FREQUENCY RESPONSE AND DAMPING ANALYSES OF STRUCTURES WITH DIFFERENT DAMPING MODELS

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The behavior of structures with different damping models has been investigated using finite element and frequency response analyses. As an example, systems with hysteretic and viscous damping were examined. The damped eigenfrequencies and the corresponding loss factors were computed based on frequency response analysis and then compared to the results obtained from free vibration analysis using the method of complex eigenvalues. Recommendations are given for a more effective employment of frequency response and damping analyses in the structures considered.

1. Introduction

The ability to absorb the vibration energy is a very important quality of structures under dynamic loading. The necessity for improving the damping characteristics of structures calls for the use of damping coatings comprising one or two layers, fiber composite materials, and discrete dynamic absorbers. The first two cases consider the structural damping, which is more often represented by the complex stiffness approach derived from the elastic-viscoelastic correspondence principle [1]. On the contrary, discrete dynamic absorbers represent the external damping and consist of masses, viscoelastic springs, and dash-pots, usually in different combinations.

Considerable progress has recently been achieved in the analysis of damping due to the increased need for high damped structures. However, most papers are dedicated either to the analysis of structures with damping coatings [2, 3] and laminated composite structures [4, 5] with viscoelastic damping, or to structures with discrete dynamic absorbers [6, 7] without structural damping. Yet in practice, rather often certain systems include different types of damping simultaneously. There exist vibrations of machine frames and supporting structures, vibrations of thin-walled structures with compartments containing fluid, vibrations of thin-walled structures in fluid, the flatter problems, etc. It should be noted that such dynamic characteristics of the examined structures as damped eigenfrequencies and the corresponding loss factors may be determined using frequency response analysis. Studies analyzing systems with different types of damping are rather few. In [8] an attempt was made to carry out the frequency response analysis of a Rayleigh–Timoshenko beam with hysteretic or viscous damping in the ambient medium with the same type of damping. Unfortunately, only a system with hysteretic damping was examined there. In [9] a frequency response analysis was carried out for a structure with a mixed viscous and hysteretic damping. The frequency-dependent flexibility matrix was obtained using the modal properties of the structural system. However, the two problems solved had a very small dimension.

The objective of this paper is to investigate the behavior of structures with different damping models using finite element and frequency response analysis. As an example, systems with hysteretic and viscous damping are examined. The damped eigenfrequencies and the corresponding loss factors are computed from the results of the frequency response analysis and compared to that of the free vibration analysis using the method of complex eigenvalues.
2. Frequency Response Analysis

Let us examine the finite element discretization of a structure. The forced vibration equation of a structure with hysteretic and viscous damping takes the matrix form as follows:

\[ M\dddot{X} + c\dot{X} + k\ddot{X} = F(t), \]

where \( M \) is the mass matrix; \( C \) is the damping matrix depending on the damping model used; \( K = K' + iK'' \) is the complex stiffness matrix (\( K' \) is determined using the elastic \( E' \) and shear \( G' \) moduli, while \( K'' \) is found using the imaginary parts of the complex moduli \( E'' = \eta_E E' \) and \( G'' = \eta_G G' \), where \( \eta_E, \eta_G \) are the material loss factors in tension–compression and shear, respectively); \( X', \dot{X}', \ddot{X}' \) are the complex vectors of displacements, velocities, and accelerations, and \( F(t) \) is the load vector. If only the harmonic vibrations \( F = Fe^{i\omega t} \) are considered and a solution to this equation is found in the form \( X' = X'e^{i\omega t} \), the system of complex linear equations takes the form

\[ \left(-\omega^2 M + i\omega C + K'\right) X' = F, \]

where \( \omega \) is the frequency; \( X' \) is the displacement, and \( F \) is the amplitude of the applied force. As a result, the displacements of a structure with hysteretic and viscous damping are obtained using the Gauss algorithm [10]. This method consumes a considerable computing time as the general solution requires that the dynamic stiffness matrix \((-\omega^2 M + i\omega C + K')\) be recalculated, decomposed, and stored at each of the numerous frequency steps.

3. Damping Analysis

It is well known [11] that the dynamic characteristics of a structure (eigenfrequencies and the corresponding loss factors) can be easily obtained using the results of frequency response analysis (Fig. 1). The structure eigenfrequencies \( f_i \) present the points of the real part of the response spectrum with zero displacements. However, the corresponding loss factors can be determined by analyzing the resonant peaks for a particular mode:

\[ \eta_i = \frac{1 - (f_i/f_a)^2}{1 + (f_i/f_a)^2}. \]

4. Numerical Results

Let us consider two problems of the frequency response in systems with hysteretic and viscous damping (Fig. 2). The finite elements of Timoshenko's and sandwich beams [12] were used for this purpose. The finite element model of a sandwich