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Electromagnetic panel deployment and retraction using the geomagnetic field in LEO satellite missions

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Abstract

Increasingly, spacecraft are installed with large-area structures that are extended and deployed post-launch. These extensible structures have been applied in several missions for power generation, thermal radiation, and solar propulsion. Here, we propose a deployment and retraction method using the electromagnetic force generated when the geomagnetic field interacts with electric current flowing on extensible panels. The panels are installed on a satellite in low Earth orbit. Specifically, electrical wires placed on the extensible panels generate magnetic moments, which interfere with the geomagnetic field. The resulting repulsive and retraction forces enable panel deployment and retraction. In the proposed method, a satellite realizes structural deployment using simple electrical wires. Furthermore, the satellite can achieve not only deployment but also retraction for avoiding damage from space debris and for agile attitude maneuvers. Moreover, because the proposed method realizes quasi-static deployment and the retraction of panels by electromagnetic forces, low impulsive force is exerted on fragile panels. The electrical wires can also be used to detect the panel deployment and retraction and generate a large magnetic moment for attitude control. The proposed method was assessed in numerical simulations based on multibody dynamics. Simulation results shows that a small cubic satellite with a wire current of 25 AT deployed 4 panels (20 cm × 20 cm) in 500 s and retracted 4 panels in 100 s.

Keywords: Extensible structure; Deployment; Retraction; Electromagnetic force

1. Introduction

Increasingly, spacecraft require a large area to accommodate their antenna and solar panels during missions. Generally, the dimensions of a spacecraft are restricted by the dimensions of rocket fairing. To meet the large-area requirements, some space structures are launched as separate components and assembled in the orbit. For cost purposes, most of these spacecraft are installed with extensible large area structures that can be deployed in the orbit post-launch (Calassa and Kackley, 1995; Lee, 2005). For example, "Furoshiki" satellites extend a large membrane for large communication antennas, heat radiators, and other structures (Nakasuka et al., 2001, 2006). Other satellites with large membrane structures are solar sail satellites, which propel under solar radiation pressure (Mori et al., 2009; Sawada et al., 2011), and the space solar power (SSP) satellite (Nagatomo, 1996). The latter was proposed for space-based solar power plants that generate electrical energy in the orbit. Large-area coverage is usually provided by large membranes or extensible panels. Some researchers have adopted an extensible structure that increases the air drag during deorbiting (Cosmo and Lorenzini, 1997). To

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generate an effective propulsion force, the satellite needs an electrodynamic tether more than several hundred meters long, which is difficult to install without a deployable system. Deployable structures are also very useful for small sized nano- and micro-satellites, which are generally very restricted in mass and spatial dimensions (Santoni, 2014; Santoni et al., 2014). The 8.5 kg nano-remote sensing satellite PRISM (Pico-satellite for Remote-sensing and Innovative Space Missions) (Komatsu and Nakasuka, 2009; Inamori et al., 2011) achieves long focal length by an extensible boom. This nano-remote sensing satellite was launched in 2009 and successfully obtained high-resolution earth images from a height of 20 m. ESTCube-1 is an Estonian student Cubesat whose mission objective is to perform the first on-orbit experiment of E-Sail (Electric Solar Wind Sail). In this mission, a 10 m tether for E-sail was deployed by a centrifugal force with a deployment system based on a piezoelectric motor (Lätt et al., 2014; Slavinskis et al., 2014). As indicated above, deployable structures have been installed in a variety of satellites, which expands the possibility of space applications. Extensible structures on satellites are typically operated under elastic forces generated by a boom, spring, and truss. Despite constituting the usual deployment method, these systems complicate the satellites and reduce their reliability. In particular, because the fragile panels are deployed at fast speed, they are vulnerable to damage by the strong impulsive forces. The satellite also needs additional sensors or cameras to detect the deployment result. Furthermore, once extended by these mechanical structures, the panels cannot be retracted. Some satellites adopt a motorized deployment mechanism, which again complicates the satellites and renders them less reliable. A novel deployment system based on electromagnetic forces has been recently proposed (Inamori et al., 2012a,b, 2015; Sugawara et al., 2013). In this method, the current flowing through electrical wires placed on a panel interacts with the electrical wires placed on adjacent panels, enabling panel deployment and retraction. Although the proposed method is useful for quasi-static deployment and retraction of extensible panels, the weak electromagnetic force is easily disturbed.

To increase the magnetic force, this study proposes a deployment and retracting system by the interaction between the geomagnetic field and electrical current flowing on extensible panels. In this method, magnetic moments generated by electrical wires placed on extensible panels interfere with the geomagnetic field to generate repulsive and retraction forces, which enable the panel deployment and retraction. The electrical wires realize a mechanically simple and reliable system. Because the deployed structures can be retracted to a small volume, the satellite can avoid damage from space debris and perform agile attitude maneuvers. The deployment result is easily detected by magnetometers. Furthermore slow deployment using electromagnetic forces can help reduce the impulsive force acting on the fragile panels.

Section 2 of this paper overviews the proposed method and develops a magnetic model of the panel deployment and retraction. Section 3 numerically assesses the model in multibody dynamic (MBD) simulations. The paper concludes with Section 4.

2. Electromagnetic torque generated by electromagnetic wires on extensible panels

2.1. Overview of the proposed deployment and retraction system

In the proposed system, extensible panels are deployed and retracted by two types of torques: one is generated between adjacent electrical wires on the panels and the other is generated by the interaction of the wires with the Earth's geomagnetic field. First, we consider the electromagnetic torque generated by adjacent electrical currents flowing along the panel. The panel deployment and retraction system using the electromagnetic torque is overviewed in Fig. 1. The electrical current provides a magnetic moment to the upside or downside of each extensible panel. If the magnetic moments supplied to neighboring panels act in opposite directions, the panels create a repulsive force that deploys them in the positive x direction, as shown in Fig. 1(a). Conversely, if the magnetic moments supplied to neighboring panels are aligned, the panels create an attractive retracting force (see Fig. 2(a)). Second, we consider the magnetic torque generated by the interaction between the geomagnetic field and the electrical currents flowing during panel retraction. Here, we consider the effect of the geomagnetic field that deploys the panels in the following two cases: one in the x-axis direction (Case 1) and the other in the y-axis direction (Case 2), as shown in Fig. 1(b) and (c), respectively. In Case 1, the x-axis of the satellite body coordinate system is aligned along the geomagnetic field by attitude actuators such as reaction wheels or MTQs. The magnetic moment generated by the electrical wires on each panel generates a torque that rotates the deployed panels until they are aligned with the geomagnetic field. However, the deployed panel orients in the negative y direction rather than the positive x direction, as shown in Fig. 1(b). In Case 2, the y-axis of the satellite body coordinate system aligns with the geomagnetic field, and the satellite deploys the panels in the positive x direction of the field, as shown in Fig. 1(c). Therefore, for successful deployment, the satellite attitude should be controlled such that the geomagnetic field orients in the positive y direction. Panel retraction induced by the geomagnetic field is illustrated in Panels (b) and (c) of Fig. 2. In Fig. 2(b), the satellite attitude is stabilized so that the geomagnetic field points in its positive x direction and the panels are retracted using the magnetic torque generated by the geomagnetic field. In Fig. 2(c), the geomagnetic field points in the positive y direction (relative to the satellite). Although the panels still retract under the magnetic torque, the retracted panels jut 90° from the satellite.