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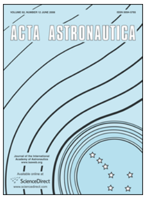

Modelling the effect of electrical harness on microvibration response of structures

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ABSTRACT

The term “microvibrations” generally refers to accelerations in the region of micro-g, occurring over a wide frequency range, up to say 500–1000 Hz. The main issues related to microvibrations are their control and minimisation, which requires their modelling and analysis. A particular challenge is posed in the mid-frequency range, where many of the micro-vibration sources on board a spacecraft tend to act. In this case, in addition to the typical issues related to predicting responses in the mid-frequency, the low amplitude of the inputs can produce further non-linear behaviour which can manifest as uncertainties. A typical example is the behaviour of cables secured onto panels; when very low forces are applied, the presence of harness can influence the characteristics of the panel in terms of stiffness and damping values. In these circumstances, the cables themselves couple with the panel, hence become paths for vibration transmission. The common practise is to model such cables as Non-Structural Mass; however, this paper illustrates that this method does not yield accurate results. In order to demonstrate this, an experimental campaign was conducted investigating a honeycomb panel, which was tested bare and with different configurations of harness secured to it. The results of this experimental campaign showed significantly different behaviour of the structure depending on the amplitude of the loads and the frequency. In particular, it was found that the effects the addition of the cables had on the panel were different depending on the frequency range considered. Based on this observation, a general methodology to deal with the whole frequency range is presented here and the basis to extend it to the case of more complex structures is also proposed.

1. Introduction

Modern satellite payloads, e.g., the new generations of optical instruments, require extreme platform stability; hence microvibrations on board spacecraft have become an issue of growing importance. The term “microvibrations” generally refers to accelerations that can reach values as low as micro-g, occurring over a wide frequency range, up to say 500–1000 Hz. Research on microvibration started with the most advanced and sophisticated spacecraft, like the Hubble Space Telescope [1,2] or the earth imaging satellite SPOT [3,4]. Nowadays, it is also a factor in the low cost end of the market, with microsatellites like the SSTL-150 platforms [5] or Skybox [6] which have the objective to carry cameras with very high pointing accuracy, and therefore even small relative displacements of the mounting points of the instrument, of the order of micro-

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List of abbreviations: FEM, Finite Element Model; BP, Bare Panel; TK_loc1, Panel with Thick Cable mounted in location 1; TN_loc1, Panel with Thin Cable mounted in location 1; TN_loc2, Panel with Thin Cable mounted in location 2; TKN, Panel with Thick Cable mounted in location 1 and Thin Cable in location 2; FMCS, Full Monte Carlo Simulation; CBSM, Craig–Bampton Stochastic Method; SQM, Structural Qualification Model

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meters, become unacceptable (as they produce large oscillations of the instrument line of sight). The research has focused on many aspects related to microvibrations, starting with the sources [7,8], and throughout the years various methodologies have been proposed for their modelling and control [9–12], e.g., simulating the interface between sources and spacecraft structures and predicting payload pointing errors [13,14]. Among the difficulties related to microvibrations, one of the main ones is their analysis, having to deal with extremely low amplitudes (μg) and a bandwidth that goes up to several hundred Hz.

Problems are also found in terms of modelling, due to non-linearity, and of testing, as the noise from a standard test facility may exceed micro-g levels. Most of the equipment on board a spacecraft does not affect the linearity of the response. This means that the transfer function does not change when the amplitude decreases. On the other hand, when it comes to hardware such as braided elements (e.g., harness/cables or thermal straps) an increase of stiffness and decrease of damping are observed. The issue here is that for sufficiently high loads and deformations (e.g., during launch) the strands move/slide with respect to each other as the forces are higher than the friction forces between strands, so that the assembly has relatively low stiffness and high damping (the latter produced by the energy dissipated via the friction). Therefore, when high loads are applied, the contribution produced by stiffness of these elements is neglected and their mass contribution to the response is often represented in the Finite Element Model (FEM) simply as Non-Structural Mass and higher damping; however when the loads are microvibrations this type of modelling is not accurate enough as the braided elements connected to the structure tend to behave like a monolithic element, hence producing a higher stiffness and lower damping. This paper investigates the effect of braided elements (i.e., multiple conductors' cables) on the structural response, and in particular non-linearity observed with respect to variations in the input loads.

Many publications can be found on the influence of cables in other applications [15], e.g., bridges [16,17], but only in the last few years, due to more challenging response prediction accuracy requirements, interest has been given to the modelling of cables in the context of spacecraft structure applications [5,18,19]. In particular, Goodding and Babuska et al. developed a method to study the behaviour of space structures supporting cables where the Finite Element Model of the structure is updated with the addition of a model of the cable [20,21]. The model updates required to represent the cable are calculated from a combination of: direct measurements, dynamic tests, static tension tests and wire handbook data (all this data is then fed into different tests to retrieve modulus of elasticity, shear modulus and damping) [22]; the cable attachments are also modelled. This work provided a good estimation of the effect the harness has on spacecraft structures and also gives excellent results for spacecraft panels with cables [22]; however extending it to whole spacecraft structures would require a substantial modelling effort which is difficult to justify in the context of a commercial spacecraft project development. In addition, even when these relatively complicated modelling techniques were applied, it would still be necessary to extend them to reproduce the nonlinearities observed in the microvibration response which are studied in this paper.

Consequently, the issue of extending the implementation of the effect cables have on more complex structures without significantly increasing the modelling and computation effort is still open. This paper proposes a methodology to deal with microvibrations acting on a simple structure which includes electrical cables and that can be easily extended to more complex structures.

2. Methodology

The development of this work followed a semi-empirical approach.

Firstly a test campaign was carried out to produce quantifiable evidence of the effect that braided elements (i.e., cables) have on the structures onto which they are fastened.

The test campaign considered a honeycomb panel, as typical spacecraft structural element, with different cables fixed in different locations. Various combinations were considered and the test item was subjected to inputs at various levels and in various locations.

The test results were then analysed methodically to identify specific trends, and a mathematical modelling technique able to envelop the effects of the presence of the cable (mass and stiffness), according to the frequency and magnitude of the inputs, was developed.

Finally the technique was extended to the case of a much more complex structural assembly.

3. Experimental campaign

The equipment used for the test campaign were an aluminium honeycomb panel of size $1050 \times 710 \times 20\ \text{mm}^3$ (cell size of 4.8 mm, cell wall of 0.038 and core density of $0.07\ \text{g/cm}^3$); and two different braided cables, both 120 mm long: one with bundle diameter of 8 mm and one with bundle diameter of 12 mm (Fig. 1). The braided cables could be situated in 2 different locations as represented in Fig. 2: location 1 is the lower one built with 15 attachment points and location 2 is the upper one built with 9 attachment points. The five different configurations listed below were tested:

- Bare Panel (BP) [Fig. 3].
- Panel with Thick Cable mounted in location 1 (TK_loc1).
- Panel with Thin Cable mounted in location 1 (TN_loc1).
- Panel with Thin Cable mounted in location 2 (TN_loc2).
- Panel with Thick Cable mounted in location 1 and Thin Cable in location 2 (TKN) [Fig. 2].

In all the configurations, a mini-shaker LDS V101—max force 3 N—was used to produce a force in a specific location and accelerometers with sensitivity of 1000 mV/g were used to acquire the response in 20 different locations. A controller software was used to create a sweep sine between 20 Hz and 1000 Hz to be used as input to the mini-shaker and 3