Optimization of dynamic characteristics of composite shells by using genetic algorithms

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Abstract

In this paper a technique of topological optimization by maximum damping criterion of multilayered shells composed of materials with different properties is considered. The semi-analytical method of finite element modeling in integral Fourier transform space is applied to construct mathematical models of composite structures. The classic genetic algorithm is used to determine the optimal combination of materials as a sequence of structure layers. It is shown that for multilayered elements of structures, an optimal project can be found by placing the material layers with constant characteristics in a sequence that provides the optimum value of the chosen optimization criterion. The examples of searching for the optimal projects of layer packages for a 15-layered shell by one or several optimization criteria, are presented.

Keywords: optimization, multilayered shells, finite element method, genetic algorithms, damping

1. Introduction

When designing engineering structures for operation under dynamic loads, a problem of optimal choice of materials and their placement within the structure emerges, e.g. when planning the placement of damping and bearing elements for increased efficiency of their functioning. The goals of this optimization can be defined as modification of frequency spectrum, increasing vibration decrements, increasing durability characteristics etc. Solving these problems requires the creation and application of appropriate methods and techniques of optimal design. It is worth noting that the classic optimization methods are ineffective due to large number of project parameters and the specific features of selection. As shown in [3, 5], an efficient process of optimal design can be organized using the evolutionary optimization techniques, especially genetic algorithms, that exploit the methods of nature of selecting the best samples.

2. Problem definition

Two approaches to design of multilayered structures can be applied to obtain the optimal project: the modification of materials [1, 7], and the modification of construction which is called topological optimization, or shape optimization.

The problem of global shape optimization lies in selecting the sequence of material layers with given parameters, specifically reinforcement angles and ratios, to ensure the optimum of optimization criterion. In case of multicriteria optimization the problem is even more complex, as several competing optimality criteria must be satisfied. Thus compromising variants should be considered, and optimal solutions are actually found according to Pareto principle [4].

2.1. Optimization method

In a modification of the classic genetic algorithm, applied in this study, a population of individuals – vectors describing the structure is employed. The vibration decrement, vibration damping speed, frequencies and minimum weight are chosen as the optimization criteria (goal functions).

The result of solving the global optimization problem contains the sequence of material layers with defined properties, that provides minimum or maximum for the chosen optimization criterion. As a result of the multicriteria optimization problem we obtain a multitude of non-dominated solutions that fit the Pareto set for the considered problem, and the respective non-dominated front. To get a single solution we have to attach additional information regarding the relative criteria importance [4], i.e. conditions which mark optimization criteria as more or less crucial.

2.2. Constructing mathematical model of shell vibrations

A shell consisting of layers of a viscoelastic materials reinforced by fibers, is considered. To construct a mathematical model that takes into account the specific features of interaction between the constituent elements (layers in case of shell) and viscoelastic properties of materials, a semi-analytical method of finite element modeling in the integral Fourier transform space, is suggested in [2, 6]. It enables to describe the dissipation of energy in the material correctly using complex moduli, the dependence of the dissipation of energy to the stressed-deformed state of material, the frequency and thermal dependencies of energy dissipation, to define and solve the problems of structure design with maximum damping characteristics and the problems of optimal placement of passive damping elements, including shells, partially covered with damping material.

According to the suggested method, a single layer of the shell (Fig. 1) is considered at the first step, then a synthesis of multi-layered shell is performed according to the constraints of layer bounding (Fig. 2).

To construct the finite element model of a single layer, the approximation of displacements by thickness (z-axis) is made with Lagrange polynomials, and by two other directions (x,y-axes) – with the Fourier orthogonal series.

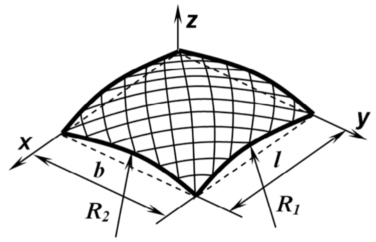

Figure 1: A computational scheme of a shell layer

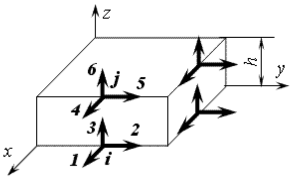

Figure 2: Shell layer bounding constraints

Considering this approximation, let's determine the matrix of dynamic stiffness of a layer, describing it as a finite element,

$$Z(i\omega) = K(i\omega) + (i\omega)^2 M \, , \tag{1}$$

where $K(i\omega)$ is a matrix of layer stiffness that depends on the complex moduli of the material, M is mass matrix, ω is vibration frequency, $i = \sqrt{-1}$.

For a multi-layered shell the matrices of dynamic stiffness are gathered into a global matrix

$$GZ(i\omega) = GK(i\omega) + (i\omega)^2 GM \tag{2}$$

considering the kinematic bounding constraints of layers by equating the respective displacements of bound nodal surfaces (Fig. 2).

To analyze the energy dissipation, a nonlinear eigenvalue problem is considered

$$GZ(i\omega)\, q = 0 \, . \tag{3}$$

Eigenvalues and eigenvectors of matrix $GZ(i\omega)$ can be determined using the technique proposed in [6].

The vibration decrement can be determined from the known eigenvalues (complex frequencies) of the matrix $GZ(i\omega)$:

$$\delta_k = \pi \cdot \arctan\frac{\omega''}{\omega'} \approx 2\pi\frac{\omega''}{\omega'}, \tag{4}$$

where $\omega_k = \omega'_k + i\omega''_k$ is the complex vibration frequency that matches the *k*-th form.

3. Calculation examples

A 15-layer hollow shell was considered with the following initial parameters: overall dimensions of shell 4×4 m; curvatures $k1 = 0{,}001$ 1/*m*, $k2 = 0.001$ 1/*m*; thicknesses of layers were taken as equal $h = 0.001$ *m*; vibration forms: $n = 1$, $m = 1$.

Also the complex moduli and densities of reinforcing material and matrix materials were given.

The matrix components of complex moduli of composite material layers were determined by the technique described in [7], density – by the rule of compounds $\rho_{ef} = \eta\rho_1 + (1-\eta)\rho_2$ (η − reinforcement ratio). Parameters of layer materials are shown in Table 1.

Table 1: Parameters of materials (ϕ – reinforcement angle)

№	ϕ	η	№	ϕ	η
0	0	0,25	**8**	$\pi/3$	0,75
1	$\pi/12$	0,25	**9**	$\pi/4$	0,75
2	$\pi/10$	0,25	**10**	$\pi/6$	0,75
3	$\pi/8$	0,25	**11**	$\pi/8$	0,75
4	$\pi/6$	0,25	**12**	$\pi/10$	0,75
5	$\pi/4$	0,25	**13**	$\pi/12$	0,75
6	$\pi/3$	0,25	**14**	0	0,75
7	$\pi/2$	0,5			

Having taken the vibration decrement as the goal function, we obtained the optimal layer package that provides the maximum decrement at the first bending form:

$$x_{opt} = [7, 7, 7, 7, 7, 6, 6, 5, 5, 4, 4, 1, 14, 14, 14]$$

$$\delta_{opt} = 0.2265 \, .$$

The oscillogram of vibration for the optimal layer sequence is shown in Fig. 3.

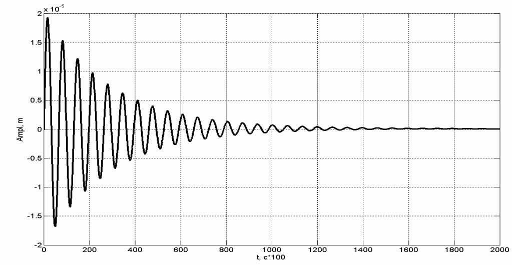

Figure 3: The oscillogram of vibration after optimization by maximum vibration decrement criterion

Also the solutions of optimization problems using several vector criteria, including minimum mass, were obtained in this study.

4. Conclusions

Considering the aforementioned arguments it is justified to state that an optimal package can be obtained for multilayered structures (beams, plates, shells) by placing the layers of materials with constant characteristics in a sequence that provides the optimal values of the chosen optimization criteria. The necessity of the presented method is caused by the technological process of producing shells and plates. The developed technique can be generalized on larger number of elements, and can also be employed to determine the optimal placement of passive damping elements in multilayered structures.

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