A NEW TYPE THERMOELASTIC COMPOSITE WITH DISPERSED PZT PARTICLE LAYERS IN PIEZO-CONTROL FORCED VIBRATIONS

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Introduction

Application of smart structures to vibration control may be traced to Baily and Hubbard [1]. Ha and coworkers [2] developed a three-dimensional composite finite element method for modeling the dynamic and static response of laminate structures containing piezoelectric sensors and actuators. Based on Hamilton's principle and finite methods, the numerical results are presented for cases of a prescribed thermal loading and the conventional piezo-control of the forced vibrations in a thermoelastic composite plate caused by sudden mechanical loading [3]. The simulated annealing algorithm is used to achieve a mechanism of active control of the structure dynamic response. Lin and Nien [4] derived a theoretical formulations based on damping modal actuator/sensor for the analysis of laminated composite beam with integrated sensors and actuators. Dynamic response with velocity feedback control of a rectangular composite plate in free vibration and force-induced vibration is conducted in this report. Harmonic vibration with different values of control gains are conducted under sinusoidal loading to investigate the thermal loading, axial force and gain value effect on composite plate.

Finite element formulation

The incorporation of Hamilton's principle, the work done by the shear force on the displacement for a laminate composite plate may be derived as

$$\int_1^2 (\delta u + \delta v + \delta k)dt = 0 \qquad (1)$$

Integrating through the structure, the approximate equation of motion can be derived as

$$\int_1^2 \int_v [p\dot{u}\delta u - \sigma_{ij}\delta\varepsilon_{ij} + D_{ij}\delta E_{ij}]dvdt + \int_1^2 \int_v [F_b \delta u]dvdt + \int_1^2 \int_s [F_s \delta u]dsdt + \int_1^2 F_c \delta u dt + \int_1^2 \int_3 [q\delta\phi]dsdt = 0 \qquad (2)$$

In which $u, \sigma_{ij}, \varepsilon_{ij}, D_i, F_b$, F_s and F_c denote displacement stress, strain, electrical body, surface, and concentrated force components, respectively. For a laminated plate, a complex stiffness method was used and the equation of motion can be described as

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F_m\} + \{F_c\} + \{F_T\} \qquad (3)$$

Where $[M]$, $[C]$ and $[K]$ are the structure mass, damping and stiffness matrices, respectively. $\{F_m\}, \{F_c\}$ and $\{F_T\}$ represent external mechanical vector, control electric vector and thermal load.

Experimental techniques

A composite structure plate with integrated piezoelectric patches and dispersed PZT-particle interlayer was depicted in Fig. 1. To prepare host structure, each composite plate was prepared by mixing

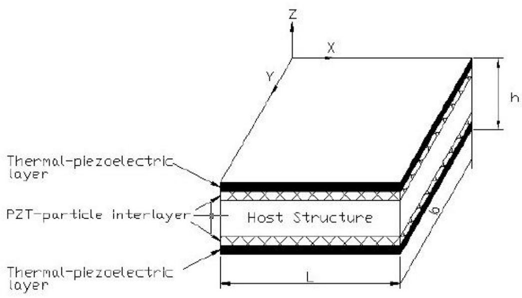

Fig. 1 sketch of a composite structure plate with integrated piezoelectric patches and dispersed PZT-particle interlayer .

the epoxy resin and CNT with different mix ratio of the CNT at ambient temperature for 1.5~2 hours to avoid of the surface-treated CNT in the matrix system. After the pre-curing procedure, a post cure process of the resin mixture was conducted at 75-85 ℃ for 1.5-2 hours and 120-130 ℃ for 2.5-3 hours. In this study, both thermopiezoelectric actuators are bonded on the top and bottom surfaces of the host structure. In order to lower the resin viscosity, the epoxy resin was preheated at 70℃ for 1 hour.

Results and discussion

The thermal environment on smart material is numerical simulated by three different thermal loading conditions. In which the temperature increases at the surface layer $\Delta T = T_{cr}$, 2 T_{cr} , and 4 T_{cr} are selected, where T_{cr} , the buckling temperature is given as T_{cr} = 18.65℃The temperature effects on free vibration of composite plate with different thermal loading induced by an applied uniform transverse force are given in Fig. 2. As the thermal loading increase, the amplitude of the tip deflection increase. The external force effect on free vibration of composite plate with different axial load is shown in Fig. 3. As can be seen from the plot, higher axial load leads to lower tip deflection and lower frequencies for the composite plate. To study the volume fraction effect of CNT on the vibration amplitude of the plate, an applied transverse load F = 2000 N/m^2 is uniformly distributed on composite structure with different volume fraction of CNT, from 0 – 25 vol%. Fig. 4 shows the dependences of the loss factors of the composites on the volume fraction of CNT under various thermal loading conditions. As expected, the pure epoxy (CNT, 0 vol%) depict a lower loss factor at point without thermal loading, and the loss factor significantly

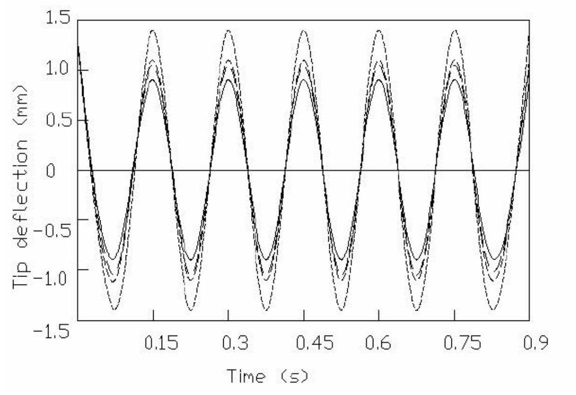

Fig. 2 Tip deflection versus time with different thermal loading induced by an applied uniform mechanical loading. (—):Without temperature effect, $\Delta T = 0T_{CR}$; (— —): $\Delta T = 1T_{CR}$; (– –): $\Delta T = 2T_{CR}$; (- - -): $\Delta T = 4T_{CR}$.

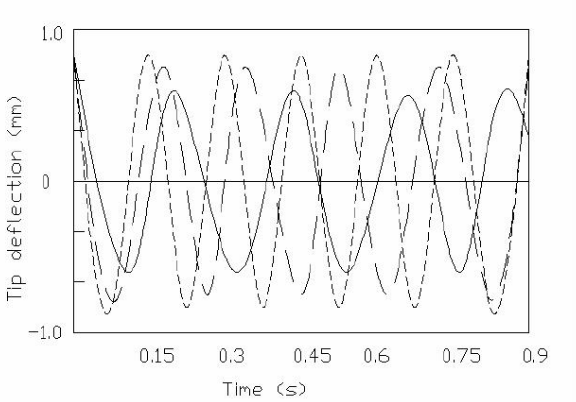

Fig. 3 Tip deflection versus time by an applied uniform mechanical loading with different axial force. (- -): $P= 0.1P_{CR}$; (– –): $P= 0.5P_{CR}$; (—): $P=1.0P_{CR}$.

increases as the volume fraction of CNT rises up to 20 vol.%. This can be attributed to the lower CNT vol% makes the epoxy in the matrix a real insulator, and the excited energy induced by external force is not fully dissipated. By considering the voltage difference ΔV in the poling direction, the increase of imposed voltages causes a higher suppression in the host structure. Fig. 5 illustrates the uncontrolled and controlled responses corresponding to an imposed voltage for the composite plate. As can be seen from the plot that as the instability condition is satisfied, the closed loop system becomes unstable and results in a divergent response. It is also observed that the control system design without gain value is ineffective in that very limited vibration reduction can be achieved, while the control gain input is considered, excessive vibration can be suppressed most in a short time. It is found that both the thermal load and axial force showed effectiveness on vibration damping in this thermoelastic composite structure.

Conclusion

The finite element formulation based on the third-order shear deformation theory for composite structures, which comprises material with different mix ratio of the epoxy resin and multi-wall carbon nanotube, has been developed. The governing finite element equations present the effect of various thermal environment and axial force on dynamic response of the host structure. The numerical results show the effectiveness of various thermal loads and axial force on composite plate with different gain values in the forced vibration control. It is found that the loss factor significantly increase as the volume fraction of CNT rise up to 20 vol% and the damping capacity is improved in the vibration system. Considering both thermal load and axial force effects simultaneously in the forced vibration control system, not only the tip deflection of the plate increases, but the higher axial force lead to a slightly increase in the period of the control structure. The control responses with higher value of gain for a composite plate, obviously presents the effects of thermal load and axial force, and the action of the piezoelectric actuator, which is required to have better response performance in the vibration control system.

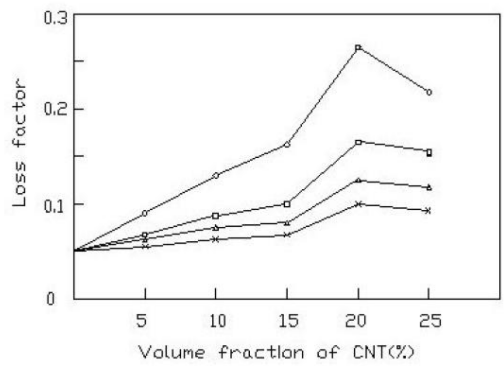

Fig. 4 Loss factor versus volume fraction of CNT at various thermal loading temperature for carbon nanotubes epoxy laminate. (x): $\Delta T = 0$; (△): $\Delta T = 1T_{CR}$; (□): $\Delta T = 2T_{CR}$; (○): $\Delta T = 4T_{CR}$.

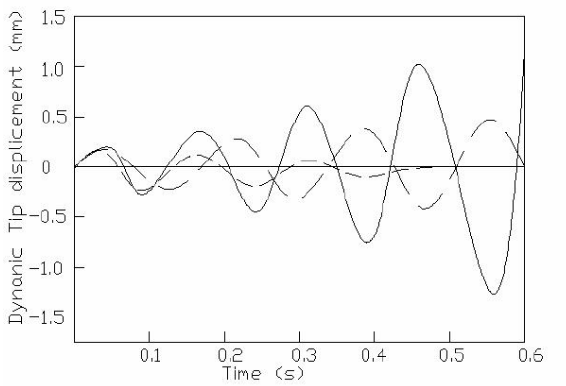

Fig. 5 Dynamic displacement response of free end for the CNT laminates plate. (—) uncontrolled transient; (– –) uncontrolled damped; (- -) controlled and damped.

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