspondingly; Q_m is the full electric charge of the spacecraft metal ground.

In equations (1)-(2), $i \in diel$ indicates that the *i-th* surface element has the dielectric surface; $i \in met$ means the same for the open surface of the spacecraft metal ground.

The spacecraft charging dynamics modeling is done in the COULOMB-2 in terms of numerical solution of the following equation system:

$$\frac{\partial \mathbf{U}}{\partial t} = \mathbf{C}^{-1}\mathrm{I} \quad , \qquad (3)$$

where **U** vector consists of potential values on the surface of dielectric elements U_i (i are the numbers of dielectric triangles on the spacecraft surface model) and the value of the spacecraft metal ground U_M ; $\mathbf{C}^{-1}$ is the backward electric capacity matrix; components of the **I** vector correspond to currents in equation (1).

In the Coulomb-2 code, the GEARB software package [4] is used for the problem numerical solution.

2.2. Electrostatics

Computation of the charged particle currents in the vicinity of the charged spacecraft takes into account the structure of the surface (see Fig. 2 below) which contains the following principle elements:
- thin dielectric coatings (e.g. enamels) on the metal frame (in the left part);
- open metal (in the right part).

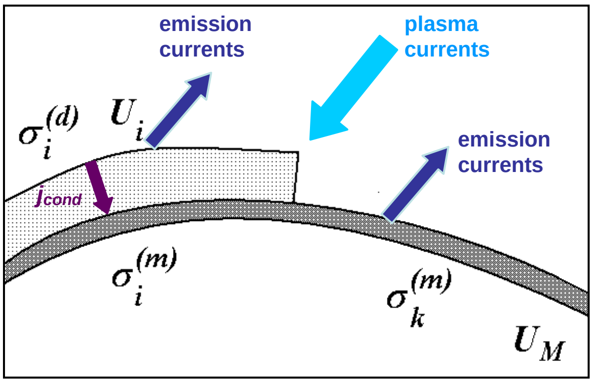

Figure 2. Spacecraft charging electrostatics

Here, principle approximation (valid for very thin dielectric layers) is following:

$$\sigma_i^{(m)} = \frac{\varepsilon \varepsilon_0}{d}(U_M - U_i),\; i \in diel \qquad (4)$$

where ε is the relative dielectric constant of the layer, ε_0 = 8.854·10^{-12} F·m^{-1}.

In Fig. 2, primary and secondary currents included in equations (1) – (2) are shown. Note, that equation (4) is used for computation of the electric field near the surface that is of great importance for correct computation of secondary electron emission and photoemission currents (see [5]).

3. RESULTS

3.1. Computation data

Electric potentials of various spacecraft elements 1 - 4 in Fig. 1 as functions of the spacecraft charging time are presented in the Fig. 3 - 5 for typical charging cases [1].

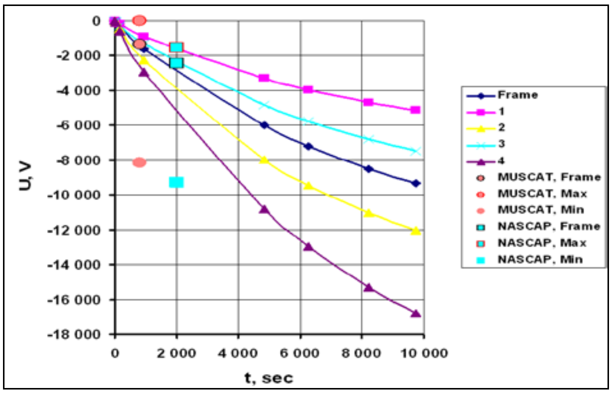

Figure 3. Electric potential of various spacecraft elements vs charging time compared with NASCAP and MUSCAT results [2] in the NASA Worst Case

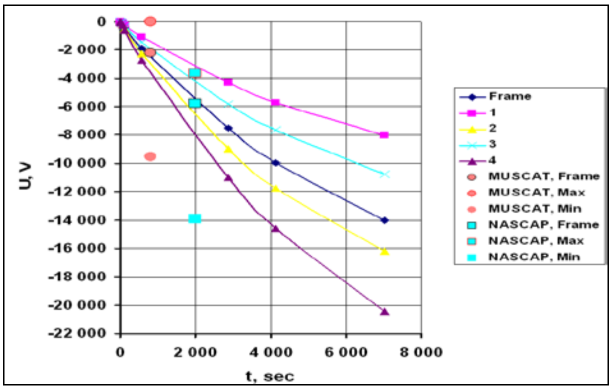

Figure 4. The same, in the ATS-6 case

Comparison of the NASCAP *Min-Max* values [1] with the COULOMB-2 results shows that the discrepancy, especially for the *Min* value is noticeable. For the same charging cases, the *Max* value and the spacecraft metal frame potential values obtained using two codes are in good agreement. Taking into account our modeling experience, we should comment that the extreme potential values (e.g. *Min* values) are very sensitive to fine peculiarities of the model used. For example, various procedures used to build the spacecraft geometrical model may lead to significantly different electrostatic field values near various model elements (triangles) that produces different secondary current values. We showed in [5] that the pecualirity makes significant influence on the local electrostatic potential values.

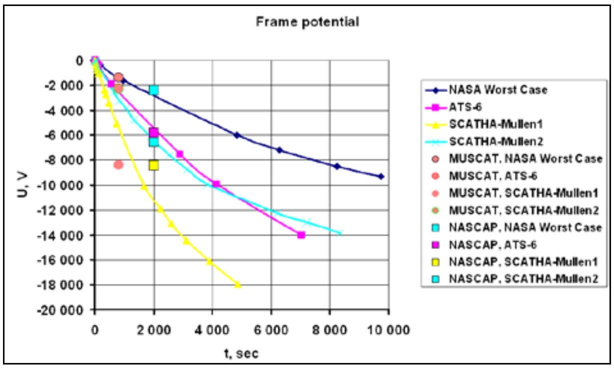

Figure 5. Electric potential of the spacecraft metal frame in the various charging cases

In Fig. 6, the stationary potential distribution picture for which the color code was used for visualization is shown. We use the blue color for low charging values, and red (orange) colors for high charging. Taking into account Fig. 4, we can't but emphasize that the real stationary potential distribution may be achieved at (3-5)·10^4 s. The charging time needed is so high, and true stationary state is expected to be unreachable in the real spacecraft charging conditions in GEO.

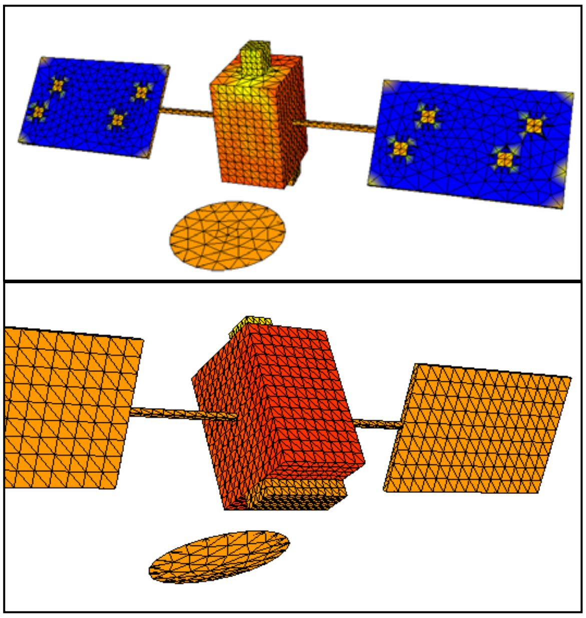

Figure 6. Stationary potential distribution in the ATS-6 case

3.2. Discussion

Comparison of our result with ones presented in [2] reveals good agreement with NASCAP results, especially for the metal frame potential. Potentials of various spacecraft dielectric elements are within *Min-Max* limits computed using MUSCAT and NASCAP. The results reveal that the spacecraft charging in the SCATHA-Mullen1 case [1] is the most dangerous.

The results above show that typical duration of differential spacecraft charging process is ~10^4 s, and stationary potential distributions discussed in [5] may be unreachable in many cases. So, the space environment parameters (e.g. plasma density and temperature) will be function of time in future COULOMB-2 code versions.

4. CONCLUSIONS

The approach to spacecraft charging modeling in GEO based on numerical solution of nonlinear equations describing primary plasma currents and secondary emission currents balance on the spacecraft surface was used to solve the problem of spacecraft charging dynamics.

For dielectric surface elements, approximation of thin dielectric layer on the conducting ground (metal frame of the spacecraft) is used in the model.

Electric potentials on every spacecraft surface discrete element as function of the charging time are computed using the COULOMB-2 code.

Typical time of spacecraft charging in GEO is ~10^4 s.

Potentials of the spacecraft metal frame computed using the COULOMB-2 code are in good agreement with ones obtained using NASCAP and MUSCAT codes.

5. REFERENCES

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