Topology Optimization of a Constrained Layer Damping Plate Coupled with an Acoustical Cavity

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An acoustical topology optimization of a constrained layer damping (CLD) plate coupled with a rigid acoustical cavity is presented to minimize the sound radiation power. A mathematical model is developed to simulate the sound radiation based on the theories of the finite element and boundary element methods together. The model is integrated with the acoustical topology optimization approach, which utilizes the genetic algorithm with an elitist strategy. The obtained results demonstrate the effectiveness of the proposed approach in attenuating the sound radiation power and the sound pressure inside the acoustical cavity simultaneously by proper layout of the CLD materials. Furthermore, experimental verification is carried out by manufacturing topology optimized CLD/plate and monitoring the sound pressure in the acoustical cavity. The experimental results are a good match with the predictions of the mathematical model. The study shows that the proposed acoustical topology optimization approach can be an effective tool in the design of a wide variety of critical structures, which is lightweight and operates quietly, such as the panels in the vehicle body and aircraft cabin.

NOMENCLATURE

a, b	Half of the element length
$\mathbf{b}$	The coefficient matrices to calculate sound pressure at point α
b_{jmn}	Element in the coefficient matrices $\mathbf{b}$
$\mathbf{B}$	The coefficient matrices to calculate the nodal sound pressure on the boundary surface
b_j	Element in the coefficient matrices $\mathbf{B}$
$C(\alpha)$	Constants in Helmholtz acoustical boundary integral equation
$E_j^{(e)}, E_{\beta v}^{(e)}$	The potential energy for the element
f	The fitness function
$\mathbf{F}$	Externally applied mechanical force
$G(\alpha, \xi)$	Green's function
h_p, h_v, h_c	The thickness of base layer, damping layer and constrained layer
$\mathbf{h}$	The coefficient matrices to calculate sound pressure at point α
$\mathbf{H}$	The coefficient matrices to calculate the nodal sound pressure on the boundary surface
$\mathbf{K}^{(e)}, \mathbf{K}$	Element stiffness matrix and global stiffness matrix
$\mathbf{M}^{(e)}, \mathbf{M}$	Element mass matrix and global mass matrix
$\mathbf{N}$	Shape function matrix
N_i	Shape function
$p(\alpha), p_Q$	Sound pressure at point α, Q
γ_{jxy}	The shear strain for each layer
$\boldsymbol{\delta}^{(e)}$	The nodal displacement vector
$\varepsilon_{jx}, \varepsilon_{jy}$	The strain at the x-direction and y-direction
θ_x, θ_y	Rotations about the x-axis and the y-axis
$p(j)$	Sound pressure at node j
$\mathbf{p}_m$	The nodal sound pressure vector of element m
$\mathbf{P}$	Nodal sound pressure vector on the boundary surface
T_j^e	The potential energy for the element
u_p, u_c, u_v	The displacement at the x-direction for base layer, damping layer and constrained layer
v_p, v_c, v_v	The displacement at the y-direction for base layer, damping layer and constrained layer
v_Q	The vibration velocity at any point Q
$\mathbf{v}_m^*$	The complex conjugate of the nodal normal vibration velocity vector of element m
$\mathbf{V}$	The nodal normal vibration velocity vector
w	The transverse displacement of the node
W	The sound radiation power
x_i	Design variables
X	The design variable set
$\mathbf{X}$	The displacement vector
α	The field point
β_x, β_y	The shear deformation at the x-direction and y-direction of the damping layer
ξ	The point on the acoustical field boundary
σ_{jx}, σ_{jy}	The stress at the x-direction and y-direction
τ_{jxy}	The shear stress for each layer

1. INTRODUCTION

CLD treatment has been regarded as an effective way to suppress structural vibration and acoustical radiation since it was proposed by Kerwin.[1] It has found its ways in aeronautical, vehicle, civil, and mechanical engineering applications. Meanwhile, the optimizations for the layout of CLD materials have been widely reported in recent years because it has been recog-