Distribution Optimization of Constrained Damping Materials Covering on Typical Panels Under Random Vibration

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This paper studies topology optimization of metallic and composite panels of three different configurations (flat, three-bay and 3×3 grid) covered by the constrained damping materials considering first modal loss factors. The vibration experiments seek to obtain the first modal loss factor and first modal frequency for the aforementioned panels, and corresponding finite element (FE) simulations are completed using commercial software ABAQUS®. According to simulation results, the distribution of constrained damping materials is optimized with evolutionary structural optimization (ESO) method developed using MATLAB. The results show that the first modal loss factors of optimized panels are reduced slightly if the constrained damping material is removed by 50%. Under the base excitation near each first modal frequency, the maximum root mean square of Von Mises equivalent stress (RMISES) of optimized flat panels and 3×3 grid stiffened panels decreases compared with panels without constrained damping materials. However, the maximum RMISES value of optimized three-bay stiffened panels nearly remains unchanged due to the configuration type of the stiffeners. These results conclude that the three-bay stiffened panel is the best to reduce the maximum RMISES value of at base structure with the same additional mass.

1. INTRODUCTION

The control of resonance vibration of structures has always been a fundamental concern in aerospace, automobiles, and other industries on topics of noise reduction and increasing service life. There are application studies on various structures, including helicopter blades, pilot seats on aircrafts, and connections to cockpit floors. An effective way to control vibration is covering passively-constrained damping material on the surface of violently vibrating structures. Although this method is simple, with reasonable distribution, it can provide high damping effects over a wide range of frequency and temperature without significantly altering structural mass or stiffness. Numerous papers have been published in the past decades on the vibration damping analysis of full-coverage constrained damping material treatment. However, full coverage treatment is impractical due to added excessive mass to base structures. Therefore, topology optimization of damping materials with partial-converage treatment is widely used where only a portion of the base structure is covered with constrained damping material. Generally, many optimization methods were adopted to optimize locations of the patches on base structures. For example, the modified gradient method, the Genetic Algorithm (GA) method, the Method of Moving Asymptote (MMA), and the evolutionary structural optimization (ESO) method were used to find optimal locations of constrained damping patches which will maximize the modal damping ratio of the structures. In most published work on partial coverage damping treatment, it has been emphasized that attention must be given to the frequency and damping properties of optimization treatment effects on the structure. For example, Kang et al. investigated damping layer optimization in shell structures under periodic excitation to minimize the structural vibration level. The complex mode superposition method in conjunction with the state space approach — which could deal with non-proportional damping — to calculate the steady state response of the vibrating structure. However, the study was only focused on flat panel and shell, not on stiffened panels. Based on this, Zhang et al. proposed the integrated topology optimization of host structures and damping layers to reduce vibration levels in the presence of harmonic excitations. During the optimization process, the localized modes in low-density areas were avoided. The analysis method applied validity only in flat panel and the hollow cylinder shell structure, not in complicated structures. Takezawa et al. carried out a new objective function to optimize damping layers for reduce resonance. In the proposed objective function, the optimization problem was formulated to maximize the complex part of the proposed complex dynamic compliance under a volume constraint. This optimization program was used in 2D/3D beam structures. Khalfi et al. presented a parametric study of partial constraining layer damping (PCLD) characteristics on the responses of a rectangular plate. The obvious suppressing vibration effects were obtained by optimization. However, there are two points that have not been discussed: 1) the optimized structure only related to the simple flat panel or shell, not stiffened panels, and 2) the fatigue life of optimized structures has been rarely investigated under random vibration, even though full-scale fatigue testing for Aerospace application of metal and composite constructions has been investigated in recent years. Reasoning can be attributed to the idea that most of optimization studies about constrained damping treatment on base structures aim to suppress vibration which is mainly characterized by damping loss factor, and that in random vibration, the fatigue life is sta-