ANALYSIS OF RECOLLECTION AND TRANSFER OF ELECTRONS EMITTED FROM CHARGED SPACECRAFT SURFACE USING COULOMB-2 CODE

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ABSTRACT

Influence of electric field of the charged spacecraft on secondary emission currents on the spacecraft surface is analyzed in terms of computation of secondary electron trajectories.

Dependences of the recollected electrons number on the electric field intensity at various distances from the emission point for standard secondary electron spectra are calculated. Criteria of the secondary electron emission suppression by the surface electric field which is applied for spacecraft charging modeling using the COULOMB-2 code are proposed.

Modeling of the emitted electron trajectories in the electric field of the charged spacecraft having complex surface configuration enables to compute correction factors added to electric current balance equations (electron recollection).

1. INTRODUCTION

Secondary electrons emitted from the spacecraft surface under the impact of hot plasma particles move in the vicinity of the spacecraft. If the spacecraft is electrically charged, the electron motion and the corresponding charge transfer produce influence on the electric charge distribution on the surface. The analysis is possible in terms of secondary electron trajectories modeling.

Computation of the secondary electrons number returned to the emitting surface due to existence of the attracting electric field near this surface enables to introduce the factor of secondary electron emission (SEE) suppression. For higher electron energies (or for lower electric field values), the transfer of the emitted electron to other surface elements is possible (electron recollection). Criteria of the secondary electron emission suppression by the surface electric field which is applied for spacecraft charging modeling using the COULOMB-2 code are proposed.

Modeling of the emitted electron trajectories in the electric field of the charged spacecraft having complex surface configuration enables to compute correction factors added to electric current balance equations (recollection matrix).

The correction mechanisms proposed – recollection matrix and SEE suppression factor – are used for solution of electric current balance equation in the COULOMB-2 code.

2. SEE SUPPRESSION AND ELECTRON RECOLLECTION PROCESSES

2.1. Two cases for analysis

Electric field near the spacecraft surface makes influence on the secondary electron motion, and on the SEE current value. If we have a model of spacecraft built of discrete surface elements (triangles), we make the spacecraft charging modeling in terms of the discrete elements. So, we propose to separate situations depending on the normal electric field value *En* as shown in Fig. 1:

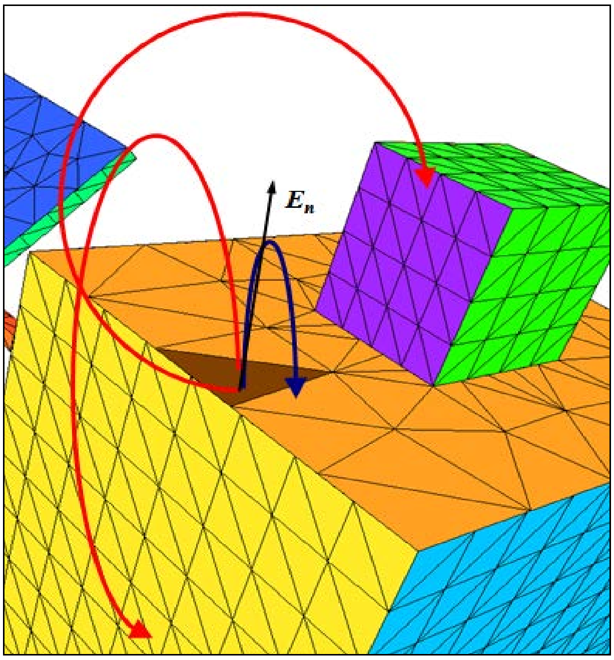

Figure 1. Examples of the secondary electron trajectories in the vicinity of the charged spacecraft

If $En > 0$, we examine the following cases:

- SEE suppression (blue line),
- secondary electron recollection (red lines).

In these two cases, various approaches to the process contribution into the spacecraft charging are needed:

- pre-computed factor to SEE coefficient for SEE suppression,
- particle motion modeling in the vicinity of the charged spacecraft for recollection

Analysis of the cases above includes computation of electric potential values on the spacecraft surface model after discretization.

Note that division of the SEE suppression case and the recollection case depends on the discrete element (brown triangle) size. So, both procedures are is used in COULOMB-2 code, and the modeling results obtained for two models of a spacecraft which have different surface discretization are close to each other.

2.2. Recollection modeling

To compute the particle trajectories in the spacecraft electric field **E** taking into account the geomagnetic field **B,** the method of calculations with non-fixed grid is used in COULOMB-2 code.

Electric field parameters are computed at every trajectory point having $\mathbf{r}_k$ coordinates, and the particle velocity values $\mathbf{V}_k$ are calculated using the time step Δt as follows:

$$\begin{gathered}\frac{\mathbf{r}_{k+1}-\mathbf{r}_k}{\Delta t}=\mathbf{V}_{k+1/2},\\ \frac{\mathbf{V}_{k+1/2}-\mathbf{V}_{k-1/2}}{\Delta t}=\frac{q}{m}\left(\mathbf{E}_k-\frac{\mathbf{V}_{k+1/2}+\mathbf{V}_{k-1/2}}{2}\times\mathbf{B}\right),\end{gathered} \quad (1)$$

where k is the step number, $\mathbf{E}_k = \mathbf{E}(\mathbf{r}_k)$, q and m are particle charge and particle mass.

The algorithm above enables to compute trajectories near the charged spacecraft with higher precision than when using the fixed grid. The time step value is set taking account the velocity and probable flight time of the computation space. The automatic correction of the time step considering the spacecraft sizes and the particle velocity is provided in the model.

The computation above is applied in COULOMB-2 code to solution of current balance equations [1] of stationary spacecraft charging:

$$\begin{cases} j_i^{(pl)}+j_i^{(se)}(En_i)+j_i^{(ph)}(En_i)+j_i^{(cond)}=0; \quad i\in diel \\ \sum\limits_{k\in met} S_k\left(j_k^{(pl)}+j_k^{(se)}(En_k)+j_k^{(ph)}(En_k)\right)-\sum\limits_{k\in diel} S_k j_k^{(cond)}=0, \end{cases} \quad (2)$$

where i is the surface element (triangle) number; 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; $i \in diel$ indicates that the *i-th* surface element has the dielectric surface, $i \in met$ means the same for the open metal surface; $j^{(se)}{}_i(En)$, $j^{(ph)}{}_i(En)$ implies that the currents depend on the local electric field En.

Solving the electric current balance equations [1], we compute primary electron currents $j^{(pl)}{}_i$ on every surface element with correction factors (*recollection matrix)* **C** taking into account recollection of secondary electron currents $j^{(se)}{}_i$ on other surface elements:

$$j_i^{(pl)} \to j_i^{(pl)}+\sum \mathbf{C}_{ik} j_k^{(se)} \quad (3)$$

3. COMPUTATION OF SEE SUPPRESSION

To solve the problem of SEE suppression, we introduce the effective radius of secondary electron capture R_c as shown in Fig. 2:

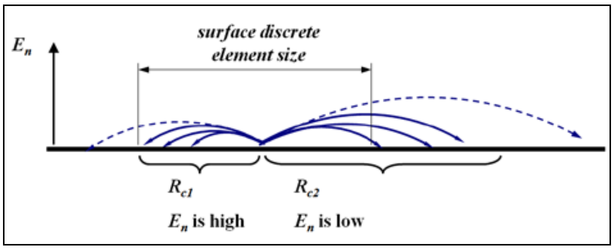

Figure 2. Introduction of the secondary electron capture radius

Now, we compare the R_c value with the discrete element size S:

- $R_c \leq S$ corresponds to SEE suppression;
- $R_c > S$ – electron recollection to other spacecraft surface elements.

Computation of the R_c value for various E_n values was done for secondary electron energy distribution for copper below 10 eV, primary electron energy 550 eV

[2] for 2 cases of the secondary electron capture probability: 65.9% (*one* σ rule) and 90%. In Fig. 3, recollection and SEE suppression regions are shown in different colors.

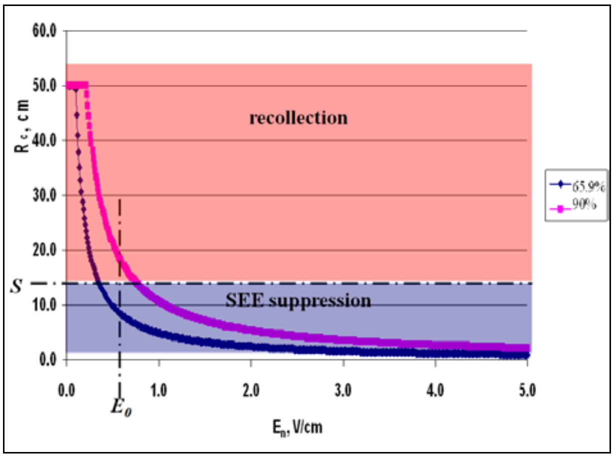

Figure 3. Recollection radius vs electrostatic value on the discrete surface element

The data presented in Fig. 3 enable to estimate the 'threshold' value of the normal electric field E_0 suppressing the SEE process on the surface element with size *S*.

For example, we have *S*~14 cm, so E_0 ~ 0.6 V·cm^{-1}in *NASCAP spacecraft model* [3] built for computation using COULOMB-2 code [1].

Having estimated the E_0 value for the spacecraft model, we use the SEE suppression factors $F(E_n)$ in the current balance equations (2):

$$j_i^{(se)}(E_{ni}) = F(E_n)\, j_i^{(se)}\,, \quad F(E_n) = e^{-E_n/E_0} \qquad (4)$$

where $j^{(se)}_i$ is the value of the secondary electron current density computed in 'standard' manner (e.g. see [2]).

Note that the potential of the charged spacecraft is very sensitive to the SEE coefficient variations. As an example, we compute stationary potential in hot plasma as function of the SEE coefficient variations for various materials [3] and plasma parameter sets. The results presented in Fig. 4 show that the spacecraft potential may alter significantly for small the SEE coefficient variations, especially in the case of high charging.

4. CONCLUSIONS

Secondary electron emission currents on the electrically charged spacecraft surface should be computed taking into account the following physical processes:

- return of the emitted electron to the same surface element which is the reason for the SEE suppression;

- transfer of emitted electrons to the other surface element of the same spacecraft construction element, or to the other spacecraft construction element (secondary electron recollection).

The surface potential is very sensitive to the SEE coefficient value.

Computation of the recollected electron trajectories using the COULOMB-2 code enables to make analysis of the SE suppression and electron recollection influence on the spacecraft surface potential.

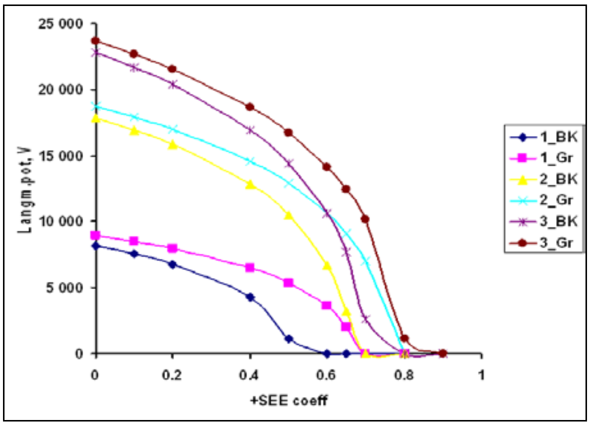

Figure 4. Potential values vs SEE coefficient variations for spacecraft charging in hot plasma with following parameters:
1 – $n_e = n_i = 0.75$ cm^{-3}; $T_e = T_i = 4$ keV;
2 – $n_e = n_i = 1.15$ cm^{-3}; $T_e = T_i = 4$ keV;
3 – $n_e = n_i = 1.15$ cm^{-3}; $T_e = T_i = 8$ keV;
2 – $n = n_i = 1.0$ cm^{-3}; $T_e = T_i = 10$ keV;

5. REFERENCES

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