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Review

Advances in structural vibration control application of magneto-rheological visco-elastomer

Zuguang Ying [a,*], Yiqing Ni [b]

[a] Department of Mechanics, School of Aeronautics and Astronautics, Zhejiang University, Hangzhou 310027, China
[b] Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong, China

HIGHLIGHTS

- New advances in structural vibration control using magnetorheological viscoelastomer.
- Dynamic optimization of periodic MR viscoelastomer sandwich structures.
- Optimal vibration control of parameter-excited MR viscoelastomer sandwich structures.

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ABSTRACT

Magneto-rheological visco-elastomer (MRVE) as a new smart material developed in recent years has several significant advantages over magneto-rheological liquid. The adjustability of structural dynamics to random environmental excitations is required in vibration control. MRVE can supply considerably adjustable damping and stiffness for structures, and the adjustment of dynamic properties is achieved only by applied magnetic fields with changeless structure design. Increasing researches on MRVE dynamic properties, modeling, and vibration control application are presented. Recent advances in MRVE dynamic properties and structural vibration control application including composite structural vibration mitigation under uniform magnetic fields, vibration response characteristics improvement through harmonic parameter distribution, and optimal bounded parametric control design based on the dynamical programming principle are reviewed. Relevant main methods and results introduced are beneficial to understanding and researches on MRVE application and development.

Contents

1. Introduction

The vibration control of both engineering structures subjected to strong excitations and vibration-sensitive apparatuses subjected to micro disturbances is a significant research subject. The purpose of structural vibration control is to improve vibration

* Corresponding author.

E-mail address: yingzg@zju.edu.cn (Z.G. Ying).

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response characteristics which can be performed by dynamic optimization and dynamical programming. Supplementing structural damping and stiffness is adopted generally for reducing vibration response. The adjustability of structural dynamics is required due to the randomness of environmental excitations. Smart materials such as magneto-rheological liquid can supply adjustable damping and stiffness for structures, and the adjustment of dynamic properties is achieved only by applied magnetic fields with changeless structure design. Extensive researches on structural vibration suppression using magneto-rheological liquid dampers and magneto-rheological liquid composite structures have been presented [1–8]. In recent years, magneto-rheological visco-elastomer (MRVE) has been developed, because it has several significant advantages over magneto-rheological liquid, for example, the improvement of magnetic particle settlement in magneto-rheological liquid and suitability for composite structure cores. Researches on MRVE dynamic properties, modeling and vibration control application have been presented [9–45].

MRVE is a smart composite material, which consists of magnetically polarizable particles and non-magnetic polymers, for example, iron particles, silicone oil, and rubber [10,24]. It combines the advantageous dynamic properties of magneto-rheological fluid and visco-elastic substrate materials, including stiffness and damping changed reversibly under external magnetic fields applied in milliseconds. Many researches have been presented on MRVE fabrication, improvement, and test for magnetic-mechanical properties and dynamic behaviors [11–20]. A static modeling for MRVE shear modulus has been given based on magnetic dipole interaction and polymeric nonlinear elasticity [14,21,22]. A complex modulus based on polymer dynamics in frequency domain has been used frequently for describing MRVE dynamic properties [19,23]. However, the complex modulus describes only MRVE linear dynamic properties in small deformation. A nonlinear hysteretic model for MRVE dynamics has been proposed further for certain large deformation [24]. MRVE based tunable vibration isolators, absorbers and dampers, and magneto-rheological fluid-elastomer composite dampers have been designed and tested for vibration control application [25–29].

In particular, MRVE composite structures with controllable dynamic properties have been studied, including periodic vibration, frequency response characteristics, dynamic stability, stochastic micro-vibration response, and dynamics under localized uniform magnetic fields [30–42]. The MRVE composite structures with area energy dissipation effectively suppress deterministic and stochastic vibration. However, the structural vibration control effectiveness is improvable and two new progresses have been made recently in the vibration control of MRVE composite structures. The non-uniform spatial distribution of structural dynamic responses has been considered, and MRVE sandwich structures with continuous harmonic distribution parameters under stochastic excitations have been studied [43]. The harmonic parameter distribution can improve greatly structural vibration response characteristics and reduce stochastic responses. On the other hand, MRVE properties such as stiffness and damping are adjustable by applied magnetic fields. The optimal adjustment of MRVE composite structures based on the dynamical programming principle can exert complete MRVE properties and achieve further vibration control effectiveness. Note that MRVE stiffness and damping are represented as composite structure parameters and bounded due to magnetic-mechanical saturation. The optimal bounded parametric control for MRVE composite structures under stochastic and shock excitations has been proposed and further remarkable vibration suppression effectiveness has been obtained [45]. This review paper focuses on the MRVE dynamic properties and modeling, composite structural vibration mitigation under uniform magnetic fields, vibration response characteristics improvement through harmonic parameter distribution, and optimal bounded parametric control design based on the dynamical programming principle. Main methods and results relevant to MRVE dynamic modeling and vibration control application are introduced respectively in the following four sections.

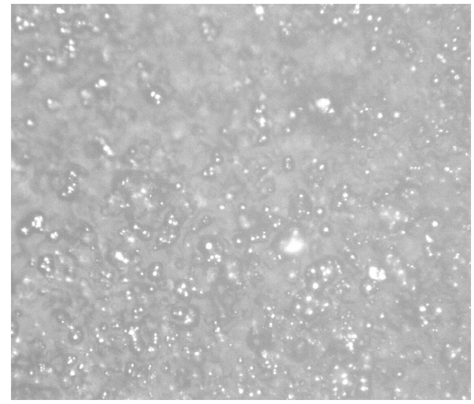

Fig. 1. MRVE section micrograph (500 optical magnification).
Source: Reproduced from Ref. [24].

2. Dynamic models of MRVE

MRVE specimens are fabricated generally by using silicone rubber, silicone oil, and carbonyl iron particles. Iron particles are used as magnetic fillers, silicone oil is used for performance regulator and silicone rubber is used as matrix material. According to certain ingredient percentage, iron particles are dispersed thoroughly in silicone oil, and the blended liquid is mixed with silicone rubber. The homogeneous mixture is poured into a mold and cured under certain temperature conditions. The micrograph of inner planar section of an MRVE specimen is shown in Fig. 1 [24]. In curing, magnetic fields can be applied to produce aligned MRVE specimens which are transversely isotropic and have better magnetic-mechanical properties. Tension, compression, and shear tests of MRVE specimens under applied magnetic fields were performed firstly for static magnetic-mechanical properties. The magnetic softening rigidity in tension, hardening rigidity in compression, and nonlinear stress–strain relationship for larger deformation of MRVE were observed [24]. A static modeling for MRVE shear modulus has been proposed based on magnetic dipole interaction and polymeric nonlinear elasticity [14,21,22]. However, dynamic characteristics have not been incorporated in the model. Dynamic behaviors of MRVE specimens under applied magnetic fields are tested by tension–compression and shear circulations with different frequencies. The MRVE dynamic stiffness increasing with magnetic field intensity was observed. A complex modulus based on polymer dynamics in frequency domain has been proposed for describing MRVE dynamic properties [19,23]. MRVE dynamic force generally consisting of elastic force and damping force can be separated equivalently. The complex modulus can be separated correspondingly into real part and imaginary part. For example, the complex shear modulus is expressed as

$$G(\omega, B_{\mathrm{m}}) = G_{\mathrm{R}}(\omega, B_{\mathrm{m}})[1 + \mathrm{j}\Delta(\omega, B_{\mathrm{m}})], \quad (1)$$

where real part G_{R} is called storage modulus representing viscoelastic stiffness, imaginary part $G_{\mathrm{R}}\Delta$ is loss modulus, Δ is called loss factor representing viscoelastic damping, ω is vibration frequency, B_{m} is magnetic field intensity, and $\mathrm{j} = \sqrt{-1}$. The real modulus and loss factor dependent on vibration frequency can be expressed approximately as

$$G_{\mathrm{R}}(\omega, B_{\mathrm{m}}) = \sum_{i=0}^{N_{\mathrm{m}}} \alpha_i(B_{\mathrm{m}})\omega^i, \quad \Delta(\omega, B_{\mathrm{m}}) = \sum_{i=0}^{N_{\mathrm{l}}} \beta_i(B_{\mathrm{m}})\omega^i, \quad (2)$$