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Smart Beams: A Semi-Analytical Method

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8.1 Introduction

One of the key challenges in structural engineering is to find better ways to control structural vibrations so as to better protect the structures from vibration-induced damages. Structural control methods can be classified into two main groups: passive control and active control. The basic role of passive control is to absorb or consume a portion of the input energy, thereby reducing the energy dissipation demand on the primary structural members and minimizing possible structural damage. On the other hand, in active control, the motion of a structure is controlled or modified by means of the action of a control system, which usually consists of sensors, actuators and controller, through certain external energy supply.

Comparing with passive control, research and development of active structural control technology has a more recent origin. In active control, the effects of undesirable forces are counteracted by an auxiliary mechanism either embedded in or bonded to the structures. The mechanism typically uses electromechanical or electromagnetic actuators, such as piezoelectric actuators. Due to the converse piezoelectric effects, a polarized piezoelectric device, when activated by applying a voltage along its polarization direction, develops compressive or extensional strains, depending upon the orientation of the applied voltage; whereas due to the direct piezoelectric effect, it generates a voltage if mechanically deformed (Ikeda, 1990). The converse and direct piezoelectric effects enable the piezoelectric materials to serve as both actuator and sensor.

Owing to its enhanced control effectiveness and significant advantages in
comparison with passive control, active vibration control of structures has attracted much attention in recent years. In particular, with the rapid development of piezoelectric materials in the past two decades, there has been extensive research on the application of piezoelectric materials as actuators and/or sensors to actively control structural vibrations. These works include solving problems in the fields of civil, mechanical and aerospace engineering, especially for structural elements like beams, plates and shells.

In 1985, Bailey and Hubbard introduced a novel technique which allowed all modes of a cantilever beam to be controlled using a spatially, uniformly distributed PVDF actuator. A linear constant-gain controller, a nonlinear constant-amplitude controller and a Lyapunov controller were designed in their study, and the first two were implemented experimentally (Bailey and Hubbard, 1985). Gaudenzi et al. (1997) demonstrated the feasibility of vibration suppression in aluminum and composite cantilever beams by a simple single-input single-output control system that utilized PZT patches as actuator and sensor. Librescu and Na (1998a; 1998b) dealt with the problem of controlling bending oscillations of a cantilever beam modeled as closed cross-section thin-walled beam and incorporating a number of non-classical effects, such as transverse shear, secondary warping, and heterogeneity, through a combined feedback control method.

Shih (2000) presented a mathematical model to study the effectiveness of active vibration control of a simply supported piezoelectric laminated curved beam. The model included the mass and stiffness of sensor/actuator for a more accurate representation of the actual system. Sun and Huang (2001) derived an analytical formulation for modeling the behavior of laminated composite beams with integrated piezoelectric sensor and actuator. Their model was based on the first-order shear deformation theory (Mindlin plate theory) and included the coupling between mechanical and electrical deformations.

Gardonio and Elliott (2005) theoretically studied the flexural vibration of a beam with a control system which implemented direct velocity feedback using either an ideal collocated force actuator or a closely located piezoelectric patch actuator. They found that, as the control gain increased, the vibration of the beam initially reduced at resonance frequencies because of the active damping effect. However, when the control gain passed an optimal value, the vibration of the beam rearranged into a new set of lightly damped resonance frequencies since the control system imposed new boundary conditions at the control position on the beam. Vasques and Rodrigues (2005) developed a fully coupled electromechanical FE formulation of a three-layered smart beam with two piezoelectric layers acting as sensors or actuators. A partial layer-wise theory was considered for the approximation of the displacement field of the core and piezoelectric layers, and an electrical model for different electric boundary conditions was adopted.

Lin and Liu (2006) designed a novel resonant fuzzy logic controller (FLC) to minimize structural vibration using collocated piezoelectric actuator/sensor pairs. The fuzzy controller increased the damping of the structures to minimize certain resonant responses. The vibration absorber was experimentally examined using a cantilever beam for impulse and near-resonant excitation cases. Karami-Mohammadi