Challenges and Prospects of Coulomb Spacecraft Formation Control

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Abstract

Spacecraft formation flying using Coulomb forces is a relatively new technology for spacecraft control, and may have application for a wide variety of mission objectives including attitude control, collision avoidance, and orbit perturbation correction. Coulomb-controlled formations appear ideally suited for close formation flying in high Earth orbits to perform wide field of view imaging missions using separated spacecraft interferometry. This paper discusses the challenges and prospects of developing spacecraft formations utilizing Coulomb forces. Formation flying on the order of tens of meters is very difficult using conventional ion propulsion methods, because the exhaust plumes will quickly interfere with the delicate on-board sensors. The Coulomb forces would allow the relative motion of satellites to be controlled without such contaminations. Since the rise time of the spacecraft charging is on the order of milli-seconds, very high bandwidth control is feasible. Further, the fuel efficiency of the control makes very long duration missions possible. Non-Keplerian steady-state orbits are discussed which could be used to generate in-plane or three-dimensional static spacecraft formations. The currently examined static solutions are unstable and require the development of a control strategy. Further, the behavior of a two-satellite Coulomb formation with constant equal or opposite charges is discussed at GEO. A nonlinear, orbit elements based feedback law is then introduced to control the relative motion within a two-satellite formation by stabilizing the orbit element differences about desired values. Global stability is analytically shown and illustrated through a numerical example. Asymptotic stability is proven for a semi-major axis only control about a circular orbit. The lack of general asymptotic stability with inter-spacecraft Coulomb forces is discussed.

Descriptors: Motion control, Spacecraft motion, Spacecraft control, Formation flying, Satellite constellations, Satellite orbits, Orbital stability, Long duration space flight, Mathematical models, Circular orbits, Interferometry, Ion propulsion, Fuel consumption, Attitude control, Mathematical analysis