OPTIMIZATION AND PARAMETER ESTIMATION IN SMART VISCOELASTIC LAMINATED SANDWICH STRUCTURES

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Introduction

Recent developments on the optimization and parameter estimation in hybrid active-passive composite sandwich structures are presented. For this purpose, a mixed layerwise finite element model has been formulated, by considering a higher order shear deformation theory to represent the displacement field in the viscoelastic core and a first order theory for the displacement fields of the adjacent laminated and piezoelectric face layers. The model is based on an eight nodded plate/shell finite element, with 17 mechanical degrees of freedom per node, after imposing inter-layer displacement continuity, and 2 electric degrees of freedom per element. The complex modulus approach is used for the viscoelastic material behavior, and the dynamic problem is solved in the frequency domain, using frequency dependent material data for the core. Active control is applied using proportional displacement and negative feedback control laws.

Damping maximization of passive, active and hybrid damping treatments is conducted, using as design variables the viscoelastic core thickness, the constraining elastic face laminae thicknesses, orientation fiber angles, as well as piezoelectric patch locations. The problems are solved using gradient optimization and/or nongradient algorithms as appropriate [1].

Identification of viscoelastic core material properties is also envisaged, where the inverse problem is formulated as a constrained optimization problem [2], by fitting the response of the numerical model to the corresponding experimental response of the structure, and considering specific parametric models for frequency dependent damping material behavior. Constraints are imposed on the design variables, arising from thermodynamic restrictions on isothermal linear viscoelasticity, and gradient based optimization techniques are used to solve the inverse problem.

Both optimization and parameter estimation applications will be presented and discussed.

Damping Optimization

As an example application, a simply supported composite laminated plate was considered, with in-plane dimensions 300 mm 200 mm, a viscoelastic soft core and two symmetric face layers each with three orthotropic elastic plies. Passive design is first conducted, by maximizing the fundamental modal loss factor, using as design variables the viscoelastic core thickness and the ply thickness and orientation angles of each face layer. Design constraints include maximum displacement, mass and Tsai-Hill failure criteria. In active design, the objective was the determination of the best locations for 4 pairs of co-located sensors and actuators in order to maximize the weighted sum of the first 7 flexural modal loss factors, using linearly decreasing weights with frequency. A negative velocity feedback control law was considered, and the problem was solved by genetic algorithms. Fig.1 shows the obtained magnitude of frequency response functions for the center node of the plate, for the initial design, optimal passive design and final active design. From the results one can conclude that all modes become significantly damped after active and passive designs.

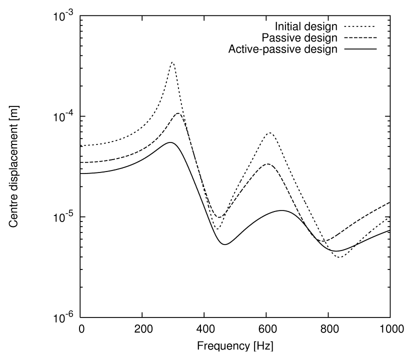

Figure 1: Frequency responses (magnitude) for the initial design, optimal passive design and final active-passive design of the hybrid simply supported sandwich plate.

Parameter Estimation

The inverse eigenvalue problem of estimation of the material properties can be solved in a number of different ways, and the approach that is used in this work consists on minimizing an error function, which expresses the deviation between experimental and numerical complex eigenvalues, with respect to the elastic, piezoelectric and frequency dependent damping material parameters:

$$\Phi = \sum_{n=1}^{I} \mathrm{w}_{\lambda_n} \left(1 - \frac{\lambda_n}{\tilde{\lambda}_n}\right)^2 + \sum_{n=1}^{I} \mathrm{w}_{\eta_n} \left(1 - \frac{\eta_n}{\tilde{\eta}_n}\right)^2 \quad (1)$$

where $\tilde{\lambda}_n$ are the real parts of the experimental eigenvalues, λ_n are the corresponding real parts of the eigenvalues predicted by the numerical model, $\tilde{\eta}_n$ and η_n are, respectively, experimental and numerical modal loss factors, w_{λ_n} and w_{η_n} are weights used to express the confidence level in each experimental eigenvalue and corresponding loss factor, respectively, and I is the total number of experimental eigenpairs under consideration. The constrained minimization problem is solved using gradient optimization and analytic sensitivities [2].

As a first approach to the identification of frequency dependent viscoelastic parameters, an isotropic material was assumed for the core of the sandwich and a fractional derivative parametric model was chosen for the complex shear modulus:

$$G(j\omega) = G_0 \frac{1 + a(j\omega)^\alpha}{1 + b(j\omega)^\alpha} \quad (2)$$

where a, b, and α are parameters to be identified, G_0 is the static shear modulus, and $j = \sqrt{-1}$. It can be shown that this model is causal and satisfies the thermodynamic constraints on linear viscoelasticity. A 300mm × 200mm laminated sandwich plate with all edges clamped and made of carbon fiber plies and a central ISD-112 viscoelastic material core is considered. The stacking sequence is $[0^\circ_c/90^\circ_c/+45^\circ_c/0^\circ_v/+45^\circ_c/90^\circ_c/0^\circ_c]$, where subscripts c and v stand for carbon fibers and viscoelastic material, respectively. The thickness of each carbon fiber ply is 0.5 mm, and the viscoelastic core is 2.5 mm thick. Material properties for ISD-112 viscoelastic damping polymer are taken from the literature, for the frequency range $f = 0 \ldots 2000$ Hz and a temperature of 23.9 °C.

The first twelve flexural natural frequencies of free vibration of the plate and corresponding modal loss factors are considered for identification. The frequency response curves using the material properties from the literature and the fractional derivative model of Eq.(2) for the shear modulus, with identified parameters $a = 4.333 \times 10^{-2}$, $b = 0$, and $\alpha = 0.642$ are presented in Fig.2. Both curves are very close, indicating that it might in fact be reliable to conduct parametric identification of viscoelastic material properties just with eigenfrequency based experimental data.

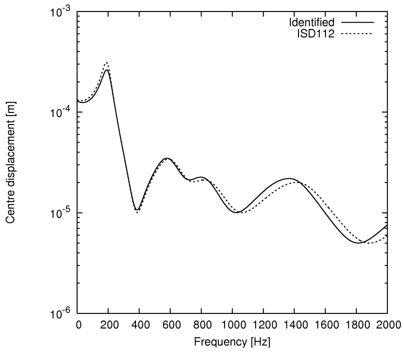

Figure 2: Identified and original frequency response curves, corresponding to central displacement due to a 10 N impulse load, applied at $t = 0$.

Conclusions

In this paper we will briefly present an overview of current research work being conducted in optimization and material parameter estimation in active-passive laminated sandwich composite structures.

Damping maximization in hybrid active-passive sandwich laminated plates with viscoelastic core and laminated face layers with co-located piezoelectric patches has been conducted. Since few plate/shell hybrid active-passive sandwich models exist, and are mostly limited to isotropic materials, a new mixed layerwise finite element model was developed for optimization purposes.

Identification of frequency dependent properties of viscoelastic core materials in a composite sandwich configuration has been presented. The obtained results indicate that the inverse problem can be solved using only information from eigenfrequencies and modal loss factors, and a fractional derivative viscoelastic behaviour model.

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References

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