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Application of particle damper on electronic packages for spacecraft

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ABSTRACT

Particle damping is an effective method of passive vibration control, which is of recent research interest. This paper presents a novel application of particle damper on an electronic package of a spacecraft, tested at ISRO Satellite Centre. The effectiveness of particle damper on the random vibration response of electronic package for spacecraft application exposed to random vibration environments experienced during the launch is studied. The use of particle damper under shock environments are also demonstrated. Optimal particle damper parameters were used based on the design guidelines derived from previous publications of the authors. The comparison of particle damper effectiveness under random vibration loads with respect to the shape of the particle damper capsule and packing ratio are also examined.

1. Introduction

A typical electronic package for spacecraft application consists of Printed Circuit Boards (PCBs), electronic components and supporting structure known as mechanical housing. The electronic package experiences severe dynamic responses due to the high intensity vibrations and shocks during the launch phase. The vibration loads are caused due to various launch events such as lift-off, excitation of solid/liquid engines, aerodynamic wind loads, engine start and shutoff.

This paper is based on studies of electronic package under the simulated launch random vibrations at ISRO Satellite Centre. The major shock loads are caused due to the launch vehicle stage separations, payload fairing separation, vehicle and spacecraft separation, operation of pyrotechnic device for deployment of payloads, solar panels and antennae in the spacecraft. One of the major design driver for the electronic package design is the launch survival. A study from NASA showed that 45% of the first day spacecraft failures were due to the damage caused by vibrations during launch phase [1]. During vibration, the PCBs experience excessive displacements which causes fatigue failure of electronic components due to the relative displacements between the PCB and the electronic components. The typical failures observed in the electronic package are in the electronic components, component inter-connections, component leads, soldering joints, structural failure of PCB laminate, etc, This phenomena occurs largely due to the harsh launch random vibration environment during the out-of-plane mode of PCBs in the electronic package. During random vibration, the localised stresses and strains develop at the electronic component interfaces on the PCB at the out-of-plane bending mode. In the past, various solutions were proposed to overcome the problem of the harsh vibration environment experienced by PCBs during launch [2,3]. There are various other mitigation techniques for the PCB in the electronic package to suppress vibration such as increasing the PCB thickness, addition of stiffeners/doublers, constrained layer damping, etc,. The present trend is to overcome the electronic package failures due to launch environment by means of suppressing the vibration thereby reducing random vibration response on the PCB during the out-of-plane mode. This avoids electronic component failure and decreases stresses present at the interface of component which in turn increases fatigue life.

Among various passive devices for structural control applications [4–7], particle dampers are highly nonlinear dampers that simultaneously utilise momentum transfer and internal energy dissipation. They have many advantages in spacecraft applications. This is a relatively new development in passive damping methods and evolves from the single particle impact damper [8]. In particle dampers, the particles absorb the vibrational kinetic energy and dissipate it into heat energy through frictional effects (coefficient of friction) and collisions (coefficient of restitution) between the particles as well as between the cavity walls and particles. Panossian [9,10] pioneered the new technique of particle damping for vibration suppression in aerospace structural members. This

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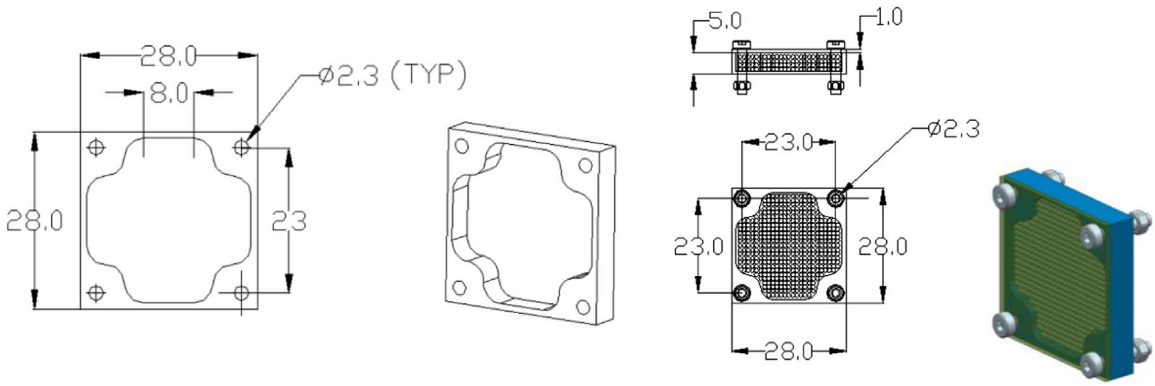

Fig. 1. Particle damper capsule (square shape) configuration including fasteners and with particles.

technique was applied in many applications. Some of them are, (i) Damper holes were drilled in an aluminium beam and were filled with particles of different sizes at various fill levels; different combinations of holes were selected and experimented both in the air and water medium. Significant damping was achieved under certain configurations. The performances of particle dampers are significantly dependent on particle size, density, volumetric packing ratio and amplitude of vibration, (ii) Delta IV components were tested for acoustic amplitude attenuation with particle damping technique, (iii) Several tests were carried out on aircraft turbine/compressor blades.

The particle damping method has been shown to be very effective and simple which can suppress broad frequency vibration in various applications [10–12]. It has distinct advantage to spacecraft applications due to its robustness, ruggedness, reliability, simple-to-design, and insensitivity to extreme temperatures together with low cost [9,13,14]. There are some important studies in the application of particle damping technology using experimental [14,15] and numerical [16–21] techniques. The empirical method based design guidelines were proposed for particle damper design from extensive experiments carried out on three structural specimens namely beam, bond arm and bond head stand [22]. The relationship between the damping ratio and the particle damper parameters such as particle size and packing ratio for various modes were studied. The experimental investigation on a mild steel beam and plate with particle damping treatment was conducted [23]. It was observed that the damping was significantly effective and strong attenuations were achieved within a broad frequency range. The particle damping technology was applied on a bond arm structure to suppress vibration [24]. As stated, the design of particle damper is very simple and particle dampers are efficient passive devices which are used to attenuate the vibrations especially in harsh environments particularly in space applications where most conventional dampers fail. Because particle dampers can be integrated into existing hardware, it has also proven to be a technology that can be used in the field.

The above review summarizes the application of particle damping method to various types of structures and the effect of damping behaviour with respect to particle damper parameters using experimental methods and analytical methods from the reported studies in the literature. However, there is no specific literature available on particle damper application on electronic package to the best of author's knowledge. In previous work [25–27], authors had extensively studied the effect of various particle damper configurations (such as packing ratio, particle size and particle density) and used the data to train a Radial Basis Function (RBF) neural network to correctly predict the design guidelines. In the current paper, this information (best combination of particle damper parameters) is used to extend the application of particle dampers to an electronic package in the spacecraft application for attenuating acceleration response of the out-of-plane bending modes under random vibration environments. Initially, the vibration suppression of a bare PCB with particle damper under random vibration and shock environment is performed. Subsequently, the effectiveness of particle damper in the vibration suppression of electronic package for spacecraft application exposed to launch random vibration environments is demonstrated.

2. Effectiveness of particle damper under random vibration loads of PCB

The effect of particle dampers on the random vibration response of PCB subjected to random vibration loads are demonstrated. PCBs are frequently used to mount various electronic components in spacecraft. The PCB configuration selected in this study is similar to that used in the spacecraft applications. The size of the PCB used in this study is 228 mm (length) $\times$ 200 mm (width) $\times$ 2 mm (thickness). The material and mass of the PCB is FR-4 and 221.67×10^{-3} kg respectively. Particle damping effect can be obtained either by filling metal particles within the cavities of the primary vibrating structure (PCB) or by attaching the damper as an external capsule. Here, the particle damper capsule was attached on the PCB because the embedment of particles on to PCB is not feasible due to its small thickness. The particle damper capsule of square shape (28 mm $\times$ 28 mm $\times$ 5 mm) and circular shape (Ø 30 mm $\times$ 9 mm) used in this study are shown in the Figs. 1 and 2 respectively. The shapes are chosen based on the guidelines provided in the existing literature [24,28,29]. The cavity volume of both square and circular shape particle damper capsule is kept constant to study the effect of vibration suppression with respect to the shape of capsule. However, the mass of the capsule is slightly different between square and circular shapes due to manufacturing complexities. The material of the capsule is aluminium alloy and the mass of the square and circular capsules (including fasteners) are 7.81×10^{-3} kg and 12.1×10^{-3} kg respectively. The configuration of the capsule is mainly driven by the layout (geometric constraints) of the PCB and the maximum allowable mass ratio (ratio of mass of particles and mass of PCB). The larger the size of the capsule, the more the particles that can be used to fill it, which in turn increases damping. However, this reduces the available area for mounting the electronic components while the mass ratio increases. Hence, it is a trade-off between the damping requirement and the mass ratio [25,27]. The external capsule is assembled on to the PCB using four M2 bolts and nuts arrangements with appropriate spring washers so that the integrity of capsule on to PCB is ensured before and after the vibration.