Application of Steinberg vibration fatigue model for structural verification of space instruments

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Abstract

Electronic components in spaceships are subjected to vibration loads during the ascent phase of the launcher. It is important to verify by tests and analysis that all parts can survive in the most severe load cases. The purpose of this paper is to present the methodology and results of the application of the Steinberg's fatigue model to estimate the life of electronic components of the EPT-HET instrument for the Solar Orbiter space mission. A Nastran finite element model (FEM) of the EPT-HET instrument was created and used for the structural analysis. The methodology is based on the use of the FEM of the entire instrument to calculate the relative displacement RDSD and RMS values of the PCBs from random vibration analysis. These values are used to estimate the fatigue life of the most susceptible electronic components with the Steinberg's fatigue damage equation and the Miner's cumulative fatigue index. The estimations are calculated for two different configurations of the instrument and three different inputs in order to support the redesign process. Finally, these analytical results are contrasted with the inspections and the functional tests made after the vibration tests, concluding that this methodology can adequately predict the fatigue damage or survival of the electronic components.

Keywords: Random vibration, fatigue life, Steinberg model, finite element, electronic components, space instrument

1. Introduction

Spaceships are subjected to several mechanical loads generated by the different causes such as rocket propulsion, aerodynamic effects and pyro-shocks actuations. It is necessary to verify by analysis and tests that all parts and equipment can withstand this severe environment. Electronic components are quite susceptible to be damaged by fatigue under random vibration and shock loads, and therefore, they need to be verified during the qualification and acceptance phases of the project. In recent years, the need for fatigue analyses in space projects has been increased due to the development of new reusable launchers as Falcon 9 [11], where their electronic equipment are subjected to the vibration loads of various ascent phases. Therefore, fatigue analysis should be implemented in the structural verification plan of the electronic equipment.

Steinberg, in Ref. [12], developed a fatigue model that predicts the life of electronic components attached to a printed circuit board (PCB), where only a few parameters of the component and the PCB need to be known. Steinberg model has the advantage of estimating in a simple way the survival of the joints between electronic components and the PCB subjected to dynamic loads like random vibration and shock. This fatigue model has been implemented in several applications as vibrationdata (see Ref. [8]), where the maximum relative displacement spectral density curve (RDSD) of the PCB expected from random vibration environment is used as input to obtain the cumulative damage index (CDI). Recent research works studied the influence of the input parameters [5] and validated the Steinberg's model [10] in order to demonstrate that can be applied for engineering projects. In Ref. [9] the Steinberg's model is compared with the Steinberg's three-band method by finite element analysis (FEA) with the objective of calibrating the parameters. Other research works [4,6,7,13,14] develop and use more sophisticated fatigue analysis methods that need detailed finite element models and the results of several tests.

2. EPT-HET instrument

The institute IDR/UPM participates in different space missions performing structural and thermal analyses of various instruments. One of these instruments is the Electron Proton Telescope – High Energy Telescope instrument (EPT-HET), which is a unit that belongs to the Energetic Particle Detector (EPD) payload of the Solar Orbiter Spacecraft.

The EPT-HET instrument is a payload of the Solar Orbiter spacecraft with the mission of measuring the energetic particles (electrons and protons) expelled from the sun. The instrument includes three PCBs assembled inside the housing: LVPS (Low Voltage Power Supply), Digital and Analogic Boards. The dimensions of the three PCBs are 120x100 mm, and the thicknesses of LVPS, Digital and Analogic boards are 1.51, 1.53 and 1.57 mm respectively. They are made of layers of FR4 (glass-reinforced epoxy composite) and copper, and each PCB is joined to the housing by 16 bolts on the contour. For the Steinberg's method estimations, each PCB is considered as simply supported plate at the four edges, which is a boundary condition similar to that of the design.

The procedure of structural verification of the EPT-HET included a fatigue analysis with the aim of assessing the life of its electronic components in different design configurations of the instrument under random vibration environment. The uncertainties of design during the early design stages of the project move this type of analysis to a more advanced stage of the design process, where the capacity to modifying the structure is limited.

3. Fatigue Analysis Procedure

The FEM of the EPT-HET instrument (see Fig. 1) is used to calculate the maximum relative displacement (RDSD and Root Mean Square (RMS) values) obtained from random vibration analysis. Figure 2 shows the relative displacement (RDSD) curves for the centre node of the Digital Board calculated by FEM analyses for three different random vibration inputs.

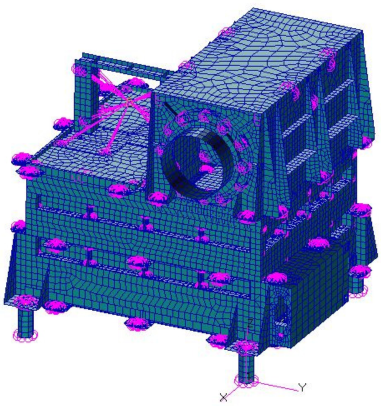

Figure 1: Finite element model of the EPT-HET instrument

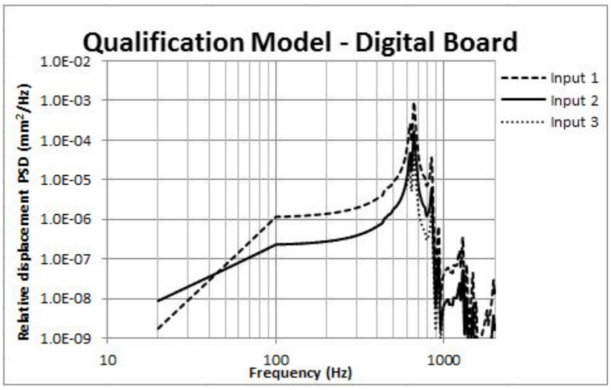

Figure 2: Relative Displacement Spectral Density (RDSD) curves for three different random excitations

The next step consists in calculating the cumulative damage index (CDI) with the Steinberg model using the values of the maximum relative displacement on each PCB, with the objective of determining the survival or damage for the most susceptible electronic components under the most severe vibration loads.

The results of the fatigue analysis are then contrasted with the visual inspections and functional tests made after the random vibration tests to determine if this methodology can adequately prevent the fatigue damage of electronic components.

4. Objective and conclusions

The objective of this study is to validate the methodology to predict the fatigue life of electronic components to be used in the structural verification procedure for future space projects. The advantage of this methodology lies in the fact that the order of magnitude of the CDI values can indicate in a quick way the risk of fatigue damage of the electronic components avoiding the need to create a new and more detailed finite element model.

In this study, this analytical estimation is made for different combinations of designs and random inputs and agrees with the inspections and functional tests made on the EPT-HET instrument to find the damage on electronic components after the vibration tests.

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