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OPTIMAL SPIN RATE CONTROL OF A SPINNING SOLAR SAIL FOR ORBITAL INCLINATION CHANGE

Abstract

Solar sails are a form of spacecraft which deploys a large sail in space and uses solar radiation pressure (SRP) for propulsion. They are expected to be a promising technology for future deep space exploration since they do not require any propellant for propulsion.

For example, "IKAROS" is a solar sail spacecraft developed by Japan Aerospace Exploration Agency (JAXA), and was launched in 2010. IKAROS is a spinning solar sail deploying and stretching its sail using the centrifugal force due to spinning. In past Japanese interplanetary missions including IKAROS, it was proven that the spin-axis direction of a spinning spacecraft is capable of tracking the Sun direction automatically and rotates around an equilibrium direction near the Sun direction due to the effect of the SRP. This phenomenon is called an "attitude drift motion".

The attitude drift motion is determined by the proportion of a torque induced by the SRP and angular momentum of the solar sail. Thus it can be controlled by the spin rate because the angular momentum varies according to the spin rate. Moreover, since the SRP force on the sail, hence the acceleration of the spacecraft, is dependent on the attitude with respect to the Sun, the orbit of a spinning solar sail can be controlled indirectly by the spin rate through the attitude drift motion. This is an interesting and important characteristic of a spinning solar sail. There are, however, no established theories of orbit control by means of the spin rate. It is a thoroughly unique and novel concept proposed by the authors.

In this paper, spin rate control of a spinning solar sail for orbital inclination change is investigated. In general, it takes a considerable amount of Delta-V (i.e. fuel) for inclination changes, and a solar sail spacecraft that uses the SRP for propulsion is suitable for such a purpose. It is assumed that the spacecraft is initially in a circular orbit in the ecliptic plane around the Sun, and the orbital inclination will be changed. The objective of the problem is to maximize the change in the orbit inclination. This is an optimal control problem, and an optimal spin rate control law is determined analytically and numerically. The study proves that the orbital inclination change can be realized efficiently with a spinning solar sail.