Dynamics of Multi-Tethered Pyramidal Satellite Formation

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We consider the dynamics of multi-tethered satellite formation (MTSF). It is assumed that the formation consists of a main body connected by means of cables with several deputy satellites. In nominal regime MTSF has a shape of a pyramid with its top directed towards the Earth.

If tethers are long enough the described MTSF can be used to maintain the main body in geosynchronous motion (i.e., in the motion with an orbital period of one sidereal day) below the geostationary orbit (assuming that the mass center O of the formation moves in GEO). If tethers are not too close to the formation's mass center O, an "ordinary" geostationary satellite can be placed there. Such a co-location of GEO satellite and MTSF allows many interesting applications.

For the first time 3D MTSF were discussed probably by I. Bekey, who proposed a double-pyramid configuration [1]. To specify formations comprised of a main body and deputy satellites attached to the main body by tethers A. Pizarro-Chong and A.K. Misra introduced the term "hub-and-spoke" [2]. Later the behavior of "hub-and-spoke" formations was studied for different dynamical environment: in circular orbit [3], in elliptic orbit [4], in halo-orbit [5,6] and near collinear Lagrangian points [7].

To keep the tethers taut the formation is spinning, but the combination of rotation with gravity-gradient is insufficient for it and, therefore, the deputy satellites are equipped with low-thrust engines to stabilize the desired dynamics of the system. We propose a control strategy that allows stabilizing the nominal spin state and maintaining the main satellite in a specified (vertical or other) position with respect to system's CoM.

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The system's proper operation is demonstrated by numerical simulation. With this aim we developed the detailed mathematical model of MTSF (an arbitrary number of deputy satellites with massive or weightless tethers is allowed; model of environment includes the Earth gravitational field (with high-degree harmonics), solar radiation pressure, Moon and Sun perturbations).

We also study the optimal choice of MTSF parameters. In this connection several optimization problems are considered: maximizing distances between the system's components (tethers and satellites) to prevent collisions, minimizing control action to decrease fuel consumption, minimizing the mass of deputy satellites relative to the main satellite (assuming deputy satellites are not used for boarding of any payload). The solutions of the optimization problems generally conflict with one another, so it is impossible to find Pareto-optimal configuration of MTSF.

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