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Author: Prof. Ryu Funase
University of Tokyo, Japan, funase@space.t.u-tokyo.ac.jp

Mr. Go Kanno
Tokai University, Japan, kanno.go@jaxa.jp
Dr. Yuichi Tsuda
Japan Aerospace Exploration Agency (JAXA), Japan, tsuda.yuichi@jaxa.jp

CONTROLLABILITY OF PROPELLANT-FREE ATTITUDE CONTROL SYSTEM FOR SPINNING SOLAR SAIL USING THIN-FILM REFLECTIVITY CONTROL DEVICES CONSIDERING ARBITRARY SAIL DEFORMATION

Abstract

A solar sail, which consists of a huge and thin membrane deployed in space that acquires propulsive force only by the reflection of sunlight, is considered to be one of the most efficient propellant-free propulsion systems for future solar system exploration.

Solar sails are grouped into two major classes: rigid-type and spin-type solar sails. The spin-type is a solar sail without a rigid support structure, where the sail membrane is deployed and extended using the centrifugal force of the spin motion. This light-weight solar sail can approximate an ideal solar sail because of its potential to achieve theoretical maximum acceleration determined by the area density of the thin membrane material. However, in terms of attitude control (or steering of the sail), the spin-type has to change the orientation of the large angular momentum of the large spinning membrane and the large amount of propellant consumption may limit the lifetime of the solar sail. Therefore, a propellant-free attitude control system is necessary for spinning solar sail to realize an ideal solar photon sail with the theoretical maximum acceleration, which is the intrinsic advantage of the spin-type solar sail.

The authors had proposed a propellant-free attitude control system for spinning solar sails that utilize only the solar radiation pressure and solar energy. In this system, specially developed thin-film reflectivity control devices that can electrically control their optical parameters such as reflectivity were attached to the edge of the sail. Thus, attitude control torque can be generated by changing the reflectivity of these devices to generate an imbalance in the solar radiation pressure applied to the edge of the sail.

This paper developed a practical attitude control torque model for the system considering arbitrary deformation of solar sail membrane. The authors had previously developed GSSM (Generalized Spinning Sail Model) to explain unique spiral attitude motion of IKAROS which was actually observed in space under solar radiation pressure. The attitude control torque model for the proposed system was derived as an extension of GSSM with time-invariant optical parameters, where the effect of the time-varying optical parameter switching control was expressed as a change of three torque parameters in GSSM. The derived torque model revealed the controllability of the system, that is, the system can generate arbitrary three-dimensional attitude control torque. The proposed system was demonstrated by IKAROS and the on-orbit attitude control results were rigorously investigated to validate the derived torque model.