

PIC Simulations on Charge Mitigation by Plasma Release

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Abstract: In the present paper, we focus on the mitigation process of differential charging of spacecraft in the polar environment by plasma release from the spacecraft surface. In the presence of aurora electron beam, the absolute charging of spacecraft sometimes becomes the order of KeV and the differential charging between the conducting surface of the spacecraft and the dielectric material on the solar panel can become several hundreds volts. To avoid the discharge due to the differential charging at the solar panel, plasma release from a plasma contactor onboard the spacecraft is proposed as one of the effective methods. In the current study, we performed three-dimensional Particle-In-Cell simulations to examine the situation of spacecraft charging and plasma release from the spacecraft surface for the charging mitigation. We particularly examined the transient process in terms of electron/ion flux to the spacecraft surface and the corresponding potential variation in the charge mitigation process by comparing the cases with or without aurora electron beam.

I. Introduction

SPACECRAFT are generally charged due to incoming electron and ion fluxes to the surface. When the net current to the surface becomes zero, the spacecraft obtains a floating potential which is normally negative with respect to the space potential in the ionosphere or polar region because of the larger electron thermal velocity than the ion velocity. Since spacecraft are made of conductors and dielectric materials, the capacitance between the two media can cause differential charging particularly between the dielectric films on solar panels and the conducting part of spacecraft. Particularly in the presence of auroral current, the differential charging is enhanced and may cause the discharge on spacecraft. In the presence of aurora electron beam, the absolute charging of spacecraft often becomes the order of KeV and the differential charging between the spacecraft and the dielectric material on the solar panel can be several hundreds volts. In order to mitigate the differential charging, plasma release from spacecraft is one of the effective methods^{1,2,3,4}. In order to understand the charging mitigation process by the plasma release from spacecraft we started to examine the transient process in terms of electron/ion flux to the spacecraft surface and the corresponding potential variation in the charge mitigation process by performing 3D PIC simulations^{5,6}.

II. Simulation model

Figure 1 shows one example of spacecraft models used in the current simulations. The spacecraft consists of conducting body and dielectric film on the solar panels shown in red and blue in the figure, respectively. We assumed no photoelectrons or

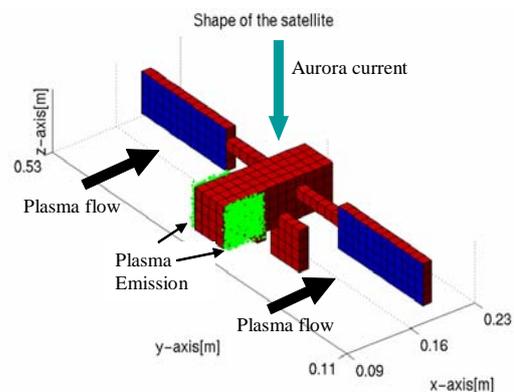


Figure 1. Simulation model

secondary electrons emitted from the spacecraft. This spacecraft system is immersed in the isothermal plasma environment. Since we take the spacecraft as a frame of reference, there is a plasma flow whose velocity is larger than the background ion thermal velocity and smaller than the electron thermal velocity. For simplicity, we have an aurora electron beam which flows along the direction perpendicular to the spacecraft drift motion. We assume that the aurora beam energy is around 100 eV which is relatively small. As will be stated later, we performed another simulation with no aurora electron beam for comparison. We started a simulation with no plasma emission from the body in order for the spacecraft to achieve a floating potential which should be negative because the electron thermal velocity is much larger than that of ions. Plasma is released for the charging mitigation from the both sides of the spacecraft shown in green in the figure. The temperature of the released plasma is the same as that of the background plasma which is 0.5eV while the plasma density is approximately 10 times larger than that of the background plasma. Since the plasma for the release is assumed to be isothermal and is diffused with the thermal velocity, the electron flux outgoing from the spacecraft is much larger than the ion flux.

III. Simulation results

Figure 2 shows the contour plots for electric potential and density of electrons emitted from the contactor obtained in a two dimensional plane. Before the plasma release, the spacecraft and the dielectric part of the solar panel achieved approximately -80V and -30V respectively. In the present model, outgoing electron flux is dominant at the plasma contactor and the emitted electrons are supposed to be accelerated toward the dielectric film of the solar panel due to the potential difference of 50 V. However, it turned out that very few electrons emitted from the

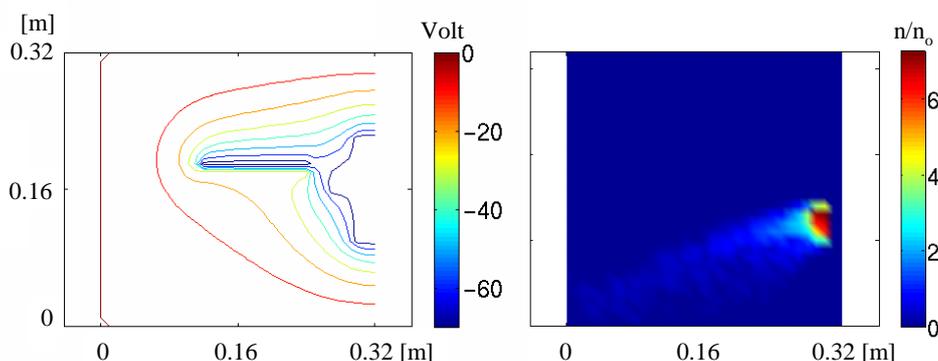


Figure 2. Contour plots for electric potential and density of electrons emitted from the contactor for the case with aurora electron beam

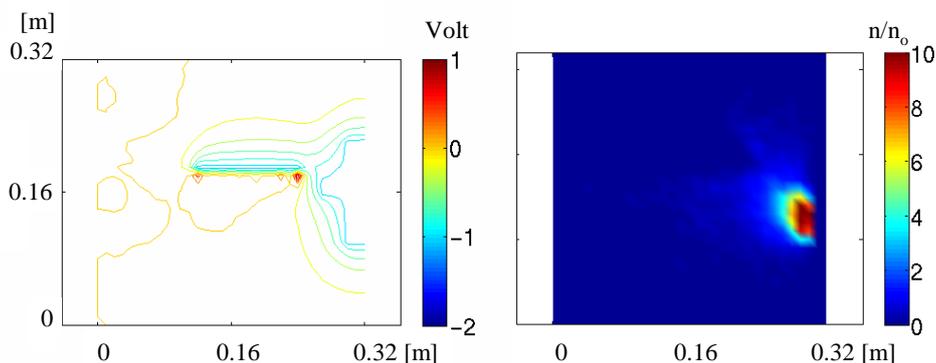


Figure 3. Contour plots for electric potential and density of electrons emitted from the contactor for the case without aurora electron beam

contactor reached the dielectric film, which implies that the differential charging is not mitigated by the electron flux from the contactor in the present case. As shown in the right panel of Fig.2, emitted electrons have no population near the dielectric surface. We will discuss the reason in the later section.

In order to examine another situation in which the absolute as well as differential charging is different from those obtained in the above-mentioned case, we performed a simulation with no aurora electron beam. Figure 3 shows the contour plots for electric potential and density of electrons emitted from the contactor obtained in a two dimensional plane. Since no aurora electron beam is assumed in the present model, the spacecraft charging occurs at very small voltage corresponding to the thermal energy of the background plasma. The conducting part of the spacecraft has approximately -1V and the differential charging between the spacecraft and the dielectric part of the solar panel is also 1V which is very small. Although the differential charging is negligibly small, we performed the same plasma release as we did in the case with the aurora electron beam. Figure 4 shows the temporal variation of potentials of the conducting part of the spacecraft and the dielectric film of solar panel respectively. The plasma started to be released at time=0. Unlike the previous case, the potential difference between the two parts of spacecraft decreased as time elapses and the blue and red lines eventually merged to each other. To see the difference from the previous case, we plotted the temporal variation of plasma flux incoming to the dielectric surface in Fig.5. As clearly shown in red in the figure, the electron flux due to the electrons emitted from the contactor is dominant at the surface and it can contribute to the potential decrease of the dielectric film. Electron population near the dielectric surface is also confirmed in the right panel of Fig 3. Simultaneously the positive charges remain in the spacecraft and cause the potential rise of the conducting part as shown in red in Fig.4.

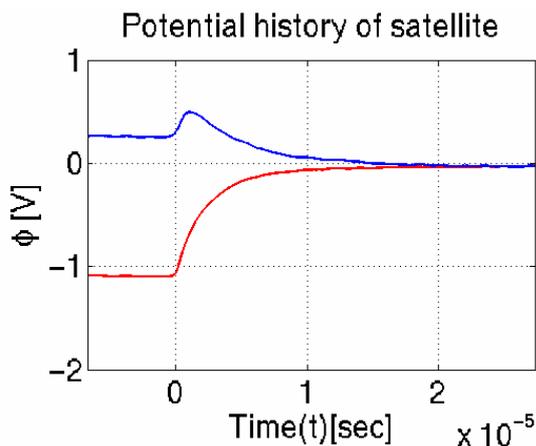


Figure 4. Temporal variation of potentials of the conducting part of the spacecraft (red curve) and the dielectric film of solar panel (blue curve) respectively.

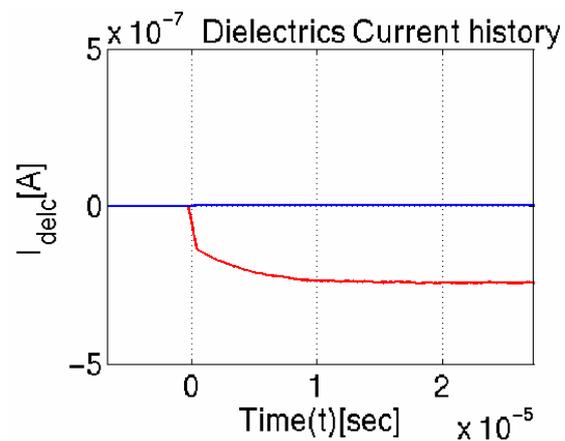


Figure 5. Temporal variation of plasma flux incoming to the dielectric surface. Red and blue curves correspond to electron and ion fluxes respectively.

IV. Discussion

We here discuss the simulation results that the differential charging was not mitigated in the first model in which aurora electron beam is included. In this case, the dielectric film has relatively higher potential than the conducting part of the spacecraft. In such a situation, it can happen that the electrons emitted from the contactor set at the conducting part of spacecraft are accelerated toward the dielectric film and can contribute to the mitigation of the differential charging. As mentioned before, however, the electron flux at the dielectric surface is very little. The right panel of Fig 2 shows the spatial distribution of the emitted electrons from the contactor for the case with aurora electron beam. As clearly shown in the panel, emitted electrons are mostly accelerated along the gradient of the potential structure of the sheath around the contactor. As shown in the right panel of Fig. 3, however, electrons are diffused in the case with no electron beam because the potential drop near the contactor is not so deep. The electron acceleration and the direction can be determined by the profiles of the electric field induced in the vicinity of the

conducting part including the contactor. In the case with aurora electron beam, the conducting part of spacecraft becomes negatively charged approximately around the electron beam energy. This implies that the induced electric field is relatively intense and the dynamics of the emitted electrons from the contactor are very much affected by the electric field. In the present case, this electron acceleration does not direct toward the dielectric surface and therefore very little electron flux is attracted at the dielectric surface. In order for the emitted electrons to be accumulated at the dielectric surface, we may need to set the contactor at the appropriate position in the very vicinity of the dielectric part of the solar panel where differential charging occurs.

V. Conclusions

In order to examine the mitigation process of the differential charging between the dielectric part of solar panel and the conducting part of spacecraft by plasma release from a plasma contactor, we performed three-dimensional PIC simulations. Although the mitigation was not observed in the case including aurora electron beam in the present study, we found one of the significant factors for the differential charging mitigation in the preliminary simulation results. By comparing the results obtained in the case without aurora electron beam, it is speculated that the relative location of plasma contactor and dielectric part where differential charging occurs can affect the dynamics of electrons emitted from the contactor because the electron acceleration depends on the sheath structure and the profiles of electric field at the gradient of the sheath in the vicinity of the plasma contactor. To confirm this factor, we are analyzing the mitigation process by changing the location of the plasma contactor in the simulation model. We will also examine the dependence of temperature and density of released plasma which can also affect the effectiveness of the charging mitigation.

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