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Genetic algorithm based wireless vibration control of multiple modal for a beam by using photostrictive actuators

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ABSTRACT

The lanthanum-modified lead zirconate titanate (PLZT) actuator, which are capable of converting photonic energy to mechanical motion, have great potential in applications of remote structural vibration control of smart structures and machines. In this paper, a novel genetic algorithm based controlling algorithm for multi-modal vibration control of beam structures via photostrictive actuators is proposed. Two pairs of photostrictive actuators are laminated with the beams and the alternation of light irradiation is in accordance with the changing of the corresponding modal velocity direction. The modal force indexes for beams with different boundary conditions are derived and a binary-coded GA is used to optimize the locations and sizes of photostrictive actuators to maximize the modal force index and guarantee the overall modal force index induced by two pairs of photostrictive actuators is positive. The control effect of multiple vibration modes of beams under irradiation of set/variable light intensity is analyzed. Numerical results demonstrate that the method is robust and efficient, and the use of strategically positioned actuator patches can effectively control the first two bending modes that dominate the structural vibration.

1. Introduction

In recent years, the traditional electromechanical transducers (such as piezoelectric, electrostrictive, and magnetostrictive actuators) have been widely used in structural vibration control [1–3]. However, requiring hard-wired connections to transmit the control signals, conventional actuators have external electromagnetic fields existence. This metallic signal wires are likely to induce electrical noise that will contaminate the control signals. The photostrictive actuators with light weight and small size do not need the hard-wire, so is immune to electromagnetic interference. And the optical materials could be applied for the non-contact actuation and remote control in the smart structure [4]. Hence, this kind of photostrictive materials can solve the problem faced in structural vibration control using the traditional electromechanical transducers, and enjoy a broad development prospects.

The lanthanum-modified lead zirconate titanate material, called PLZT, could be used to make photostrictive actuator. This actuator exhibits large photostriction under uniform illumination of high-intensity light. The photostriction mechanism arises from a superposition phenomenon of photovoltaic and converse piezoelectric effect. And mechanical strain is induced due to the converse piezoelectric effect of the photostrictive materials. Therefore, the constitutive equations of the photostrictive materials should involve both photovoltaic effects and piezoelectric effects [5]. In the last decades, there is emerging some research on the application of photostrictive actuator in active structural control, but relevant research are still in the

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initial stage and not mature. Liu and Tzou [4] proposed a wireless vibration control method of plates using distributed photostrictive actuators. Since the pioneering work of Liu and Tzou [4], some researchers have investigated vibration control of PLZT actuated structures, such as plate structures [6,7], cylindrical shells [8,9], shallow spherical shells [10] and parabolic shell [11]. Zheng [12] presented the finite element simulation of wireless structural vibration control with photostrictive actuators. Chen and Zheng [13] proposed a binary-coded GA based combined optimal placement and LQR control scheme to maximize the closed loop damping and minimize input light intensity to the actuators. The analytical models of a beam with photostrictive actuators have also been derived and the applications of photostrictive actuators for shape [14], displacement [15] and vibration control [16] have been evaluated. Shih et al. proposed a method to seek the optimum position and size of the segmented actuators on the beam with different boundary conditions [17].

From the literature review, it has been observed that some works are available in the form of active wireless vibration control of smart structures. However, as far as the authors are aware, all of the past works in the area of wireless vibration control have focused on the investigation of single mode vibration control [4–17]. In order to verify the feasibility of multiple modal control of the photostrictive laminated structure, this paper addresses the controllability aspect in multiple modal vibration control of beam structures via photostrictive actuators. It is worth noting that the behaviors of photostrictive actuators are different from usual piezoelectric actuators. The main difference is that the light intensity is always positive and the deformation of the photostrictive actuators is always tensile, too. However, the electrical voltage input can be positive or negative to induce the piezoelectric actuators to deform in extension or contraction [18]. So the light illumination should be alternatively applied to the top and bottom photostrictive actuators to induce positive or negative bending moment. Due to the inconsistency of switching actuation, the multiple modals will interfere with each other. It is very probable that one modal will be incited, simultaneously another modal is suppressed. To the best knowledge of the authors, there are no research works reported to optimize the locations and sizes of photostrictive actuators for multiple modal vibration control. In this paper, a novel genetic algorithm based controlling algorithm for multi-modal vibration control of beam structures via photostrictive actuators is proposed. Two pairs of photostrictive actuators are laminated with the beams and the alternation of light irradiation is in accordance with the changing of the corresponding modal velocity direction. A total modal force index, which has taken into account the mode number, the spatial distribution, and the dimension of the actuators, is chosen as an objective function to determine the optimal locations of photostrictive actuators. A binary-coded GA is used to optimize the location and size of photostrictive actuators to maximize the modal force index and guarantee the overall modal force index induced by two pairs of photostrictive actuator is positive.

2. An opto-electromechanical actuator

The photostrictive optical actuator is shown in Fig. 1, with length *a* and width *b*. The polarization is in the *x* direction and the $y-z$ planes are the planes of the electrodes. When the high-energy illumination is irradiated on the photostrictive actuator, due to the photovoltaic effect, the light causes a voltage generation between the end surfaces paired electrodes. And the converse piezoelectric effect makes the induced photovoltaic voltage (E_l), and induces actuation strains along its polarization direction. In the meantime, the light energy also heats up the opto-electromechanical actuator and the body temperature of the actuator rises. This temperature change $\theta(t)$ would trigger the pyroelectric effect and generate an additional voltage $E_\theta(t)$, and also could induce strain.

The photovoltaic voltage E_l and the pyroelectric voltage $E_\theta(t)$ can be expressed as

$$E_l(t) = [E_s - E_l(t_0)]\left[1 - e^{-(\alpha/\alpha_s)I(t)\Delta t}\right], \tag{1}$$

$$E_\theta(t) = \frac{P_n}{\varepsilon}\theta, \tag{2}$$

where $I(t)$ is the light intensity. The induced electric field $E_l(t)$ and the temperature change $\theta(t)$ at the time instant t_j can be estimated

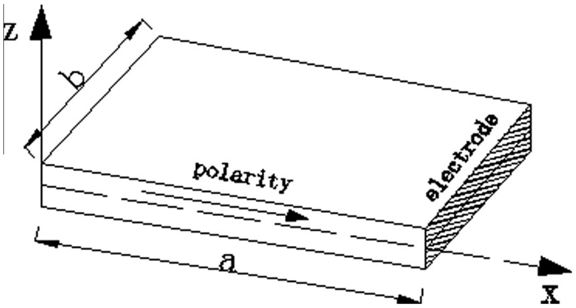

Fig. 1. Photostrictive optical actuator.