A new Concept of Vibration Damper Based on Friction Induced Dissipation Between Magnetic Materials

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ABSTRACT

This paper presents a new concept for passive vibration mitigation in sandwich structures. The test structure in the present work is composed of permanently magnetized MagnetoActive Elastomers (MAEs) and ferromagnetic sheets representing the core and the skins of the sandwich respectively. The magnetic forces which develop between the core and the skins in the contact interfaces are sufficient to maintain the structure assembled without the need of glue. The sandwich structure is subjected to harmonic vibrations around a single resonance mode with different excitation magnitudes. A nonlinear evolution of the frequency response function's (FRF) amplitude are stated. This non-linearity induces on the one hand a decrease of the resonance frequency. On the other hand, the damping evolves in a non-monotonic way according to the excitation amplitude. This is very characteristic of frictional damping.

Keywords: Vibration Damping, Magnetoactive Elastomers, Assembled Structure, Magnetic Contact Pressure, Friction

INTRODUCTION

The capacity of assembled structures to mitigate vibrations has been the subject of intensive research over the last years [1]. Nowadays, the existence of reliable characterization methods allows the optimization of existing solutions as well as the testing of new concepts. In this work we propose a new type of assembled structure in which magnetoactive elastomers are used to mitigate vibrations efficiently by friction damping. Friction damping is a passive mechanism for vibration mitigation. It occurs in contact interfaces of vibrating assembled structures. When contact surfaces in the assembly are in relative motion, the friction partially opposes the movement which leads to the attenuation effect. Depending on the ratio of tangential stress and normal stress in a contact interface, the contact state can range from total stick to partial sliding to mainly sliding [2]. The tightening load establishes the normal stress which affects friction damping as well as the stiffness of the structure [3]. Vibrations generate tangential stresses and the contact state therefore depends on the vibration magnitude [4,5]. This leads to a variation of the resonance frequency and a nonlinear evolution of the system's response when the contact state changes from total stick to mainly sliding.

An emerging type of mechanical joint in assembled structures is based on magnetically induced forces, where electromagnets [6] or permanent magnets [7,8] have been used to generate the normal tightening load. Permanent magnets are particularly interesting for this purpose as the tightening load is maintained without an external energy supply. However, the magnets add a considerable mass to the system and existing solutions are rather bulky. In this work, we present a concept for vibration mitigation that relies on a magnetic tightening load. The latter is generated by MagnetoActive Elastomers (MAEs) in a sandwich structure. Existing studies on vibration damping with MAE sandwich structures deal with the adaptive control of the material properties of non-permanently magnetized MAEs [9-11]. In these studies, all contact interfaces are assumed to be full sticking. In contrast to the prior studies, we aim to explore the possibility of passive vibration attenuation by friction in sandwich structures with permanently magnetized MAE.

BACKGROUND

To demonstrate the concept, a sandwich structure is assembled from two steel skins, five MAE patches and an aluminum spacer (figure 1a). Our MAE is a permanently magnetized composite material with a residual magnetic flux density of 0.3 T [12]. The sandwich is tested under clamped/free boundary conditions. The sandwich is designed so that the clamp does not influence the vibratory responses of the structure. The outer dimensions of the sandwich measure 22 cm x 3 cm x 0.26 cm.

In the sandwich, the ferromagnetic skins are attracted by the magnetized MAE. The magneto-mechanical interactions maintain the skins clamped to the core without additional means of fixation. The normal stress in the contact interfaces (figure 1b) is hence established by the magneto-mechanical interactions. When the structure is subjected to transverse vibrations, it is deformed and shear stresses appear in the contact interface. While the magnetic normal stresses remain constant, the tangential shear stresses vary with the excitation magnitude and hence determine the contact state.

In the experiment, the sandwich is clamped directly on an electromagnetic shaker (figure 1b). A reference signal is measured by an accelerometer placed on the base. The velocity of the sandwich beam is measured with a contactless laser vibrometer. A harmonic excitation is performed with different acceleration magnitudes around the resonance frequency to study the nonlinear response of the structure. For the harmonic excitation, stepped-sine signals with amplitudes between 1 m/s^2 and 90 m/s^2 are used in tests with increasing frequency ("f up") and decreasing frequency ("f down"). Figure 1c shows the experimentally obtained FRF amplitudes of the third resonance mode for the different tests.

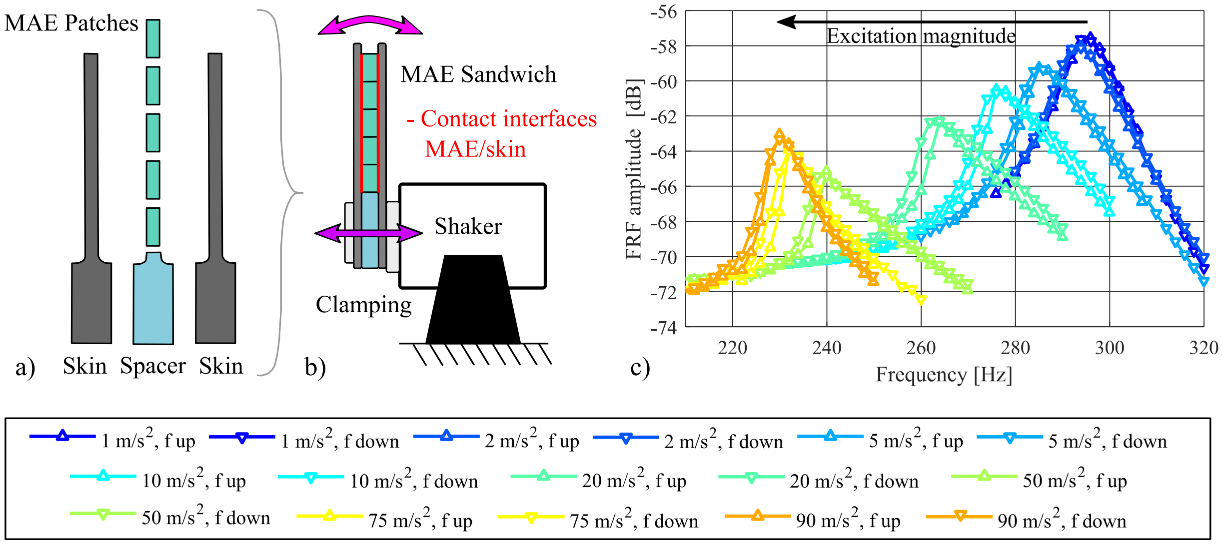

Figure 1: Components of the MAE sandwich structure (a), schematic side view of the experimental setup (b) and FRF amplitudes for the third bending mode of the structure with different excitation amplitudes in frequency-up ("f up") and frequency-down ("f down") tests (c).

ANALYSIS

The structure shows a nonlinear behavior with respect to the excitation magnitude: the resonance frequency decreases with increasing amplitude and the shape of the amplitude peaks is modified. For the lowest excitation magnitudes, the FRF is symmetric around the resonance frequency. When the excitation magnitude increases, the maximum value of the FRF decreases and the peak is distorted to the left. The decrease of the peak amplitude of the FRF shows that the damping increases with the acceleration magnitude from 1 m/s^2 up to 50 m/s^2. For a further increase of the excitation magnitude, the peak of the transfer function straightens, its shape becomes more symmetric. The inclination of the resonance peak and the nonlinear evolution of the peak amplitude are characteristic for systems which include friction damping. For small excitation magnitudes, the tangential stresses are small. The contact surfaces mainly stick together and the system behaves like a single beam structure. With increasing excitation magnitude up to 50 m/s^2, more parts of the contact interface start to slide as the shear stresses increase. The stiffness of the structure is therefore decreased and friction damping occurs. Above the threshold of 50 m/s^2, the shear stresses become much larger than the normal stresses. The contact surfaces mainly slide above each other which reduces the effect of friction damping. Since the nonlinear damping effect becomes smaller, the resonance peak straightens again.

A finite element model of the experiment has been implemented to obtain information about the local contact state. The results of the numerical simulations confirm the constant, relatively distributed contact pressure. Moreover, in studies with increasing excitation magnitudes, the local contact state evolves from mainly sticking to mainly sliding which confirms the experimental observations.

CONCLUSION

The present work outlines the concept of magnetically induced friction damping in sandwich structures which contain permanently magnetized magnetoactive elastomers. The sandwich structure studied in this work illustrates how to employ magnetoactive elastomers for friction damping. Compared to rigid magnets, the MAEs are more lightweight and can adapt to the deformation of the assembly. The main drawback of the concept is the added mass. A possible subject for future studies is the influence of the sandwich design on the FRF. Instead of using a full core, isolated patches could be placed at different locations in the sandwich for example. Harmonic excitations with different controlled amplitudes reveal the characteristic, nonlinear behavior of the sandwich structure and proof the existence of friction damping. The advantage of a shape adaptability is that is maintains the contact interface which favors friction damping. The local contact state has been analyzed by the help of a numerical model of the experiment. The simulation results indicate that the contact state evolves with the vibration amplitude which confirms the experimental results. The characteristic evolution of the FRF amplitudes clearly shows the presence of nonlinear damping. It is assumed presently that is results from friction. However, additional passive mechanisms of energy dissipation like viscoelastic damping and eddy current damping are probably activated in the sandwich structure. The contribution of these different passive damping mechanisms will be quantified in future studies.

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