24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

DESIGN AND FABRICATING OF LIGHT WEIGHT VIBRATION ISOLATOR WITH REQUIRED FILTERING PROPERTIES

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The design of a lightweight vibro-isolating element is considered. It is based on the theory of grid-like elastic structure that demonstrates the perfect filtering properties with respect to vibrations and may significantly decrease amplitudes of vibration at the frequency of several hundred Hz. The selective laser melting technology is used for making the structure with minimized weight of such element. Both the mechanical properties of the synthesized material and its structure have been studied to ensure the mechanical and filtering properties of the printed vibroisolators. Mechanical tests of the samples of vibroisolators were performed to confirm their mechanical properties and high filtering efficiency. The results may be useful for development of high precision instruments for space applications.
Keywords: vibroisolation, periodic structure, 3D printing technology

1. Introduction

Designing of vibro-isolating elements for scientific instruments to be installed at spacecraft have to address to several particular requirements. The first of them is low space temperature and deep space vacuum that prevents from using various elastic materials, such as rubber, which are commonly used on the Earth. Metals are the most appropriate materials for the purpose. The second requirement is that the system should be of minimum mass, since mass is often a crucial parameter of all elements of a spacecraft. Strength is also very important property because of high level static and dynamic loads especially at the launch stages of a flight. All these conditions, together with the absence of gravity, make the mitigation of vibrations at spacecraft a special problem. One example of the effective *vibration isolator* (VI) is presented in this paper, which has been developed for the space instrument to prevent “microphonic” effect during its operation. It is used as a mechanical interface between the instrument foot prints and vibrating Science Deck of a spacecraft. The modified version of VI is also presented below, which was manufactured by the selective laser melting (SLM) technology to minimizing the weight and maximize the strength.

2. Requirement parameters and design concept for vibration isolator

The following requirements for the parameters of VI structure have to be taken into account:

- High rigidity to satisfy the conditions of strong random vibrations and shocks during the launch.

- Acceptable low level at the space instrument of propagating external vibrations from the foot prints at the certain frequency range.
- Minimum mass and longtime operation.
- The simplest possible installation process of instrument on the Science Deck of the spacecraft.

The first and second requirements are looking as opposite to each other, and the second one is practically equivalent to the requirement to reduce the reference vibration level down to the certain value.

2.1 Concept and design of vibration isolator

The original design of the VI was based on the vibration filtering properties of periodic grid-like elastic structures. Such structures are known to provide the efficient filtering properties with respect to vibrations, and their *frequency response functions* (FRFs) consist of interchanged stop and pass frequency bands. At the pass bands elastic waves propagate through the grid without attenuation, while at the stop bands they decay exponentially along the length of the structure. So the mechanical concept of VI was suggested, as a set of several thin washers of steel interconnected with each other on a chess-board order via small masses forming a grid-like structure (see Fig.1, where VI is shown with three intermediate rings and upper interface element, namely VI-3). Under the applied vibration, the washer executes rather complicated motions. For theoretical studies, they were modelled by coupled flexural-torsion (out-of-plane) vibrations and flexural-longitudinal (in-plane) vibrations of an elastic thin ring [1].

Figure 1: VI-3 washers with separate upper interface for the foot print of the instrument (left) and 3D printing sample (right).

Four VI-5 elements with five intermediate rings were used for isolating Russian space instrument HEND (NASA Mars Odyssey mission [2]) from vibrations of the spacecraft Science Deck, where it was installed. In this particular case VI-5 elements have been optimised in accordance with three basic requirements: to satisfy mechanical environments (high level vibrations of 11 g in frequency range 100-2000 Hz), to provide stop band for vibrations at 550-700 Hz, and to ensure the fundamental frequency of the entire instrument on four VIs higher than 50 Hz. The number of the washers and their mechanical parameters were chosen to get the stress safety factor about 2.0 corresponding to the reference data. The used steel had the breaking stress $\sigma_b=1200MPa$. All mechanical and functional tests of the instrument with VI-5 have been successfully passed before integration on the Science Deck of the spacecraft.

2.2 Experimental results

The efficiency of vibration isolation by VI-5 is illustrated on Fig.2, where the frequency dependences of vibration amplitudes of the instrument are presented with and without VIs: blue dash line presents the average vibration level without VI in the frequency range 500-900 Hz during ordinary operations; red line shows the reference level for vibrations at the launch stage (in term of power spectral density psd, g^2/Hz). It is obvious that vibrations at the range 500 – 900 Hz are much smaller for the instrument with VIs. The efficiency factor of vibro-isolation at this range corresponds to ~20 dB. On the other hand, the fundamental frequency of the instrument with such VIs is still rather high 65 Hz that was accepted by the mission technical requirements.

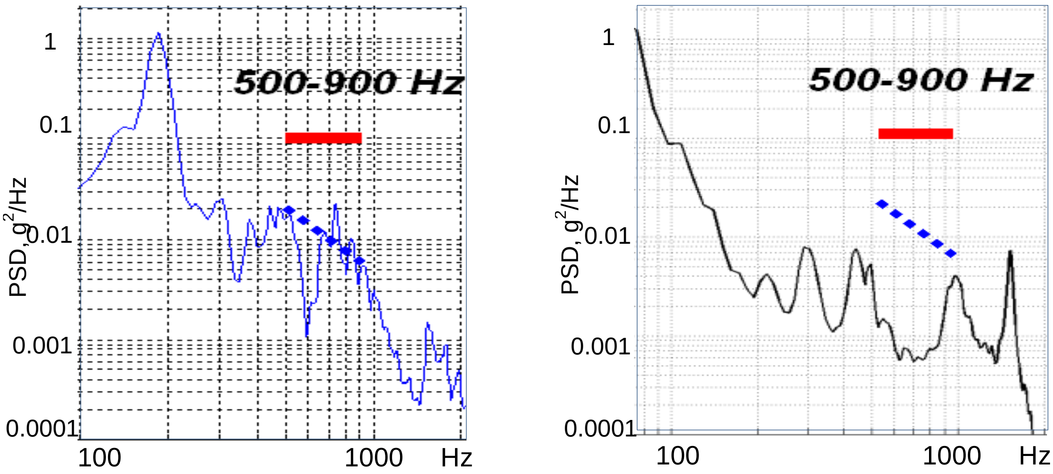

Figure 2: Random vibrating tests of the instrument without VI-5 (left) and with VI-5 (right); blue dash line indicates overage vibration level without VIs; red line is a reference level for the mechanical test.

2.3 SLM VI design and tests

The original design of the VI element was redesigned for usage of the additive technology for its manufacturing: the fixation and interface elements were included into the main part of the VI assembly so that the VI became a single unit; see Fig.1 (on the right). That minimized the mass by ~20%. The mass of VI-3 element, which was made with casting material by the ordinary manufacturing technology is equal to 80 grams, while the mass of VI-3 element made by SLM technology is equal to 65 grams.

The mechanical test of SLIM-made VI elements was performed and metallographic studies of the synthesized material were carried out to analyse their material properties (see details in [3]). The vibration tests of SLM-made VIs have also been successfully passed and the perfect vibration isolation effect has been verified. The suppression coefficient was estimated as 20 dB, as the ratio of input vibe amplitudes at the fixation points to the vibe amplitude in the most sensitive element of the instrument.

3. Summary

The design and experimental studies of steel VIs, as based on filtering properties of periodic grid-like elastic structures, show their high efficiency for suppression of vibrations at the certain frequency range. The concept of VIs elements with steel grid-like washers may be used for other space instruments, which require high accuracy of pointing or low level of vibrations during operations in the space conditions. The application of the additive technology has very promising perspectives for designing and manufacturing VIs isolators for pre-determined capabilities, minimum mass and maximal strength. However, more detailed studies of the SLM processes are still required to ensure the best combination of the achievable properties of the final products: the high mechanical strength and the minimal mass are thought to be the most important among them.

This work was supported by the Russian Science Foundation grant (project no.15-19-00284)

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