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COULOMB TETHER DOUBLE-PYRAMID SATELLITE FORMATIONS: WITH APPLICATION TO GEO SATELLITE COLLOCATION

Abstract

Due to high economic value of geostationary orbit (GEO), a large number of satellites have been sent to this special orbit for the purpose of communication, broadcasting, and weather monitoring. As a result, GEO grows more crowded than ever, especially at key locations above densely populated areas (Asia-Pacific, Far East, etc.). As of 1 July 2016, 506 operational satellites and hundreds of space debris are tracked along GEO. In order to utilize the limited orbit resources efficiently, the concept of collocating multiple satellites within an assigned window (typically ± 0.1 deg width in latitude and longitude) about the GEO is proposed. Traditional collocation method is based on eccentricity and inclination separations, in which the effort to maintain a safe inter-satellite separation whilst coping with orbit constraints will cause excessive fuel usage.

A satellite formation termed "Coulomb tether double-pyramid (CTDP)" is proposed by the authors to combine the best features of tethered formation and Coulomb formation to collocating the GEO satellites. CTDP formation contains a cluster of satellites and two counterweights, and the center of mass of the formation is prescribed to move along GEO. All satellites, arranged in a ring in the Earth-facing plane normal to the GEO, are charged bodies and virtually connected by Coulomb forces. Each satellite is connected with two counterweights via massless, long straight tether, such that the Earth-facing plane can be maintained by utilizing gravity gradient torques. Coulomb repulsive forces, tether tension and gravity gradient forces can achieve a balance and a collision-safe distance between the satellites can be easily maintained by only adjusting the satellite charges, which is nearly propellantless.

In this study, equations of motion of the system, with prescribed motion of the center of mass of the formation, are derived in the local-vertical/local-horizontal frame via Lagrange equations. The Hamiltonian is derived and both static and spinning solutions are analytically determined. It is found that spinning solutions are more stable than static solutions. In order to initiate the spin easily, only one satellite is equipped with thrusters and a closed-loop charge control strategy is developed to transfer kinetic energy between satellites. The Debye length, which is a measure of the plasma-related charge shielding effect, is about 100 - 1400 m at GEO. If a 50 m inter-satellite separation is assumed, the number of the collocated satellites can be up to about 175, which can definitely satisfy the needs for GEO satellites.