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A study on fabrication of monolithic lightweight composite electronic housing for space application

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ABSTRACT

This paper dealt with an alternative approach of enhancing mass savings in spacecraft avionics design by replacing conventional aluminum alloy housing widely used for various spacecraft avionics with lightweight composite materials. For this purpose, key design requirements were defined to build up composite housing with various functionalities as well as more lightweight characteristics as compared with aluminum alloy housing. The proposed composite housing can be equipped with multiple electronics boards; and it can provide mechanical and electrical interfaces with ease. A fabrication process was also designed to overcome low machinability of CFRP and to minimize the post-treatment such as machining CFRP after curing. In addition, the composite housing with monolithic grid-stiffened frame was fabricated by co-curing through vacuum bag molding method. Its physical properties were also investigated with regard to launch environmental random load, stiffness, thermal conductivity, EMI protection. As a result, it was shown that the composite housing can have good performance comparable to aluminum and provide the mass savings over the aluminum housing having the same dimension. The proposed concept for composite electronic housing will be an effective alternative for lightweight avionics design for space application.

1. Introduction

Spacecraft electronic housing generally protects the electronic circuitry from space radiation environment as well as external loading during launch. It can also transfer the heat generated by electronics into surroundings outside the electronics. For this purpose, aluminum has been widely used for spacecraft electronic housing because it can provide the high stiffness and strength, good thermal conductivity, excellent radiation shielding and EMI protection as well as good machinability. Average weight percentage of major spacecraft subsystems such as power, TT & C (Telemetry, Tracking and Command), ADCS (Attitude Determination and Control Subsystem) with respect to spacecraft dry mass amounts to 40∼50% [1] and the electronic housing made of aluminum alloy would be up to 20%. However aluminum housing may be a parasitic structure in view point of electronic functionality of spacecraft avionics; thus the application of more lightweight housing is essentially required for compact and lightweight spacecraft design.

Many researchers [2–8] have made an effort to replace aluminum housing with lightweight composite one. Krumweide et al. [2] proposed the configuration of double-walled CFRP electronic housing with an array of high conductivity CFRP ribs between walls. Composite Optics Inc. has developed the novel technique for the construction of the electronic housing solely from flat

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laminates which are then joined in an assembly of mortise and tenon joints to produce a stiff structure [3]. Aglietti [4] proposed an alternative design of electronic housing which was based on the use of carbon fiber reinforced plastic sandwich panels and the substitution of the PCB anti-vibration frames for construction of the enclosure. Wienhold et al. [5] and Roberts et al. [6] studied a simple three-piece prototype card cage enclosure with integral mounting flanges that could be easily fabricated and assembled using adhesives. Machining CFRP flat panels and joining multiple CFRP parts into a housing assembly by adhesive bonding are expected to be a simple and easy way to manufacture CFRP housing. Machining CFRP, however, is quite difficult than aluminum and may cause quality problems such as delamination, un-cut fibers, feathering of fibers and so on. In addition, the management of tight dimensional tolerances required for assembling CFRP parts is never easy if a number of CFRP parts should be bonded or joined into a housing assembly. Brander et al. [7] and Jussila et al. [8] carried out a series of analysis, manufacturing and assembly of CFRP electronic housing for a satellite, which consisted of five major CFRP parts such as four flat panels and one large, wide, U-shaped hat section. From their study, it was reported that machining of the CFRP parts turned out to be more complicated than expected; in addition, a number of bonded joint and tight dimensional tolerances in assembly process led to situation where a lot of part fittings were performed and non-designed small modifications were needed.

To solve these problems, machining CFRP laminates and bonding CFRP parts into housing assembly should be minimized in fabrication and assembly of composite electronic housing. If the primary structure of composite housing is made of nearly an end-product by single curing process, then post-curing treatments such as machining, bonding and joining can be drastically reduced. For this reason, this paper suggests a novel concept for fabrication of monolithic lightweight CFRP housing made by single curing process and validates the build-up process by fabrication of composite housing. The key feature of the approach is to fabricate grid-stiffened composite frame by co-curing as the primary load supporting structure of the housing and to apply the minimal treatments of machining and bonding in assembly. This study also deals with physical characteristics of the fabricated composite electronic housing with respect to launch environmental random loads, stiffness, thermal conductivity, EMI shielding.

2. Design of composite electronic housing

2.1. Design requirements

The electronic housing generally has the functional requirements on physical interface with electronics boards, mechanical loading during launch environment, thermal conductivity, EMI protection and environmental shielding. Thus the lightweight composite housing also needs to satisfy the major requirements as follows: it should accommodate multiple printed circuit boards (PCB) within the structure without any failure; it should provide the thermal conductivity comparable to aluminum; it should have sufficient EMI protection and chassis grounding characteristics; it should also have the radiation shielding performance equivalent to aluminum with 2 mm thickness. In detail, durability requirement for random vibration in launch load was set to 14.1 Grms, which is based on the NASA-GEVS-SE specification [9]. The stiffness requirement of the composite housing was defined to be greater than 100 Hz to avoid the resonance with spacecraft lower modes of vibration. EMI shielding capability was defined to have the attenuation of at least 20 dB in commonly used frequency range of 30 MHz to 1.5 GHz. As for radiation shielding, proton shielding capability comparable to aluminum of 2 mm thickness was required for the composite housing. These requirements were developed based on the widely used ranges in common electronic housing for low-earth orbit satellite application. Key requirements for composite electronic housing are summarized as shown in Table 1.

2.2. Overall configuration

The composite electronic housing was designed to have the following physical interface concept: easy installation of multiple, same-sized PCB with scalable ranges up to 8 boards; simple electrical interface with conventional D-sub connectors. By this concept, all the PCB have the standard size of Eurocard 6U (160 mm × 233 mm) and they are easily clamped on each PCB guide rail by the commercial PCB locking retainers, as shown in Fig. 1.

The composite electronic housing consists of major three parts: a housing main body, a front cover and a rear cover, as shown in Fig. 2. The housing main body in detail is composed of a grid-stiffened CFRP frame; and aluminum parts such as PCB guide rails, bosses and lugs made of AL7075. An array of bosses is used to fasten the front and rear covers to housing main body, thus they should have internal thread. Lugs are appendages with holes for fastening the composite housing onto spacecraft structure. Both PCB guide rails at top and bottom make an arrangement of multiple PCB in alignment. Font and rear covers are the enclosure plates fabricated by flat CFRP plate. A series of PCB are assembled into the PCB guide rails and are clamped by the locking retainers.

Unique feature of the design is to fabricate the entire grid-stiffened CFRP frame with embedded bosses as a monolithic structure by co-curing process. The only parts to be joined after curing into the housing main body are the PCB guide rails and lugs.

2.3. Material selection

In order to compensate the low thermal conductivity of general CFRP laminate and enhance the thermal management of the housing main body, pitch-based carbon fibers prepreg YS95A/RS36 (Tencate, USA) was determined to be used for grid-stiffened CFRP frame. Pitch-based fibers generally have excellent thermal conductivity in fiber direction, for example YS95A fiber itself has approximately 600 W/