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Author: Mr. Hideyuki Takahashi
Tokai University, Japan, takahashi.hideyuki@ac.jaxa.jp

Dr. Osamu Mori
Japan Aerospace Exploration Agency (JAXA), Japan, mori.osamu@isas.jaxa.jp
Dr. Masanori Matsushita
Japan Aerospace Exploration Agency (JAXA), Japan, matsushita.masanori@jaxa.jp
Mr. Yuki Takao
Japan Aerospace Exploration Agency (JAXA), Japan, takao.yuki@ac.jaxa.jp
Dr. Hiroaki Tsunoda
Tokai University, Japan, tsunoda@tokai-u.jp
Dr. N. Okuizumi
Japan Aerospace Exploration Agency (JAXA), Japan, okuizumi@isas.jaxa.jp
Dr. Yasutaka Satou
Japan Aerospace Exploration Agency (JAXA), ISAS, Japan, satoh.yasutaka2@jaxa.jp

SHAPE CONTROL OF SOLAR SAIL USING SELECTIVE OPERATION OF MEMBRANE MOUNTING SMA WIRES

Abstract

A solar sail is not only propelled by solar radiation pressure (SRP), but also generates torque using SRP. In particular, when a sail membrane's shape is not flat, unexpected torque due to SRP is generated. In the solar sail demonstrator spacecraft IKAROS, launched by JAXA, the out-of-plane direction torque of the sail increased due to an unexpected deformation of the sail membrane, requiring a substantial consumption of fuel to offset this torque. Given this background, in order to operate a solar sail for long periods and to reduce fuel consumption, it is necessary to control the sail membrane's shape and the resulting SRP torque. Membrane shape control is a common issue not only in solar sails but also in space membrane structures, such as membrane antennas and power sails with thin-film solar cell. A torque control method using a Reflectance Control Device (RCD) was proposed; however, it is disadvantages included restrictions on the control of torque direction, and it is relatively large mass.

In this study, we propose a method to actively control the in-plane and out-of-plane torque by deformation of the membrane's shape using Shape Memory Alloy wires (SMA wires). An SMA wire is a type of soft actuator that contracts when heated. It has the characteristics of being lighter and capable of actuating using less voltage than RCD. In the proposed method, SMA wires are attached at several locations on the sail membrane, allowing the entire membrane to deform out-of-plane at these locations when the SMA wires contract. Furthermore, it is possible to control the membrane shape according to the situation by selectively contracting subsets of SMA wires.

In order to verify this method, we determine the membrane shapes required for generating in-plane and out-of-plane direction torques via numerical analysis. Additionally, appropriate SMA wire arrangements necessary to deform into the desired membrane shapes are investigated using finite element analysis. The membrane shape is controlled so as to generate each directional torque using only a small number of SMA wires. As verification, we experiment with multiple SMA wires attached to a square membrane in the form of a solar sail, measuring the shape of the deformed membrane using a 3D scanner. The membrane

shape deformation is validated in comparison with the analytical results, ultimately demonstrating the usefulness of this control method.