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Stochastic microvibration response analysis of a magnetorheological viscoelastomer based sandwich beam under localized magnetic fields

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ABSTRACT

The microvibration of a horizontal magnetorheological viscoelastomer (MRVE) based sandwich beam with supported mass under random disturbances and localized magnetic fields is studied to verify its control effectiveness. The localized magnetic field covering incompletely the beam results in the MRVE properties varying in space. The effects of the localized magnetic field distribution on the microvibration are considered in the analysis. The vibration equations with spatial parametric variation and temporal randomness of the beam system under the localized magnetic field are derived, and solved by the modal transformation and frequency spectrum analysis. Then the expression of the root-mean-square velocity criterion for microvibration is given, where the non-homogeneous MRVE modulus is considered due to the localized magnetic field. The proposed analysis method can be extended to other random excited composite structures with viscoelastic cores. The stochastic microvibration control effectiveness of the beam system and the effects of the localized magnetic field intensity and placement on the microvibration response are verified by numerical results.

1. Introduction

In many fields, precise apparatuses with disturbance susceptivity require completely steady operation surroundings. For instance, to ensure the steadiness of electron beams, the synchrotron radiation equipment requires its surrounding-induced wobble controlled with displacement in micrometers [1]. This slight wobble is called microvibration. The apparatuses are disturbed ineluctably by actual surroundings with broad frequency domains, and then the stochastic microvibration control is very important to them [2–4]. The microvibration criterion for apparatuses with disturbance susceptivity has been presented by the root-mean-square velocity spectrum [5]. The microvibration control of structures supporting apparatuses has been studied by using passive/active isolators. However, composite structures with smart materials can be used for effectively controlling the random microvibration by broad energy dissipation.

Magnetorheological viscoelastomer (MRVE) is a new sort of smart materials which is fabricated generally by magnetically polarizable iron particles, nonmagnetic silicone rubber and silicone oil [6,7]. The MRVE has the advantageous properties of magnetorheological fluids and viscoelastic substrate materials such as stiffness and damping regulable by applied magnetic

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fields. The MRVE improves the potential disadvantage of magnetic particle settlement in magnetorheological fluids. Many studies were presented on the MRVE fabrication and test for magnetic mechanical properties and dynamic behaviors [8–17]. The MRVE nonlinear dynamic model and equivalent linear model in the frequency domain for microvibration have been proposed [18]. The MRVE based vibration isolators and absorbers, and magnetorheological fluid-elastomer combined dampers have been designed and tested for strong vibration controls [19–22].

As a potential application, the MRVE can be used to design combination structures with regulable dynamic characteristics for mitigating vibration. The vibration of sandwich beams with uncontrollable viscoelastic damping has been studied early [23,24]. The study on MRVE sandwich beams has been presented recently including the periodic vibration and adjustable stiffness [25,26]; frequency response characteristics [27]; dynamic stability under periodic axial loads [28,29] and sound transmission characteristics [30]. However, those studies considered only deterministic periodic dynamic characteristics and relatively simple solutions were obtained. The stochastic microvibration response of an MRVE sandwich beam and plate under a completely covering magnetic field has been studied [31,32], but in the case of complete homogeneous magnetic fields, the MRVE dynamic characteristics have a simple expression with spatial invariability so that corresponding vibration equations are simplified.

The homogeneous magnetic field covering completely a large structure is not so realistic and may not be optimum. The stochastic microvibration response of MRVE combination structures under localized magnetic fields needs to be studied further. The localized magnetic field covers incompletely a combination structure and then the MRVE core has dynamic characteristics or complex modulus varying in space. The corresponding vibration equations are partial differential equations with spatial parametric variation and temporal randomness so that the microvibration problem is more complicated than the previous. The series solution to the deterministic vibrations of non-uniform thickness beams and the spectral element method for beam vibrations have been presented recently which are applicable to the MRVE combination structures [33–35].

The stochastic microvibration of an MRVE sandwich plate under an incompletely covering magnetic field has been considered [36], but the mass such as apparatus with disturbance susceptivity supported on the plate was not included. In this paper, a horizontal MRVE sandwich beam with supported mass is considered, which model is more realistic. The microvibration response of the beam system under random support disturbances is studied. The localized magnetic field covering incompletely the beam is considered so that the MRVE complex modulus is non-homogeneous and depends on the spatial distribution of the magnetic field. Firstly, the vibration equations of the beam system under the localized magnetic field are derived. Secondly, the equations are transformed into those in the modal space, and solved in the frequency domain. Thirdly, the root-mean-square (RMS) velocity of the beam system as the microvibration criterion is given. Finally, numerical results are obtained to exhibit the stochastic microvibration control effectiveness of the MRVE sandwich beam and the effects of the localized magnetic field intensity and placement on the microvibration response.

2. Vibration equations of an MRVE sandwich beam under localized magnetic field

Consider a horizontal MRVE sandwich beam with supported mass under random support disturbances and localized magnetic fields, as shown in Fig. 1. The two surface layer materials are linear elastic and have an equal elastic modulus, E_1. The MRVE core material is viscoelastic and has a complex shear modulus, G_{2m}, for microvibration [18]. The supported mass is fixed at the mid of the beam and has a mass per unit length and width, m_c. The support disturbances have an equal vertical displacement v_0 or acceleration $\ddot{v}_0$.

The main assumptions for the sandwich beam are: (1) two surface layers and core materials are homogeneous and continuous, respectively; (2) normal stresses in the core are neglected by comparing with those in the surface layers; (3) normal stresses of the surface layers in the y-axis direction are neglected by comparing with those in the x-axis direction; (4) the

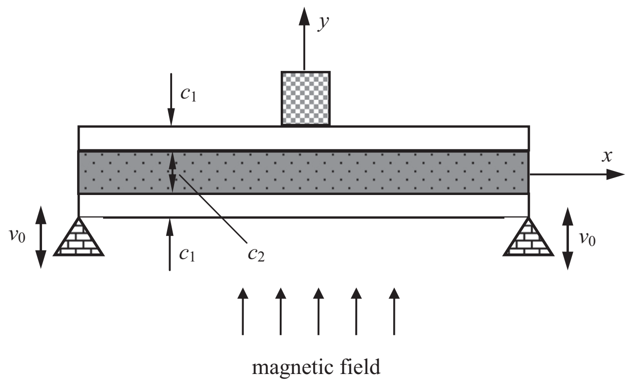

Fig. 1. A sandwich beam with MRVE core and mass under localized magnetic field.