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Numerical estimation of coupling loss factors in building acoustics

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ABSTRACT

A study on the optimal procedure for obtaining SEA (statistical energy analysis) coupling loss factors (CLF) numerically is presented. The energies of an SEA system with two subsystems (one excited, the other one unexcited) are obtained from deterministic numerical simulations. Three different ways of isolating the CLF are explored: from the power balance of the excited subsystem (first approach) or the unexcited subsystem (second approach) and from the power transmitted through the connection (third approach). An error propagation analysis shows that the first approach is unreliable and that the second approach is the best option. As application examples, the CLF between some typical building structures is computed. These examples illustrate the potential of the estimated CLFs to solve larger problems with SEA and show the influence of the type of excitation on the coupling loss factor estimation. Finally, a simplified technique to account for the effect of studs in double walls with SEA is presented.

1. Introduction

Dealing with real-life vibroacoustic problems with statistical energy analysis (SEA) is not a straightforward task. The obtention of the coupling loss factors (CLF) may be a limiting factor for complex connections. In this paper a study on the optimal technique for obtaining the coupling loss factors between two subsystems, independently of the device connecting them, is presented.

Statistical energy analysis is an energy-based approach to vibroacoustic problems, widely used in building design due to its low computational cost and simplicity. It was first described by Lyon [1] as a framework of analysis based on the sound behaviour at high frequencies, and consists in performing power balances in an averaged way between the different subsystems of the vibroacoustic system. Due to this averaged nature, SEA is not designed to take into account small details of the problem geometry or heterogeneities.

For complex systems, the parameters required in the SEA formulation, such as the coupling loss factors, cannot be calculated analytically. One option for obtaining these parameters is to identify them from laboratory measurements. Some authors working in that direction are Semprini and Barbaresi [2], De Langhe and Sas [3], Gélat and Lalor [4], Renji and Mahalakshmi [5] or Bies and Hamid [6]. Most of them use the power injection method (PIM). This is a very common technique for estimating coupling loss factors from experiments. It is based on measuring energies and powers experimentally and fitting the CLFs from power balances.

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Another option to estimate these parameters is using deterministic formulations and the help of numerical methods. In the past decades, several authors have presented different approaches to estimate CLFs from numerical simulations. Some of them [7–10] use finite element methods (FEM) to obtain the energy fluxes in the problem, and then estimate SEA parameters from them. They mainly focus on mechanical problems with no acoustic interaction and do not apply the obtained parameters for solving larger problems.

Maxit and Guyader [11] estimate the coupling loss factors from modal parameters of the SEA subsystems. They use modal analysis to obtain these parameters by means of simplifying the problem with the help of substructuring. The substructuring criterion restricts the approach to domains where there are two distinct subsystems and one of them has a clearly stiffer behaviour than the other one. Problems where the subsystems are not in direct contact but connected by a third element, such as double walls, should be approached differently. Maxit and Guyader apply their approach to obtain coupling loss factors between beams and plates with common edges and Totaro et al. [12] use the same approach to compute coupling loss factors between structures and cavities.

Finally, Thite and Mace [13] deal with the idea of obtaining robust estimators of these parameters from the deterministic results. They explore the usefulness of Monte Carlo simulations for obtaining robust enough values of the coupling loss factors to be used later in different types of problems.

The main contribution of this paper is the study on the optimal approach for obtaining the coupling loss factors between two subsystems from numerical simulations. The choice of the approach is based on the error propagation committed by operating the approximated values of the energies. Other contributions derived from exploiting the chosen technique are the following:

- An analytical expression, based on the wave approach, for the coupling loss factor between two plates connected by an elastic rotational joint.
- An analysis, based on numerical simulations, of the effects of considering the cavity between the two leaves of a double wall as an SEA subsystem or as a connection between subsystems. It is followed by the proposal of a combined approach that accounts for all the transmission phenomena relevant in the double wall.
- An analysis on the influence of the excitation used in the CLF estimation when this factor is applied for solving larger vibroacoustic problems with SEA.
- A simplified approach to obtain the coupling loss factor caused by the studs between the two leaves of a double wall. Also a comparison of the coupling effect of the air cavity and the effect of the studs.

An outline of the paper follows. The bases of the CLF estimation are explained in Section 2. Three different ways of computing the CLF once the energies of the subsystems are known are described. An error propagation analysis is performed, identifying the best expressions to use in the CLF computation. At the end of the section, the deterministic approach [14,15] is briefly reviewed. In Section 3 some application examples are shown. The coupling loss factor between structures connected by different mechanical devices is obtained and compared with analytical expressions in order to validate the technique. The computed values are then used to solve more complex problems with low computational cost. The coupling loss factors associated to double walls are also computed. The effect of the air cavity is analysed and compared with typical SEA expressions. Moreover, an example of the applicability of the CLF estimations to obtain the sound reduction index of double walls is shown, considering walls with and without studs between the leaves. Finally, the conclusions of the work are presented in Section 4.

2. Methodology

The technique for computing the CLF between two subsystems is presented here. For any connecting device between them, the deterministic vibroacoustic problem is solved numerically and the coupling loss factor is computed from the numerical results.

2.1. CLF calculation

The CLF calculations are done for systems consisting of two subsystems. The SEA formulation in this case is

$$\begin{Bmatrix} \Pi_{1,\mathrm{in}} \\ \Pi_{2,\mathrm{in}} \end{Bmatrix} = \omega \begin{bmatrix} \eta_{11}+\eta_{12} & -\eta_{21} \\ -\eta_{12} & \eta_{21}+\eta_{22} \end{bmatrix} \begin{Bmatrix} \langle E_1 \rangle \\ \langle E_2 \rangle \end{Bmatrix}, \tag{1}$$

where η_{ii} and $\langle E_i \rangle$ are the internal loss factor and averaged energy of subsystem i respectively, $\Pi_{i,\mathrm{in}}$ is the input power in subsystem i and η_{ij} is the coupling loss factor between subsystems i and j (with $i \neq j$). This factor satisfies the consistency relationship

$$\eta_{ij} n_i = \eta_{ji} n_j \tag{2}$$

where n_i is the modal density (number of modes per Hz) of subsystem i.