Mechanical Systems and Signal Processing 52-53 (2015) 722–740

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Partial scaling of finite element models for the analysis of the coupling between short and long structural wavelengths

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ARTICLE INFO

Article history:
Received 6 September 2013
Received in revised form
28 May 2014
Accepted 11 June 2014
Available online 1 July 2014

Keywords:
Finite element approach
Statistical energy analysis
Structural response
Scaling procedure

ABSTRACT

This work deals with the analysis of the coupling between long and short structural wavelengths on simple test configurations. The aim is pursued using standard and scaled finite element models. The first is the classical one based on the sampling of the given wavelength; the second is built by scaling only the finite element model of the component carrying the shortest waves. The physical domain carrying the shortest waves is thus reduced and its original damping is increased to recover the correct energy response. The results highlight the limits and the advantages of such scaling procedure in analysing the specific coupling schemes.

1. Introduction

Structural waves can travel, be reflected, transmitted and dissipated inside different spatial domains and according to different wave types [1]. The study of this complicated wave mechanism is one of the most challenging research themes since it is related to the investigations aimed at the reduction of the vibration levels and at the analysis of the energy distribution for a given dynamic load.

The coupling between short and long wavelengths, in given structural domains, has been investigated for two aims: (i) to study the physics of the wave exchange [2–4] and (ii) to produce a hybrid method [5–7]; here *hybrid* means a method able to link cinematic degrees of freedom (displacement, velocity and acceleration at a given frequency in a given point), as in FEA (*Finite Element Approach*), with energy ones (mean square velocity at a given frequency), as in SEA (*Statistical Energy Analysis*). Other relevant hybrid methods are in [8,9].

FEA is based on the discretization of a differential problem (differential equation set, boundary and initial conditions); then, it is associated to the possibility to have a correct representation of the selected wavelength: at least four elements have to be used [10]. SEA estimates the dissipated energies inside each subsystem and the exchanged energies among all the subsystems, for given input powers; it provides very cheap results in a frequency range where some conditions are fulfilled [11]: the increasing values (greater than unit one) of the modal overlap factor is one of the engineering rules of thumb. It has to be underlined that in [11] the relation between modes, energy and subsystem is also formally presented.

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http://dx.doi.org/10.1016/j.ymssp.2014.06.007

Langley [12] more correctly introduces the concept of statistical modal overlap factor but this point is not addressed and analysed here.

The formal development of a method able to manage both techniques is intrinsically complex because the variables are of different form. Langley and Bremner [5] and Cotoni et al. [6] highlight the possibility to adopt a common scheme and then, to design a tool that should be able to select the best technique to analyse the given component response and the proper coupling scheme. The dynamic structural assembly is partitioned according to the specific modal overlap factor values, in FEA and SEA degrees of freedom: for increasing excitation frequencies all the degrees of freedom evolve to a SEA system, whereas in the low frequency range, the system is represented by a full FEA set. The mid-frequency is such that both FEA and SEA degrees of freedom are necessary.

At the same time, some other methods, aimed at reducing the computational costs or at improving the predictive quality, have to be cited too. Guyader [13] investigates the possibility to reduce the dynamic model of a system with a high modal density. Desmet presents some advances of the wave based superpositon technique [14]; Shorter gives a general overview of the predictive techniques to be applied in the low, mid and high frequency range [15]. The literature is very large about the specific subject; it has to be cited too a EU FP7 Marie-Curie programme on the *mid-frequency* problems [16].

The novelty of the present work has to be focused on the possibility to analyse the partial scaling of a given finite element model built to evaluate the coupling between long and short structural wavelength carriers.

The scaling method is named ASMA (*Asymptotic Scaled Modal Analysis*) and it is focused on the possibility to scale (reduce) a given model in order to generate artificially high modal overlap factor conditions, while keeping or reducing the computational costs (CPU time). ASMA has been applied to a single system response [17] and to simple assemblies composed by two beams or two plates [18]. It is already tested for the prediction of the energy influence coefficients [18], but only recently it has been applied to generic schemes where short and long wavelengths are coupled [19]. In addition, up to date, ASMA has been analysed only for the solution of domains having similar modal densities.

Some interesting developments, specifically devoted to the scaling procedure, appeared very recently [20,21]. Others have addressed the problem of exact and distorted dynamic similitudes [22–24].

Now ASMA is framed inside a more general approach involving the similitude between structural linear systems and it represents a result associated to a given choice of the similitude parameter set: ASMA represents an incomplete similitude [25].

In the present work, the coupling between two structural waveguides is investigated through a scaling procedure and, on the contrary, its applicability to more complex coupled configurations (three or more components) is not addressed. In fact, as later discussed, there are some topological constraints which make these more complex configurations as very difficult cases. The presented approach is related to a couple of waveguides in order to evaluate the energy exchange and as consequence it could be used to estimate the energy influence coefficients, as defined in EDA (*Energy Distribution Approach*). This aim is pursued for the first time between subsystem carrying waves of different wavelengths.

After these initial remarks, some theoretical backgrounds concerning EDA and ASMA are given in Section 2. Section 3 presents some considerations about the topologies for the scaled models; it has been there defined the monolithic scaling and the partial one which is the principal topic of the present work. A summary of the previous application of the scaling procedure is also given for the sake of completeness. Sections 3 and 4 present the results for two specific configurations: a first assembly composed by two in-line rods (longitudinal waves) and a second one composed by a beam coupled to a plate (flexural waves). General highlights about the limits of the scaling procedure, thus involving the allowed choice of the scaling coefficient, are presented in Section 5 with the results of some specific configurations. Some final remarks are in Section 6 which closes the work.

2. From the energy distribution approach to the asymptotic scaled modal analysis

This paper deals with a strategy aimed at taking into account long and short wavelengths by reducing the complexity of the model. The aim is pursued by invoking ASMA; this is a method which uses low frequency global modes to estimate the response at high frequency. ASMA can be viewed as an extension of the Mace's EDA [11].

As matter of fact, ASMA considers that the modal density and the damping loss factor can be modified in order to have a scaled system (i) geometrically smaller than the original one and (ii) damped at a level higher than the original one. The approach is fully justified by invoking the *energy distribution approach*, EDA which allows the use of the global modes for getting the energy and input power.

ASMA is based on an original model and generates a parent (scaled) one in which the original dimensions are reduced and the original damping is artificially augmented so that the prediction of the energy distribution is improved for increasing values of the excitation frequency. Basically, the same set of modes is moved at higher excitation frequency with damped amplitudes. This section is fully devoted to introduce EDA and ASMA.

2.1. Energy distribution approach (EDA)

EDA allows the use of eigensolutions (natural frequencies and global mode shapes) in order to obtain the distribution of energy in each subsystem. Then, using EDA, it is possible to estimate the unknown energy vector, **E**, for a given input power