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Electromagnetic panel deployment and retraction in satellite missions

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ABSTRACT

An increasing number of satellites is presently utilizing extensible and deployable large area structures after launch, while in orbit. A deployment and retracting method using an electromagnetic force for extensible panels on satellites is proposed. Using the proposed method, a satellite can retract panels to a much smaller volume to avoid damage from space debris and achieve agile attitude maneuvers. Furthermore, panels can be deployed quasi-statically using electromagnetic forces to reduce the impulsive force exerted on fragile panels in the deployment operation. Finally, numerical simulations were conducted to assess the usefulness of the proposed method using multibody dynamics (MBD). From these simulations, the satellite can deploy 10 panels in 6000 s using 1 A current for a small cubic satellite of 20 cm dimension. Under the same conditions, the satellite can retract the 10 panels in 1400 s.

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1. Introduction

Recently, an increasing number of satellites designed with extensible structures has been launched for various space applications. Generally, satellite dimensions depend on the dimensions of the rocket payload fairing. In order to launch satellites requiring large areas, extensible structures that can be deployed in orbit are commonly utilized in satellite design. Space solar power (SSP) satellite [7] is an example. SSP satellites are space-based solar power plants that generate electrical energy in orbit, and utilize large deployable solar panels. “Furoshiki” satellites are another space applications that deploy a large membrane structure (Shinich [8,9]). The membranes are folded within a very small volume during launch, and achieved a large area in orbits for space applications such as solar power generation, large communication antennas, and large heat radiators. Other satellites utilizing large membrane structures are solar sail satellites, which employ a form of spacecraft propulsion using the solar radiation pressure [6,12,2]. As demonstrated by these satellites, deployable structures can be applied to a variety of satellite missions. Many previous satellites have deployed these structures using a boom, spring, and truss mechanism employing an elastic force. Unfortunately, these systems generally cause satellites to be more complicated, less reliable, and heavier. To ensure the reliability of the deployment, the system can be tested several times on the ground. However, using this system, satellites cannot easily confirm deployment, nor can the structures be retracted after deployment. In some satellites, a motor has been utilized for the deployment. These systems also cause satellites to be more complicated and less reliable. In some satellite designs, these structures are deployed using centrifugal force. Although a deployment system using

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centrifugal force is useful for achieving large area structures in orbit, the attitude of these deployed structures cannot be precisely controlled, and deployment cannot be easily confirmed and retracted after deployment.

A method is proposed to deploy extensible structures using the electromagnetic force generated from electrical wires on the deployed structures ([3,4,3], n.d.) [13]. A concept of deployment using an electromagnetic force generated from superconducting wires has been surveyed in previous studies [10,11]. The focus of these previous studies has considered such matters as thermal and magnetic designs of the system, but has not considered the motion of these structures during deployment operations based on satellite dynamics. In addition, in the current state of the art, superconducting wires can only be rarely utilized in satellite applications. The present study focuses on the application of electromagnetic forces generated from conventional conducting wires for common panel deployment. In this system, a satellite can easily confirm deployment using magnetometers. In addition, the deployed structures can be retracted to a small volume to avoid damage from space debris and for agile attitude maneuvers. Furthermore quasi-static deployment of panels using electromagnetic forces can reduce the impulsive force exerted on fragile panels during deployment operations. In this paper, Section 2 presents an overview of the proposed electromagnetic force deployment and retraction system. In addition, the electromagnetic force generated by electrical currents is formulated using the Biot–Savart law. Section 3 presents numerical modeling of a satellite with extensible panels using multibody dynamics (MBD), and discusses the results of numerical simulations.

2. Panel deployment and retraction using electromagnetic forces

2.1. Overview of the proposed system

As an application of the deployment system, this research focuses on a simple panel deployment satellite, as shown in Fig. 1. Fig. 1(a) shows a simple wiring pattern on the panels. As will be later discussed quantitatively, this wiring pattern can generate an electromagnetic force on a single side only for deployment of the panels because electrical wires that face each other on the two panels create strictly a repulsion force between them. To achieve both deployment and retraction of the panels, the current direction of the electrical wires that face each other must be changed on both sides. Fig. 1(b) shows a possible wiring pattern to generate both attractive and repulsive forces. In Fig. 1(b), electrical currents flowing in the same direction through each wire generate a repulsion force between electrical wires that face each other on two adjacent panels, while electrical currents flowing in opposite directions generate an attractive force. Thus, this wiring pattern can achieve both deployment and retraction.

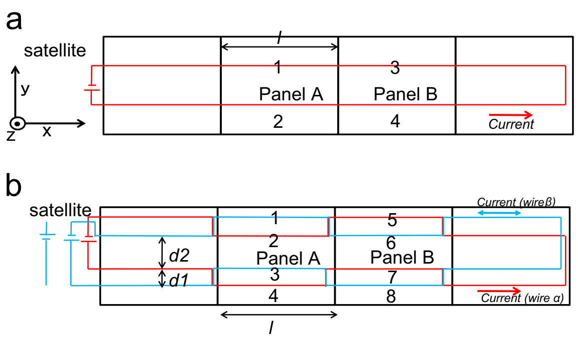

Fig. 1. Wiring pattern on the panels for the deployment and retraction system. (a) Electrical wiring pattern only for deployment. (b) Electrical wiring pattern for both deployment and retraction.

Generally, large area satellites have a higher collision risk with space debris. Thus, extensible structures increase the probability of a collision. In the proposed method, satellites can retract the structures after receiving warning of collision, as predicted by the Joint Space Operations Center (JSpOC). In addition, the satellite can retract the structures to reduce its moment of inertia for agile attitude control. Furthermore, the electrical wires on the extensible panels can be utilized as large magnetic torquers (MTQs) for attitude control in low earth orbit (LEO). Furthermore, magnetic field generated by the wires can confirm the deployment operation using onboard magnetometers. The use of magnetometers would inform the satellite of panel positions, and enable an active control system. Finally, in this method, the satellite can control the electromagnetic force for deployment; thus, the satellite can achieve quasi-static deployment of the panels to reduce the impulsive forces exerted on fragile panels.

2.2. Electromagnetic force model

The electromagnetic torque acting between two current carrying wires can be calculated using the Biot–Savart law. As a simple model, we consider an electrical wire of length 2 L which is bent at the middle point of the wire, as shown in Fig. 2. Here, an electromagnetic torque is exerted on electrical wire 2 by the magnetic field generated by electrical wire 1. Electrical wire 1, having current I_0, generates an axial magnetic field as follows:

$$B_\theta = \frac{\mu I_0}{4\pi} \int_0^l \frac{dz}{r^2 + z^2} \sin\,\phi \tag{1}$$

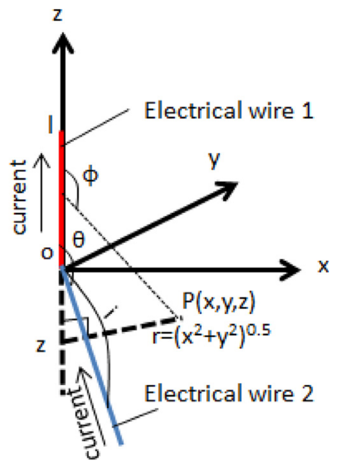

Fig. 2. The geometry of an electrical wire of length 2L that is folded at the middle point of the wire.

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