Journal of Sound and Vibration 414 (2018) 218–232

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

A new method of smart and optimal flutter control for composite laminated panels in supersonic airflow under thermal effects

Zhi-Guang Song [a, b], Feng-Ming Li [a, *], Erasmo Carrera [c, **], Peter Hagedorn [b]

[a] College of Aerospace and Civil Engineering, Harbin Engineering University, Harbin 150001, China
[b] Dynamics and Vibrations Group, Numerical Methods in Mechanical Engineering, Technische Universität Darmstadt, Dolivostr. 15, Darmstadt 64293, Germany
[c] Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Corso Duca Degli Abruzzi 24, 10129 Torino, Italy

ARTICLE INFO

Article history:
Received 6 September 2017
Received in revised form 25 October 2017
Accepted 3 November 2017

Keywords:
Composite laminated panel
Supersonic airflow
Smart and optimal flutter control
Genetic algorithm
Thermal effects

ABSTRACT

In most of the active flutter controls, the feedback control gains are selected arbitrarily or by trial and error. These methods are inaccurate and time-consuming. In the present study, a smart and optimal method is proposed to investigate the thermal flutter control of composite laminated panels in supersonic airflow based on a genetic algorithm (GA), in which the feedback control gains of all the piezoelectric actuators are represented by the chromosomes and the fitness is set to be the difference between the present flutter bound and the expected one. Then, according to the GA process, a set of optimal feedback control gains can be obtained, and the flutter bounds of the structural system can be suppressed to any expected values by means of the optimal control gains. Furthermore, the maximum flutter bound of the panel and the corresponding feedback control gains can also be obtained. In the investigations, the aerodynamic pressure is evaluated by the supersonic piston theory and the controller is designed by the displacement feedback method. The influences of the placements of piezoelectric patches on the active flutter control effects are analyzed. Some interesting phenomena are obtained and discussed.

1. Introduction

Panel flutter is a self-excited vibration possible if one side of the panel is exposed to the free stream, and it may harm the health of the structure. Therefore it is significant to conduct the panel flutter analysis and control. Asadi et al. [1–3] studied the aeroelastic flutter behaviors of carbon nanotube (CNT) reinforced composite beams, flat panels and cylindrical shells. They also investigated the aeroelastic buckling and flutter instability of CNT reinforced pressurized cylindrical shells, truncated conical shells and truncated conical curved panels in supersonic airflow, as well as the nonlinear aero-thermal flutter postponement of laminated beams [4–7]. Kuo [8] carried out the aerothermoelastic analysis of angle-ply laminates with variable fiber spacing. Cunha et al. [9,10] investigated the flutter suppression of rectangular plates applying passive constrained viscoelastic layer. Carrera and Zappino [11] analyzed the panel flutter behavior of panels supported by a fixed number

* Corresponding author.
** Corresponding author.
E-mail addresses: lifengming@hrbeu.edu.cn (F.-M. Li), erasmo.carrera@polito.it (E. Carrera).

https://doi.org/10.1016/j.jsv.2017.11.008

of pinched points and exposed to flow conditions varying with altitude. Wang et al. [12] studied the active flutter control of subsonic and supersonic panels using the eigenvector orientation method. Fazelzadeh and Jafari [13] performed the active optimal flutter suppression for a supersonic plate under the gust disturbance effects with piezoelectric actuators using the integral/feed forward control method. Park and Kim [14] investigated the aerothermoelastic properties of composite panels embedded with macro fiber composite actuators subjected to combined aerodynamic, thermal and piezoelectric loads. Song et al. [15–19] studied the active flutter control of different structures using different control methods.

To realize active control more effectively, an optimal design is always carried out. One of the most common methods is the genetic algorithm (GA). Zhang et al. [20] proposed a novel optimal criterion for actuators and sensors ensuring good controllability of the structure. Bruant et al. [21] studied the optimization of piezoelectric actuators and sensors locations in the active vibration control of simply supported plates. Two modified optimization criteria were used. Based on the GA, Kumar and Narayanan [22] investigated the optimal placements of collocated piezoelectric patches on beams using an LQR controller. Moon and Hwang [23] studied the optimal panel flutter suppression. The shape and location of the piezoelectric patches were determined by the GA. Song et al. [19,24–26] conducted the optimal flutter and vibration control for composite laminated panels, conical shells, lattice sandwich panels and CNT reinforced composite panels using the GA.

Based on the above facts, it is noted that although the optimal placements of piezoelectric patches have been studied, in most of the active flutter controls, feedback control gains are normally selected arbitrarily or by trial and error. Recently, Song et al. have studied the shape control of CNT reinforced composite plates [27]. Inspired by this work, in this study, a smart and optimal flutter control method is proposed based on the GA, in which the feedback control gains of all the piezoelectric actuators are represented by the chromosomes and the fitness is set to be the difference between the present and expected flutter bounds. Then according to the GA process, a set of optimal feedback control gains can be obtained, and the flutter bound of the structural system can be suppressed to any expected values accordingly. Furthermore, the maximum flutter bound of the panel and the corresponding feedback control gains can also be obtained. The influences of the placements of piezoelectric patches on the active flutter control effects are analyzed in details.

2. Theoretical formulation

2.1. Structural modeling

The composite laminated panel with piezoelectric patches studied in this research is shown in Fig. 1. In the figure, a, b and h are length, width and thickness of the host laminated panel, respectively. The piezoelectric patches are bonded on the corresponding positions of the top and bottom surfaces of the host panel to act as actuators and sensors whose thickness is denoted by h_p. Since the laminated panel is relatively thin, the classical plate theory (CPT) is applied. The displacement fields of the laminated panel can be expressed as

$$u = u_0 - z\frac{\partial w}{\partial x}, v = v_0 - z\frac{\partial w}{\partial y}, w = w_0, \tag{1}$$

where u_0 and v_0 are the in-plane displacements of the neutral plane in the x and y directions, and w_0 is the transverse displacement. The strain-displacement relation is given as

$$\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}_0 + z\boldsymbol{\kappa}, \tag{2}$$

where $\boldsymbol{\varepsilon}_0 = [u_{0,x}, v_{0,y}, u_{0,y} + v_{0,x}]^{\mathrm{T}}$ and $\boldsymbol{\kappa} = -[w_{,xx}, w_{,yy}, 2w_{,xy}]^{\mathrm{T}}$. The force and moment resultants can be calculated by the equations:

$$\mathbf{N}_0 = \mathbf{A}_0\boldsymbol{\varepsilon}_0 + \mathbf{B}_0\boldsymbol{\kappa} - \mathbf{N}_{\Delta T}, \mathbf{M}_0 = \mathbf{B}_0\boldsymbol{\varepsilon}_0 + \mathbf{D}_0\boldsymbol{\kappa} - \mathbf{M}_{\Delta T}, \tag{3}$$

where $\boldsymbol{A}_0$, $\boldsymbol{B}_0$ and $\boldsymbol{D}_0$ are the coefficient matrices, $\boldsymbol{N}_{\Delta T}$ and $\boldsymbol{M}_{\Delta T}$ are the thermal force and moment resultants, calculated by

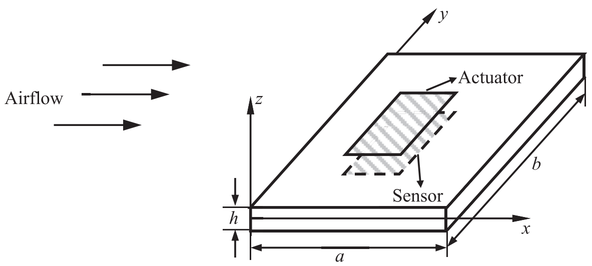

Fig. 1. Schematic diagram of the composite laminated panel with piezoelectric actuator and sensor in supersonic airflow.