ANALYSIS OF DENSE-ELECTRON-INDUCED SPACECRAFT CHARGING IN GEOSYNCHRONOUS ORBIT

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ABSTRACT

The energetic electrons with temperatures of a few tens keV at magnetospheric substorm are mainly responsible for deep surface charging of GEO spacecrafts. However, the dense electrons with temperatures of several keV also could cause serious differential charging. A GEO plasma environment data suggests that these events are rare but not negligible (~0.12 %). We verify their spacecraft potential and plasma parameters using the plasma energy flux spectra. As the result, we find that many of them are unreliable and their occurrence rate downs to ~0.0032 %.

1. INTRODUCTION

Spacecraft anomalies sometimes occur due to discharging arcs caused by spacecraft surface charging in the geosynchronous Earth orbit (GEO). Since the spacecraft charging is influenced by the ambient plasma environment, analysis of the charging environment is important. Cho et al. [1] found that the discharging arcs may occur with differential voltage of as low as 400 V under simulated GEO plasma conditions during a ground experiment. Then Cho et al. [2] statistically analyzed the arcing occurrence rate using the Magnetospheric plasma analyzer (MPA) key parameter data of the Los Alamos National Laboratory (LANL) geostationary satellites and NASCAP simulations. The NASCAP simulation results suggested that dense and hot electron may develop serious differential charging. They shows that the occurrence rate of the dense and hot electron events (n_e>2.5 cm^{-3} and T_e > 3 keV) is small but not negligible (~0.12 %). However, it is known that there are some unreliable values in the MPA key parameter data. Therefore we study these events in detail and estimate their occurrence rate.

2. LANL MPA DATA

The MPA instruments of the LANL geostationary satellites observe the ion and electron fluxes at 40 logarithmically spaced energy channels ranging from ~40 keV/e down to ~1 eV/e [3]. The spacecraft potential, plasma temperature, and plasma density are calculated by using the ion and electron energy flux spectrum data. These calculated values are available as the LANL MPA key parameter data at the NASA Goddard CDAWeb site [4]. However, it is known that there are some unreliable values in the key parameter data. In particular, the incorrect spacecraft potential makes plasma densities and temperatures incorrect.

In this study, we used the LANL MPA data of the five LANL satellites (LANL 1989-046, 1991-080, 1990-095, 1994-084, and 97A), which are the same data that Cho et al. [2] used.

3. DENSE-HOT-ELECTRON CHARGING EVENTS

Cho et al. [2] show that the events with n_e > 2.5 cm^{-3} and T_e > 3 keV could cause serious differential voltages, which are larger than 400 V, using the NASCAP simulations. We call these events as the dense-hot-electron events in this study. Their occurrence rate is ~0.12 %.

To verify the charging potential of the dense-hot-electron events recorded in the key parameter data, we use the ion and electron flux spectrograms, which are available from the LANL MPA website [5]. If the spacecraft charged negative, the ambient ions are accelerated by the spacecraft potential. The ambient low energy ions make a flux peak of the ion spectrum around the spacecraft potential (multiplied by the electron charge) and charging lines on the ion spectrograms. Therefore we can evaluate the spacecraft charging potential as the energy of the charging lines, if they appear on the ion spectrograms.

Fig.1 shows a part of the ion flux spectrogram trimmed from the spectrograms of the LANL 1991-080 satellite on 29 Mar. 2003. The horizontal axis is for the time in UT and the vertical axis is for the energy of the particle in eV (logarithmic scale), the color scale is for the differential flux in cm^{-2} s^{-1} st^{-1} eV^{-1}. We plot the spacecraft potential (multiplied by the electron charge) in the key parameter data with red points on the spectrogram. The dense-hot-electron charging events are recorded in the key parameter data around 12 UT. The clear charging lines are observed in the energy range between 10^2 and 10^3 eV at that time. Since the charging lines appear close to the spacecraft potential (multiplied by the electron charge), we consider that the

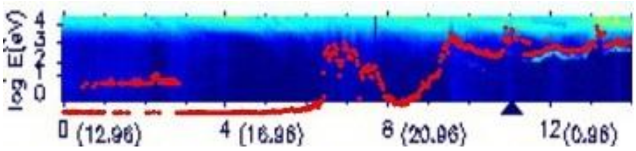

Figure 1. The ion flux spectrogram of the LANL 1991-080 satellite on 29 Mar., 2003. The spacecraft potential (multiplied by the electron charge) is plotted with red points.

key parameter data are reliable in this event. If the spacecraft potential is incorrect, it makes a false dense-hot-electron event as shown in the next section.

For statistical analysis, we tentatively pick up 1000 days, when the dense-hot-electron events are recorded in the key parameter data and can obtain the plasma flux spectrograms on the 991 days of them. We verify the charging potential of the first dense-hot-electron events of the days. As the result, we found that many of them are unreliable but the 27 events (~2.7 %) are consistent with the spectrogram data. Therefore we suggest that their verified occurrence rate is ~0.0032 %.

Fig.2 shows the histogram of their spacecraft potential. Although there are no events lower than -3000 V, the serious different charging could be induced when the spacecraft potential is lower than -1000 V [2]. Fig. 3 shows their scatter plot of spacecraft potential versus for

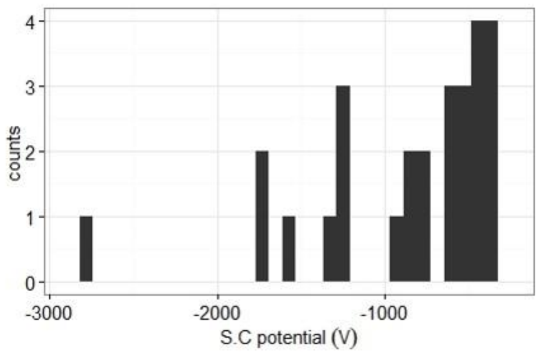

Figure 2. A histogram of the spacecraft potential for the verified events.

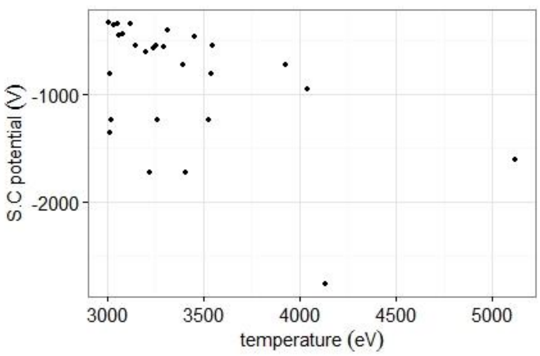

Figure 3. A scatter plot of the spacecraft potential versus the electron temperature for the verified events.

electron temperature. The data points are rather distributed in the plot.

4. PLASMA PARAMETERS CALCULATED WITH FLUX SPECTRUM

To study the dense-hot-electron events in more detail, we need to go back to the original digital plasma energy flux spectrum data. We have obtained the digital plasma flux spectrum data of the LANL 1994-084 satellite on 12 Jan. and 16 Feb. 2003. We can calculate spacecraft potential, plasma density and plasma temperature with them (e.g. Davis et al. [6]).

On 12 Jan. 2003, the dense-hot-electron charging events are recorded in the key parameter data. Fig. 4 shows the time profile of the spacecraft potential in the key parameter data. Fig.5 shows the time profiles of the electron density (upper panel) and the electron temperature (lower panel) in the key parameter data with black lines. The first clear dense-hot-electron charging event is observed at 13:37:55 UT. Its spacecraft potential is extremely negative value compared to the just before and after data points. We cannot verify this event using the ion spectrogram due to their limited graphical resolution. Fig. 6 shows the ion energy flux spectrum at 13:37:55 UT. In the figure, the vertical red line indicates the spacecraft potential (multiplied by the electron charge) in the key parameter data and the black dotted line indicates one count level of the MPA instruments. Neither clear peak nor cut-off of the ions flux spectrum is observed around the vertical red line. Therefore we consider the spacecraft potential is incorrect. This incorrect spacecraft potential makes the false dense-hot-electron event. We newly calculate the plasma density and temperature with the digital plasma flux spectrum data using the appropriate spacecraft potential. We use the average spacecraft potential values between the just before and after data points as the spacecraft potential when the spacecraft potential is incorrect. The calculated electron density and temperature are plotted with red points in Fig. 5. We can detect the false dense-hot-electron events and correct the parameters.

On 16 Feb. 2003, Fig. 7 shows the time profile of the spacecraft potential and Fig. 8 shows the time profile of the time profiles of the electron density (upper panel) and the electron temperature (lower panel). There are no dense-hot-electron events. We verify the spacecraft potential in the key parameter data and confirm that they are almost reliable. We calculate the electron density and temperature with the digital plasma flux spectrum data using the spacecraft potential in the key parameter data and plotted them with red points in Fig. 8 They almost agree with the key parameter data.

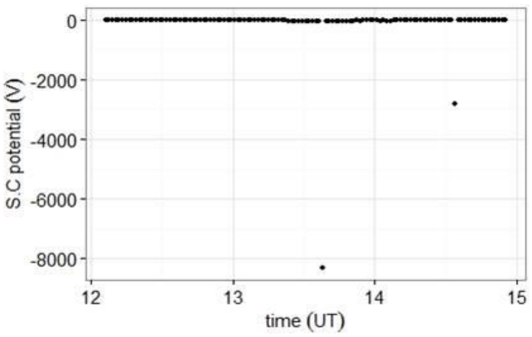

Figure 4. The spacecraft potential of the LANL 1994-084 satellite on 12 Jan 2003.

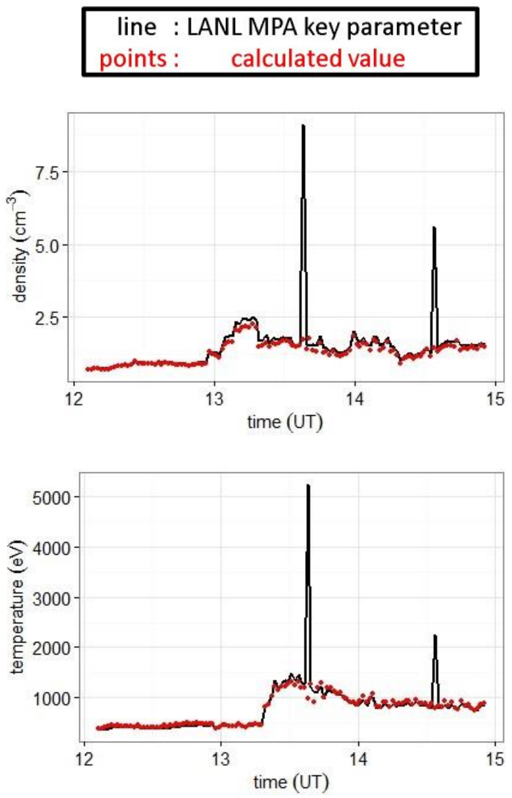

Figure 5. The electron density (upper panel) and the temperature (lower panel) of the LANL 1994-084 satellite on 12 Jan. 2003.

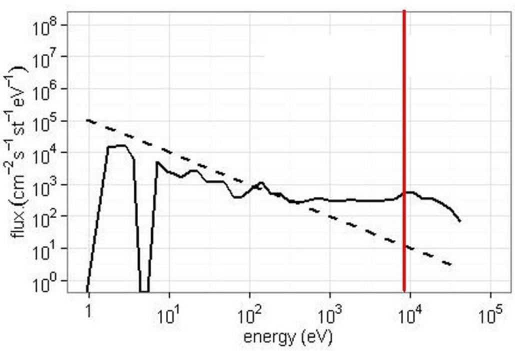

Figure 6. The ion energy flux spectrum at 13:37:55 UT of the LANL 1994-084 satellite on 12 Jan 2003.

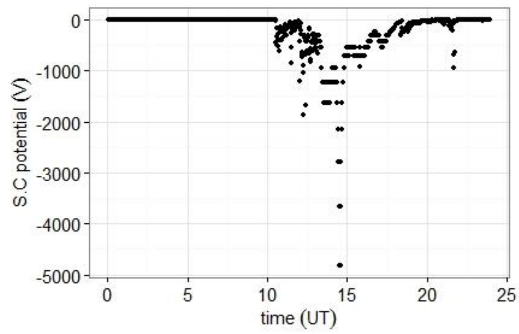

Figure 7. The spacecraft potential of the LANL 1994-084 satellite on 16 Feb, 2003.

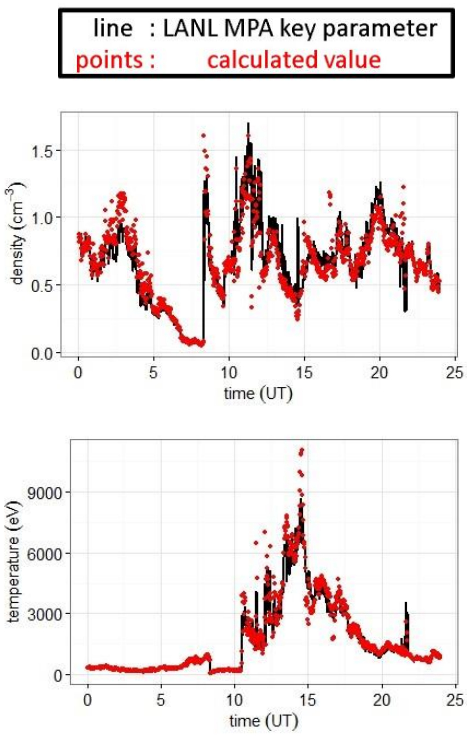

Figure 8. The electron density (upper panel) and the temperature (lower panel) of the LANL 1994-084 satellite on 16 Feb, 2003.

5. SUMMARY

We study the dense-hot-electron charging events (n_e > 2.5 cm^{-3} and T_e > 3 keV) recorded in the LANL MPA key parameter data. We verify their spacecraft potential using the ion flux spectrograms and find that many of them are unreliable but a few events are still reliable. Since the incorrect spacecraft potential makes to the false dense-hot-electron events, we estimate that the occurrence rate of the dense-electron-induced spacecraft charging events is ~0.0032 %.

We can verify the dense-hot-electron events more properly and correct the parameters using the digital plasm energy flux spectra data as shown in section 4.

For more precise and statistical studies, it is necessary to analyze the whole data.

Acknowledgments

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