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A feedback control system for vibration of magnetostrictive plate subjected to follower force using sinusoidal shear deformation theory

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Velocity feedback gain

Abstract In this research, the vibrational behavior of magnetostrictive plate (MsP) as a smart component is studied. The plate is subjected to an external follower force and a magnetic field in which the vibration response of MsP has been investigated for both loading combinations. The velocity feedback gain parameter is evaluated to study the effect of magnetic field which is generated by the coil. Sinusoidal shear deformation theory is utilized due to its accuracy of polynomial function with respect to other plate theories. Equations of motion are derived using Hamilton's principle and solved by differential quadrature method (DQM) considering general boundary conditions. The effects of aspect ratio, thickness ratio, follower force and velocity feedback gain are investigated on the frequency response of MsP. Results indicate that magneto-mechanical coupling in MsM helps to control vibrational behaviors of systems such as electro-hydraulic actuator, wireless linear Motors and sensors.

1. Introduction

Joule [1] is the first person who discovered the magnetostrictive effect or Joule's effect in 1842. He studied length change in iron and measured it as a result of magnetization. Villari in 1864 observed that the permeability of ferromagnetic materials depends on the stress state [2]. This phenomenon is the inverse of Joule effect and now called Villari's effect [3].

After the discovery of Joule and Villari effects, investigation about magnetostriction began. All of ferromagnetic materials have inherent properties that generate magnetostrictive effects due to motion of electrons. In the structure of an atom, orbital magnetic moment is due to electron revolution about the nucleus and spin magnetic moment is generated by electron spinning about its own axis. The superposition of orbital and spin magnetic moment is called atomic magnetic moment. Magnetic domain is a small region containing 109–1015 atoms, in which the orientations of all atomic magnetic moments are the same because of the spontaneous magnetization.

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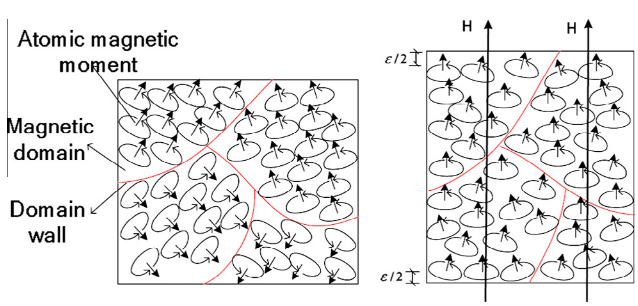
Ferromagnetic materials exhibit magnetism on macroscopic scale when they are subjected to external magnetic field [4]. Scientists use this property in design of new structures or to control the disruptive behaviors of the systems and many other applications (see Fig. 1).

The brief reports cited above, show the complexity and interesting aspects of this topic. In this regard, some published papers have been collected to review before introducing present work.

Free vibration problem of two-dimensional magneto-electro-elastic laminate plate was investigated by Ramirez et al. [6]. In this work, the composite plate was made of linear homogeneous elastic, piezoelectric, or magnetostrictive layers considering perfect bonding between two layers. They used Ritz method to obtain displacements, electric potential, and magnetic potential with combining discrete layers. Liu [7] investigated an exact deformation analysis for the magneto-electro-elastic (MEE) fiber-reinforced thin plate. In this regard some characteristics such as elastic displacements, electric potential and magnetic induction for MEE rectangular plate were studied using Kirchhoff's thin-plate theory. Research about nonlinear principal resonance frequency of an orthotropic and magneto-elastic rectangular plate was done by Xue et al. [8]. Applying a transverse magnetic field and a transverse harmonic mechanical load, the nonlinear vibrational equation for an orthotropic thin plate was derived based on the von Karman plate theory. In this research, the effect of magnetic field, orthotropic material property, plate thickness and mechanical load on the principal resonance behavior was investigated. Based on the nonlinear constitutive equation for giant MsM and linear constitutive relationships for piezoelectric material, a theoretical model was proposed for nonlinear magneto-electric (ME) response in trilayer laminated composites by Yu et al. [9]. The equivalent circuit method was utilized to characterize the ME response considering mechanical losses.

In continuation of related papers, Hong [10,11] presented the transient response of MsPs with and without shear effects in two separate papers. In these works, the variation of thermal stresses and center displacement was studied on transient response of thin and thick plates. His results indicated that some parameters could be controlled to desirable values with suitable velocity feedback control gain value. From now on, the referred papers focus on high-order shear deformation plate theory.



(a) (b)

Figure 1 (a) Spontaneous magnetism and random orientation of magnetic moments without external field and (b) the alignment of moments under an external magnetic field [4,5].

Vibration and buckling equations of symmetric laminated plates with various boundary conditions were developed by Nosier and Reddy [12]. In the first part, they derived Levinson's third-order shear deformation theory from Reddy's third-order theory to study a laminated plate composed of transversely isotropic layers. In the second part, they derived the first-order shear deformation theory and the third-order theory of Reddy to study the vibration and buckling of plates. Free vibration of a functionally graded (FG) piezoelectric rectangular plate was investigated by Chen and Ding [13]. Two independent state equations with variable coefficients were derived based on three-dimensional elasticity theory. Considering different boundary conditions at four edges, the exact closed-form solutions were obtained. Free vibration analysis of composite plate assemblies was studied using symbolic computation by Fazzolari et al. [14]. For the first time they developed an exact dynamic stiffness method based on higher-order shear deformation theory. Mantari and Guedes Soares [15] developed a new trigonometric higher-order theory by considering stretching effect. They investigated a FG plate subjected to transverse bi-sinusoidal load and used Navier-type solution for simply supported boundary conditions. To evaluate the accuracy of results, they compared their conclusion with 3D exact solution and other higher-order shear deformation theories. Thai and Kim [16] developed a simple quasi-3D sinusoidal shear deformation theory for bending of FG plates with considering both shear deformation and thickness stretching effects. They used analytical solutions for simplified equations with simply supported edges. Also they compared the accuracy of results with 3D and quasi-3D solutions and those predicted by higher-order shear deformation theories. They concluded that the obtained results are more accurate than those obtained by higher-order shear deformation theories.

Hamidi et al. [17] presented a new four variable refined plate theory for thermo-mechanical bending analysis of FG sandwich plates. In their work, the number of unknown functions was only four, unlike any other shear deformation theory. This theory did not require shear correction factor and satisfied shear stress free surface conditions. They validated the result by the classical, the first-order and the other higher-order theories. They concluded that the proposed theory is accurate and simple in solving such a problem.

Despite the above mentioned researches, free vibration analysis of MsP using sinusoidal shear deformation theory is a novel topic that cannot be found in the literature. Moreover, MsP is subjected to a tangential surface force which follows the geometry of the system that is called follower force. This is used to control the vibrational behavior of system. Another control parameter is velocity feedback gain which significantly reduces the frequency to desired value. It is assumed that magnetic field is generated by the electric coil and its magnitude varies with coil constant and coil current. In this regard, the velocity feedback gain is defined as a control parameter. Considering above conditions, the effect of various parameters such as the thickness ratio and aspect ratio is studied and results are presented in the form of tables and figures. The results of this work introduce important control factors in vibrational behaviors of MsPs that can help the engineers to design and control new structures.