VIBRATION CONTROL OF STIFFENED PLATES WITH INTEGRATED PIEZOELECTRICS

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Summary Vibration control of stiffened plate with piezoelectric sensors and actuators subjected to normal blast shock wave is studied. The model is a laminated composite plate with stiffeners and PZT piezoceramic layers. Using linear quadratic regulator, vibration characteristics and transient response are studied. The effect of stiffener's location and piezoelectric patch's position on the transient response of the stiffened plate subjected to blast load is investigated.

INTRODUCTION

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. The blast wave makes a sharp pressure to the structure in an instant. Due to the advantages of piezoelectric materials such as fast response, large force output, it is competent to control the vibration of stiffened laminated composite plates under the blast load.

FORMULATION

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), the plate element has elastic degrees of freedom $u_p^o, v_p^o, \theta_{xp}, \theta_{yp}$ and w_p^o per node and one electrical degree of freedom ϕ per piezoelectric layer. The electric potential ϕ is assumed to be constant over an element piezoelectric layer and varying linearly through the thickness of the piezoelectric layer. The stiffener element is three-node beam element with three degree of freedom at each node. Using transformation matrix $\mathbf{T}_{xs}$, the nodal displacement of stiffener elements can be written as that of plate elements.

Applying Hamilton's principle, the state-space form of the global dynamic equation can be written as

$\dot{\boldsymbol{\xi}} = \mathbf{A}_{st}\boldsymbol{\xi} + \mathbf{B}_{st}\phi_a + \mathbf{U}_f$. where ϕ_a is the control input.

And actuating voltage of LQR can be expressed as $\phi_a(t) = -\mathbf{G}_c\boldsymbol{\xi} = -\mathbf{R}^{-1}\mathbf{B}_{st}{}^T\mathbf{P}\boldsymbol{\xi}$

NUMERICAL RESULTS

A cantilevered laminated composite plate with two x-stiffeners is analyzed. The plate(T300/976 graphite-epoxy) is bonded at the upper and lower surfaces by piezoelectric ceramics(PZT G1195N). Dimensions of the plate which consists of four composite layers ($15^\circ/-15^\circ/-15^\circ/15^\circ$) with $(0.4/0.4/0.4/0.4)\,mm$ layers are 0.4m X 0.2m.

The eccentric stiffeners with width 6mm and depth 12mm are made of the same material and consist of four composite layers ($0^\circ/0^\circ/0^\circ/0^\circ$). Each piezoceramic layer is of thickness 0.2mm. The adhesive layers are neglected. In vibration control, the upper piezoelectric layer is assumed as sensor and the lower piezoelectric layer is assumed as actuators. Modal superposition method is used in the analysis, considering first six modes. And the initial damping ratio for each of the modes is assumed to be 0.7%.

The effect of stiffener's location is investigated. The two stiffeners are placed at the same distance (d) from the centerline along the width of the plate. And the stiffener's location can be defined as $\mu = 2d/C$.
where C is the width of the plate. Natural frequencies of the stiffened plate under different stiffener's locations are compared. It can be seen that natural frequencies of the bending mode at $0.4 \le \mu \le 0.6$ are higher than those of the others. And the natural frequencies of the twisting mode at $0.8 \le \mu \le 1$ are higher than those of the others. To investigate the effect of stiffener's location on control performance, typical configurations (μ = 0, 0.5 and 1) of stiffened plate are considered in the present study. From the frequency response and time response of stiffener's location at $\mu = 1$, 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. The other cases can be investigated in a similar way.

The effect of piezoelectric patch's position on the transient response of the stiffened plate subjected to blast load is investigated. Piezoelectric patch model has dimensions of 0.05m X 0.05m. The centers of Model Ⅰ, Ⅱ, Ⅲ and Ⅳ are 0.05m, 0.15m, 0.25m and 0.35m away from the clamped edge, respectively. To compare the control effects, two performance parameters are introduced. One parameter is Settling time which oscillation doesn't exceed limit value of each transient response. The limit values of vertical displacement, transverse bending and lateral twisting are 0.4mm, 0.002 and 0.002, respectively. And the other is maximum response. For $\mu = 1$, Model Ⅰ and Ⅳ have shorter settling time than that of the others in vertical displacement and transverse bending. And Model Ⅲ can control the lateral twisting more effectively.

CONCLUSIONS

When the stiffeners are placed between centerline and free edge, the stiffness of the stiffened plates is increased for bending mode. But the stiffness of twisting mode is increased at free edge. LQR can control bending mode and twisting mode effectively. This is because it changes the system damping including natural frequency. It can be determined the most effective position of piezoelectric patches by comparing with settling time and maximum response. The most effective positions of piezoelectric patches are different for each stiffener location.

References

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