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Spacecraft-charging Mitigation of a High-Power Electron Beam Emitted by a Magnetospheric Spacecraft

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Extended Abstract

The idea of using a high-power electron beam to actively probe magnetic-field-line connectivity in space has been discussed since the 1970's. It could solve longstanding questions in magnetospheric/ionospheric physics by establishing connectivity and causality between phenomena occurring in the magnetosphere and their image in the ionosphere [1,2]. However, this idea has never been realized onboard a magnetospheric spacecraft because the tenuous magnetospheric plasma cannot provide the return current necessary to keep the charging of the spacecraft under control.

Recently, Delzanno et al. [3] have proposed a spacecraft-charging mitigation scheme to enable the emission of a high-power electron beam from a magnetospheric spacecraft. It is based on the contactor plasma, i.e. a high density neutral plasma emitted prior to and with the electron beam. The contactor acts as an ion emitter (not as an electron collector, as previously thought): a high ion current can be emitted off the quasi-spherical contactor surface, where the space-charge limits are higher than those typical of planar ion beams, and the electron-beam current can be successfully compensated.

In this work, we will discuss our theoretical/simulation effort to improve the understanding of contactor-based ion emission. First, we will present a simplified mathematical model useful for the interpretation of the results of [3]. The model is in spherical geometry and the contactor is represented by only two surfaces (its quasi-neutral surface and the front of the outermost ions), whose dynamics is coupled to the electron beam and the Child-Langmuir law. It captures the results of self-consistent Particle-In-Cell (PIC) simulations with reasonable accuracy and highlights the physics behind the charge-mitigation scheme clearly. PIC simulations connecting the 1D model to the actual geometry of the problem will also be presented to obtain the scaling of the spacecraft potential varying contactor emission area. Finally, results for conditions relevant to an actual mission will also be discussed.

We will also present our latest results on ground-based experimental validation of the physical principles underlying our charge-mitigation scheme. Experiments were performed at the University of Michigan's Plasmadynamics and Electric Propulsion Laboratory (PEPL). A hollow cathode system mimicking the spacecraft was biased to several voltages to examine the effect on ion emission. RPA measurements were performed to measure ion flow velocity and direction as these measurements relate directly to the expected space-charge limit. Planar probe measurements were also made to measure the current emission density around the chamber to determine where ion emission primarily occurred. While a detailed comparison between simulations and experiments is ongoing, these measurements demonstrate that ion currents above those accessible with an ion beam can indeed be obtained with a hollow cathode, qualitatively confirming the results of [3].

References

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