Attitude and Orbit Control of a Spinning Solar Sail by the Vibrational Input on the Sail Membrane

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An attitude and orbit control method for a spinning solar sail utilizing the active shape control of the sail membrane is investigated. Since the thrust vector of a solar sail generated by the photon propulsion is basically determined by the orientation of the sail to the sun, the attitude of the spacecraft plays a dominant role in its orbital motion. However, the attitude of the spacecraft drifts under the effect of solar radiation pressure (SRP). This is because of the SRP torque, which originates from the offset between the center of mass of the system and the center of the SRP. This SRP torque is strongly affected by the deformation of the sail; such as folding, wrinkles, and deflections [1]. It is almost impossible to predict the exact state of the deformation that arises after the deployment of the sail. Hence, conventional ways of solar sailing needs to estimate the overall shape of the sail membrane on the orbit, and to control the attitude motion which is affected by the uncertain deformations.

This paper proposes a method to actively change the shape of the sail to control the SRP effect on the sail. In case of the spinning solar sail demonstrator IKAROS, launched in 2010 by Japan Aerospace Exploration Agency, the sail membrane is connected with the main body of the spacecraft by tethers. In the proposed method, these tethers are mechanically vibrated by internal actuators to induce certain vibration modes on the sail membrane. When the frequency of the actuators is synchronized with the spin rate of the system (i.e. the frequency is an integral multiple of the spin rate), a static deformation of the sail is observed in the inertial frame (Fig. 1). This results in the constant change of the SRP effect on the sail membrane.

The static deformations can be classified into two types, the first mode deformation and the higher mode deformations. The first mode, whose input frequency is identical to the spin rate, induces a flat, inclined deformation. This corresponds to changing the sail orientation against the main body to perform the orbit control, without needing any attitude maneuver. The superposition of the higher mode deformations on the first mode makes it possible also to alter the SRP torque (Fig. 2). This allows controlling the attitude motion to cancel out disturbances caused by the unknown deformations such as wrinkles. In this study, the vibration modes of a spinning sail are investigated, and the effect of the SRP on the shape-controlled sail membrane is described. Finally, an attitude and orbit control scheme for a spinning solar sail is proposed utilizing the developed shape control method.

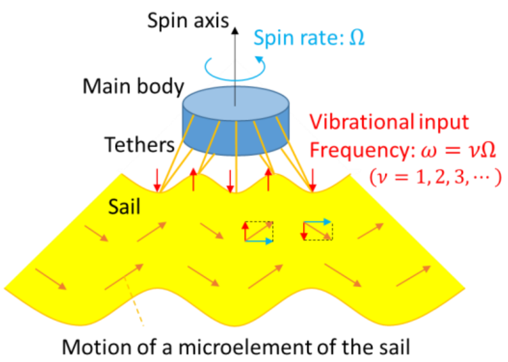

Fig. 1. Concept of making a static deformation

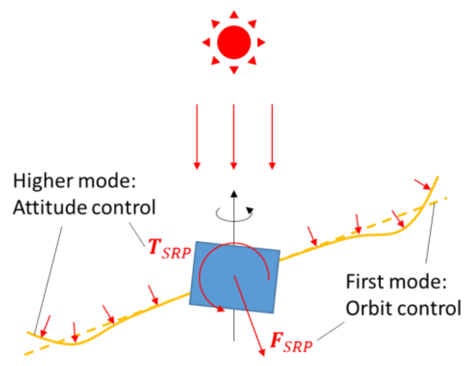

Fig. 2. Attitude and orbit control method

References

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