Acta Mechanica Solida Sinica, Vol. 28, No. 1, February, 2015 ISSN 0894-9166
Published by AMSS Press, Wuhan, China

VIBRATION SUPPRESSION OF CANTILEVER LAMINATED COMPOSITE PLATE WITH NONLINEAR GIANT MAGNETOSTRICTIVE MATERIAL LAYERS**

Yongfei Zhang[1,2] **Haomiao Zhou**[3] **Youhe Zhou**[1,2*]

([1] *Key Laboratory of Mechanics on Disaster and Environment in Western China, the Ministry of Education of China, Lanzhou University, Lanzhou* 730000*, China*)
([2] *Department of Mechanics and Engineering Sciences, College of Civil Engineering and Mechanics, Lanzhou University, Lanzhou* 730000*, China*)
([3] *College of Information Engineering, China Jiliang University, Hangzhou* 310018*, China*)

Received 18 February 2013, revision received 4 September 2013

ABSTRACT In this paper, a nonlinear and coupled constitutive model for giant magnetostrictive materials (GMM) is employed to predict the active vibration suppression process of cantilever laminated composite plate with GMM layers. The nonlinear and coupled constitutive model has great advantages in demonstrating the inherent and complicated nonlinearities of GMM in response to applied magnetic field under variable bias conditions (pre-stress and bias magnetic field). The Hamilton principle is used to derive the nonlinear and coupled governing differential equation for a cantilever laminated composite plate with GMM layers. The derived equation is handled by the finite element method (FEM) in space domain, and solved with Newmark method and an iteration process in time domain. The numerical simulation results indicate that the proposed active control system by embedding GMM layers in cantilever laminated composite plate can efficiently suppress vibrations under variable bias conditions. The effects of embedded placement of GMM layers and control gain on vibration suppression are discussed respectively in detail.

KEY WORDS giant magnetostrictive materials, nonlinear constitutive model, active vibration suppression, cantilever laminated composite plate

I. INTRODUCTION

Some magnetic materials located in an applied magnetic field can elongate or contract. The generated strains are attributed to the realignment of a large amount of magnetic domains caused by spontaneous magnetization. This phenomenon is called magnetostriction. Giant magnetostrictive materials (GMM) have some distinctive advantages over other smart materials, for example, the ability to generate large forces at a voltage lower than that of piezoelectric ceramic material (PZT), to react more rapidly than shape memory alloy (SMA), to retain their properties even after being ground into particles. It can also be embedded in host materials and then laminated with carbon fiber reinforced plastics (CFRP) or glass fiber reinforced plastics (GFRP) easily without losing the integrity of the whole host structure.

* Corresponding author. E-mail: zhouyh@lzu.edu.cn
** Project supported by the National Natural Science Foundation of China (Nos. 10972094, 11032006, 11172285, 11121202 and 11202087), the Fundamental Research Funds for the Central Universities (lzujbky-2011-6) and the Specialized Research Fund for the Doctoral Program of Higher Education under Grant 20110211120027 and the Zhejiang Provincial Natural Science Foundation of China (No. LR13A020002).

Such distinctive advantages motivate many researchers to investigate the applications of GMM in many aspects such as high power ultrasonic transducers, linear motors, micro pumps, micro valves, micro positioners and active vibration absorbers[1–3].

In recent years some researchers have especially focused on investigation of design and theoretical research in active control of flexible beams/plates with GMM as the actuating layer[4–10]. But the linear constitutive relations for GMM are usually selected in their work so that the control system is characterized by linearity. As a matter of fact, it has often been shown by experiment that an inherent nonlinearity exits between an applied magnetic field and deformation in GMM[11,12]. This means the control system based on the linear constitutive relations is only tenable and effective in a narrow approximately linear region on the deformation versus applied magnetic field curves of GMM. Recently, Zheng and Liu have developed an analytically theoretical model to fully describe the experimental results[13]. To utilize the full potential of GMM, based on this nonlinear and coupled constitutive model, some extended investigations have been carried out. Sun and Zheng studied the coupling behavior of Terfenol-D rods[14]. Zhou and his co-workers investigated the active vibration control of Terfenol-D rods and laminated composite beams[15,16].

In this paper, based on the nonlinear and coupled constitutive model[13] and the negative feedback control law, a finite element formula for active vibration suppression of cantilever laminated composite plate with nonlinear GMM layers is presented and solved. First, the Hamilton principle is used to derive the governing differential equations in §II. After that, the nonlinear and coupled governing equations are solved by adopting the Newmark method and an iteration process in §III. Then in §IV, numerical simulations of the active vibration suppression process are performed on a 10-layered cantilever plate containing one GMM layer at the bottom and nine CFRP layers on top. The effects of pre-stress, bias magnetic field and embedded placement of GMM layers with respect to laminated mid-plane are also simulated in this section. Finally the paper is concluded with some conclusions in §V.

II. GOVERNING EQUATIONS OF DEFLECTION

2.1. Strain Fields

Consider a laminated composite cantilever plate composed of n layers with the mth layer made by setting Terfenol-D particles in a suitable resin, such as epoxy. The remaining $n-1$ layers are made of a fiber-reinforced material such as CFRP. All the layers are of uniform thickness and bonded together without any possibility of slip. In the present analysis the weights of resin and glue are ignored. Thus, the parameters of monolithic GMM are chosen for the embedded composite Terfenol-D layer in the present research. A schematic of a laminated composite cantilever plate with one GMM layer is depicted in Fig.1.

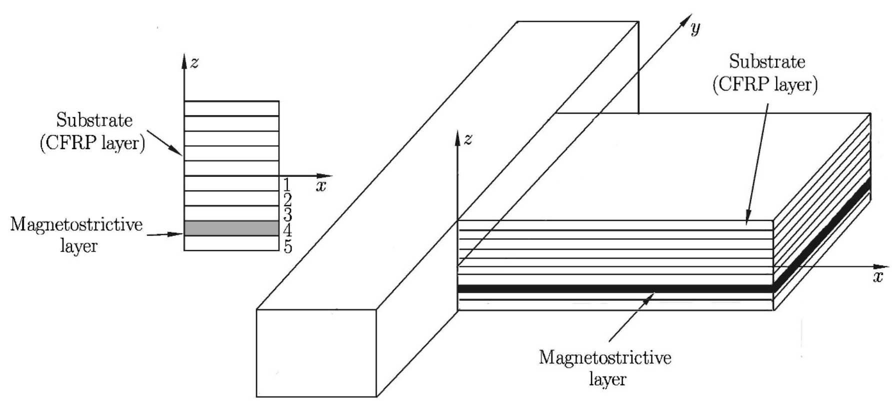

Fig. 1. Schematic of a cantilever laminated composite plate.