Vibration Behaviors of Stiffened Plates with Piezoelectrics under Blast Loads

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1. Introduction

Recently, studies relevant to the use of piezoelectric materials as sensors and actuators to control the vibration of structures are extensively addressed in the literatures. That is to say, the applications of the piezoelectric materials include shape control, size control, active damping and vibration suppression etc. First of all, there are two main characteristics to be used as sensors or actuators. Direct piezoelectric effect is that the materials generate an electric charge when subjected to a mechanical deformation. Conversely, they are deformed if some electric charge is imposed to them, which is called the converse piezoelectric effect. Using these characteristics, active structures constructed with piezoelectric sensors and actuators have self-inspection and inherent adaptive capabilities.

Many researchers have investigated laminated composite structures with integrated piezoelectric sensors and actuators. Hwang and Park [1] used the finite element method to simulate the active damping control with piezoelectric actuators, and employed the classical laminated plate theory (CLPT). On the other hand, Chen et al. [2] applied the first-order shear deformation theory (FSDT) of plate to the finite element formulations. Further, the amplitude-frequency and the phase-frequency characteristics of the closed-loop system were studied. Reddy [3] shows theoretical formulations, the solutions and finite element models based on the classical and shear deformation plate theories for the analysis of laminated composite plates with integrated sensors and actuators and subjected to both mechanical and electrical loadings.

An application of stiffened laminated composite plate has greatly enhanced structures for aircraft, aerospace and other industries. In the application, the stiffened laminated composite plates are subjected to different loading conditions such as air blast loading.

In this paper, it is investigated the active vibration control of stiffened laminated plates subjected to normal blast shock wave with piezoelectrics. A laminated composite plate with PZT piezoceramic layers embedded on top and bottom surfaces to act as sensor and actuator is considered. The formulation is based on the first-order shear deformation theory of plates, and the extended Hamilton's principle is used to derive the finite element equation of motion. Finite element method is adopted by using a nine-node plate element and three-node beam element. A simple negative velocity feedback control algorithm is adopted in the active control. Numerical model in this study is validated by comparison with previous data. Numerical examples for vibration control of stiffened laminated plates subjected to blast load are discussed in detail. The effect of control gain on the responses of the cantilevered plate is considered. Additionally, the effect of the piezoelectric patch's position also studied.

2. Modeling

Figure 1 shows the model for a piezo-laminated composite plate which is reinforced with stiffeners. For the simplicity, the stiffeners are assumed to be placed parallel to the geometric coordinates *x* and *y*.

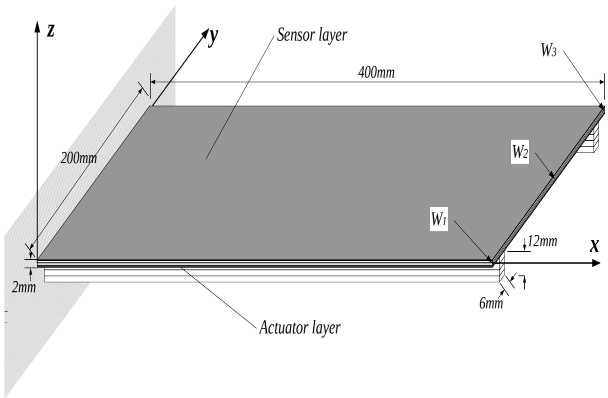

Fig. 1 Cantilevered composite plate with two x-stiffeners and piezoelectric sensors and actuators

The k^{th} layer's linear piezoelectric coupling between the elastic field and the electric field can be expressed by the direct and the converse piezoelectric equations, respectively. The transformed equations of a piezoelectric material can be written as

$$\mathbf{D}_k = \mathbf{e}_k \boldsymbol{\varepsilon}_k + \in_k \mathbf{E}_k, \qquad \boldsymbol{\sigma}_k = \mathbf{Q}_k \boldsymbol{\varepsilon}_k - \mathbf{e}_k^T \mathbf{E}_k \tag{1}$$

where $\boldsymbol{\varepsilon}$, $\boldsymbol{\sigma}$, $\mathbf{D}$ and $\mathbf{E}$ are strain, stress, electric displacement and electric field vectors, and

$\mathbf{e}$, $\in$ and $\mathbf{Q}$ are piezoelectric constants, permittivity coefficients and plane-stress reduced elastic constants matrices, respectively. Equation (1) describes the 'direct piezoelectric effect' and equation (2) describes the 'converse piezoelectric effect'.

The stiffened plate element is composed of a plate element and a number of stiffener elements. Both the plate and stiffeners are assumed to be made up of laminated composites. Using the first-order shear deformation theory (FSDT) are used. The strains of plate are expressed as a function of the nodal displacement variables by using finite element method. Extended Hamilton's principle is applied.

The sensor voltage is fed back into the actuator. Using a constant gain control algorithm, the actuating voltage can be expressed as

$$V_a = G_i V_s = G_i G_c \frac{dq(t)}{dt} = G \sum_{j=1}^{N_s} \mathbf{K}_{sv}^{j} \dot{\boldsymbol{\delta}} \qquad (2)$$

where G_i is the gain to provide feedback control.

Finally, the global dynamic equation as follows

$$\mathbf{M}\ddot{\boldsymbol{\delta}} + \left(\mathbf{C} - \mathbf{K}_{av}\mathbf{G}\mathbf{K}_{sv}\right)\dot{\boldsymbol{\delta}} + \mathbf{K}\boldsymbol{\delta} = \mathbf{F} \qquad (3)$$

3. Numerical results

The plate is bonded at the upper and lower surfaces by piezoelectric ceramics. The material properties of the composite plate (T300/976 graphite-epoxy) and the piezoceramic (PZT G1195N) are used. The Newmark- β direct integration method is used to calculate the transient response of the plate.

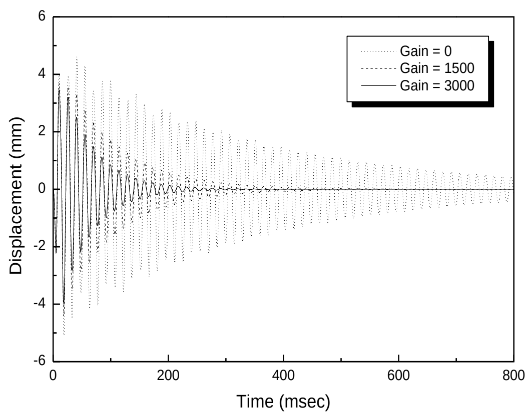

Fig. 2 Responses of the vertical displacement of the model with various control gains

Figure 2 shows the responses of the vertical displacement of the model with various control gains. The piezoelectric sensors and actuators can control the first, second and third bending modes effectively, and the vibration is damped out more quickly for higher control parameter.

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