Numerical Method Using Filter Banks for Vibroacoustic Analysis in the Medium Frequency Range

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Abstract: Efficient numerical tools are needed to predict the vibroacoustic response of a viscoelastic structure in the medium frequency range. The presented method is formulated within the framework of nonuniform modulated filter banks, a signal processing tool. The method consists in dividing the frequency domain of interest into several subdomains and hence in solving only one time domain equation of motion for each subdomain. The complete displacement field is then reconstructed from the different time domain solutions. This time-frequency computation relies on the design of analysis and synthesis filter banks. Flexural vibrations of plates are studied in order to illustrate the numerical efficiency of the method.

INTRODUCTION

For many industrial applications, numerical tools such as finite elements methods are used to predict the vibroacoustic response of structures. The mathematical problem lies in solving a large system of second order differential equations. For low frequencies, modal methods or time domain integration computations are appropriate. The limitation of these methods lies in the medium and high frequencies. In the medium frequency range, an increasing number of modes or degrees of freedom is needed and the resolution for every frequency step represents heavy numerical requirements. The aim of this work is to propose a medium frequency predictive tool for systems with frequency dependent properties.

A time-frequency analysis-synthesis method, as given by Soize [1], is proposed. Using a matrix description of the dynamical system, the method presented in [2] is formulated within the framework of nonuniform modulated filter banks [3]. The method consists in dividing the frequency domain of interest into several subdomains and hence in solving the time domain equation of motion for each subdomain. A signal processing tool is used to avoid numerical problems related to the choice of an initial time value to integrate each time domain equation.

NUMERICAL METHOD USING FILTER BANKS

The starting point of the presented method is a matrix description of the vibroacoustic system resulting, for instance, from a finite elements formulation or from a Rayleigh-Ritz approximation. The presented examples deal with plates submitted to harmonic forces. Using nonuniform modulated filter banks, the initial frequency problem is linearized and transformed into a set of equations of motion corresponding to the frequency division. The complete displacement field vector of the initial physical problem is then reconstructed from the different time domain solutions. The main objective is to compute the mean squared velocity over the frequency domain. Moreover, the method allows to indicate where the structure is likely to vibrate as a function of time.

The division of the frequency domain must take into account the physical meaning as well as the signal processing requirements. Each frequency subdomain is defined by its central frequency and its frequency width. The mass matrix, the stiffness matrix and the damping matrix of the system are assumed to take constant values for each subdomain. For example, values at the central frequency can be used. The presented time-frequency computation relies on the design of analysis and synthesis filter banks. It is proposed to analyze the excitation signal using compact time support windows. Hence, the frequency domain synthesis is based on the shape of these filters. It has been chosen to use successive subdomains with different widths. Due to signal processing requirements, there must be a sufficiently wide such that there exists an overlap between two successive subdomains. The reconstructed solution results from the different time domain solutions of the successive subdomains depending on the frequency range. As the objective is to compute the mean square velocity over the frequency domain, the filters used for the reconstruction verify a frequency condition which ensure a good reconstruction.
For each frequency subdomain, the time domain integration is computed by a numerical scheme, a Newmark’s scheme for example. The analysis filter bank is based on a causal low pass filter function. This function is defined in such a way that the initial time domain conditions are verified. It is shown that two numerical parameters are required. The first parameter is the time step to integrate the time domain equation. It is defined using an integer number of the sampling rate. The second parameter is the stopping integration of the time domain integration. This final time is obtained by using an energy criterion, based on the convergence of a finite cumulative dissipative energy quantity. At the end of the time domain integration, the displacement field is given for a certain number of time domain samples. This number of samples is an indication of the memory requirement.

RESULTS

Several test cases of flexural vibrations of plates are presented to illustrate the numerical efficiency of the method. The first example is vacuo cantilever steel plate modeled by finite elements. An excellent agreement is obtained between the presented results and those given by a direct computation in term of mean squared velocity. This simple case allows an investigation on the optimal number of frequency subdomains.

The second example shows the influence of the synthesis filter bank resulting from the frequency domain division. It concerns a finite element model of a clamped steel L-shaped plate. Signal processing artefacts, giving nonexistent resonance peaks, can results from an inadequate frequency subdivision. This point out the importance of carefully choosing the frequency domain division.

The third and fourth examples deal with system having frequency-dependent properties. For a steel plate radiating in air, the advantage of the presented method lies in the need for computing the radiation coefficients at the central frequencies only. Using the same Rayleigh-Ritz spatial description, a direct method would computes these coefficients for each frequency. The last example is devoted to a sandwich plate with a viscoelastic layer discretized by a finite element model. The results, when compared with a direct computation based on an analytical solution, show a good agreement.

Results show that the proposed method allows for a more efficient computation in the frequency domains where classical modal methods and direct time-domain methods are numerically inefficient. This numerical tool is of great interest for the study of structures having frequency-dependent properties. The presented method was built using a specific signal processing tool. Numerical improvement lies in the development of time domain stopping criterion and spatial description.

REFERENCES