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VALIDATION OF ANALYTIC SEA AND EFEM FOR INTERIOR NOISE PREDICTION IN THIN WALLED CAVITIES

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ABSTRACT

Analytic or predictive statistical energy analysis (SEA) and the energy finite element method (EFEM) are tools for the prediction of the vibro-acoustic behavior of mechanical structures in the high frequency range. In this paper, analytic SEA and EFEM are validated on an irregular box made up of plexiglas plates. A series of experiments has been conducted to identify the loss factors of the plates and the cavity. Other parameters, like the power transmission coefficients used in both methods, were analytically derived. Results of SEA and EFEM are compared and validated by experiments in which the testbox was structurally excited. The aim of the research is to evaluate the applicability, accuracy, efficiency and robustness of these predictive tools and to gain a better understanding of the mechanisms governing sound transmission in thin walled cavities.

1 - INTRODUCTION

At high frequencies, Statistical Energy Analysis (SEA) [1,2] represents a widely accepted, theoretical framework for analyzing the dynamic response of complex systems. SEA uses kinetic energy as a general response descriptor. Complex vibro-acoustic systems are modeled as a composition of subsystems. SEA parameters describe the ability of subsystems to store energy (modal density), to dissipate energy (internal loss factor) and to transfer energy (coupling loss factors). The energy flow between subsystems is proportional to the difference in modal energy of the subsystems.

The Energy Finite Element Method (EFEM) [3-5] is a more recent tool for the prediction of the vibrational behavior of structures in the high frequency range. Like SEA, EFEM predicts mechanical energy based on energy equilibrium equations but where SEA uses macro subsystems, EFEM uses infinitesimal structural or acoustic subsystems. As a result, EFEM is capable of predicting the smoothed spatial variation of the mechanical energy and the application of local effects such as localized power inputs and local damping treatments is more straightforward. As shown in [3], the smoothed energy of EFEM in components like beams, plates or acoustic volumes is conceptually similar to the equations of static heat flow, which can easily be solved by the finite element method [7]. At the coupling of the basic components, power transmission coefficients describe reflection and transmission of waves of different types. Because of the finite element formulation of EFEM, a *low-frequency* classical FEM database can be used for a *high-frequency* EFEM calculation. This is a big advantage over SEA since SEA needs a completely different database (SEA parameters).

In the presented research, SEA and EFEM are applied to a testbox that was constructed as a scale model of a cabin. The box consists of five plexiglas plates with a trapezoidal base. Since this box is of limited complexity compared to the real cabin, one has better control over possible model deficiencies. The internal loss factors are experimentally determined; other parameters were analytically derived. The results of SEA and EFEM were validated by PIM experiments in which the testbox was structurally excited.

2 - THE TEST STRUCTURE

The testbox has a cubic shape, as shown in figure 1. The dimensions are approximately 80 ×90 ×75 cm. All the faces have a trapezoidal shape. Different plexiglas types are used for the different plates. The difference in plate thickness and dynamic characteristics of the plates allows simulating the distinct cabin structural parts (roof, floor, doors and windscreen). The plates were glued in order to get a rigid connection between the plates. During the experiments, the box is placed on a rubber plate to minimize the effect of background vibration and to avoid flanking transmission through the laboratory floor.

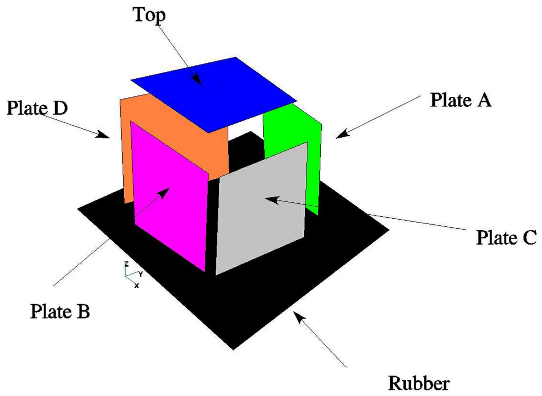

Figure 1: Schematic view of the testbox.

	Thickness (mm)	Area (m^2)	Density (kg/m^3)	Young's modulus (N/m^2)
Plate A	2.2	0.48	1.1385	2.2930
Plate B	2.3	0.68	1.2088	4.6025
Plate C and D	5	0.62	1.2171	1.8110
Top plate	3	0.64	1.3087	2.8500

Table 1: Geometric and material properties of the box.

To determine correct values of all geometric and material parameters several experimental tests are performed. A modal analysis hammer test was performed on clamped plate samples to identify the plate Young's module. Table 1 gives the geometric and material properties.

The Power Injection Method (PIM) was used to evaluate the plate internal loss factors. The values are included in both analytical SEA and EFEM analysis. Each plate was suspended individually with springs to simulate free/free conditions. PIM requires several structural input and output acquisition points. On each plate five input points were randomly distributed and the accelerations were acquired in ten structural points. Figure 2 shows the loss factors for the different plates. In order to get the internal loss factor of the cavity, the plates were assembled as in figure 1. A 0.46 m^3 cavity is created that rests on a 1.2 m^2 rubber mat of 5 mm. PIM was used to evaluate the box cavity internal loss factor. Microphones were placed in six different positions to measure the sound from a speaker. Figure 3 shows the cavity loss factor.

3 - SEA AND EFEM MODEL OF THE TESTBOX

The analytical SEA box model is created using SEADS v.1.2. The SEA model consists of 6 subsystems: 5 plates and the acoustical cavity. For each subsystem, the geometry is defined and the relevant structural and acoustics proprieties are entered. The experimental plate and cavity internal loss factors were imported directly in the SEADS software. The connections between the subsystems are defined as symmetric and rigid. The top plate is connected with all the other subsystems. Plate A is connected with plate C, plate D and the cavity. Similar connections are valid for all the lateral plates. The input power from the shaker is applied to the excited top plate. Figure 4 shows the resulting SEA model in SEADS.

Figure 5 shows the EFEM model. Each plate is divided into 8 by 8 elements. Note that this number must be much higher for classical FEM in order to have a suitable number of elements per wavelength. The

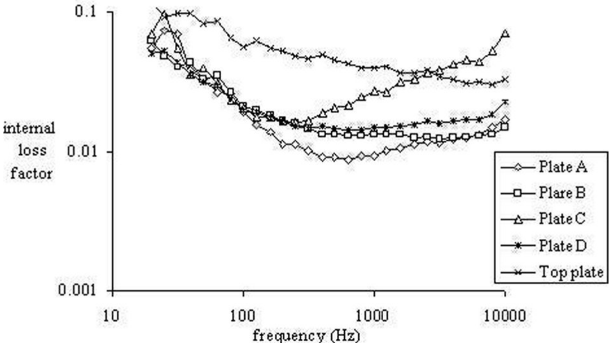

Figure 2: Internal loss factor of the plates.

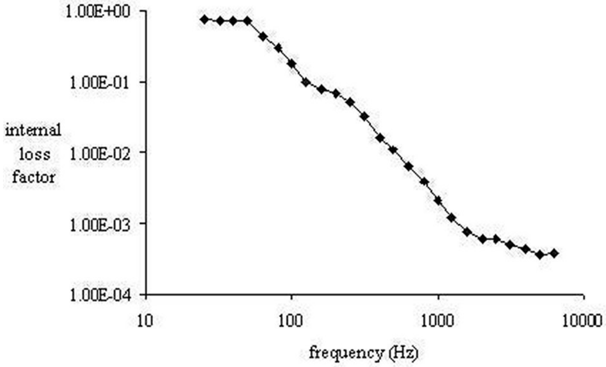

Figure 3: Internal loss factor of the cavity.

measured internal loss factors are included in the EFEM analysis. The power transmission coefficients are calculated analytically as in [6] for coupled semi-infinite plates and as in [4] for the plate-acoustic coupling. The power was applied to the appropriate nodes on the top plate. The EFEM calculations were performed in MATLAB.

4 - RESULTS OF THE EXPERIMENTAL VALIDATION

The SEA and EFEM models are validated by PIM measurements with structural excitation by a shaker on the top plate. Figure 6, figure 7, figure 8 show the results for the total energy of respectively the excited top plate, one of the other plates (plate A) and the cavity. Both SEA and EFEM agree well with the test data. As reported in literature, EFEM tends to underestimate the energy levels close to the excitation and to overestimate the energy levels farther away from the excitation point. This tendency can also be seen in figure 9 that shows the energy density of 2 individual points on the top plate. The first point is the excitation point in the middle of the plate. The second point is a point close to one of the corners of the top plate. The EFEM results at these 2 points are compared to individual measurements. As stated in the introduction, SEA is not capable of predicting energy levels at distinct points. From this result, one may conclude that EFEM is able to predict the smoothed spatial behavior.

5 - CONCLUSIONS

In this paper, analytic SEA and EFEM are validated with experimental results on an irregular box made up of plexiglas plates. A good correlation was obtained between analytic SEA, EFEM and the measurement results for the prediction of the total energy level of the different plates of the testbox. It is also demonstrated that EFEM is able to predict the smoothed spatial distribution of energy.

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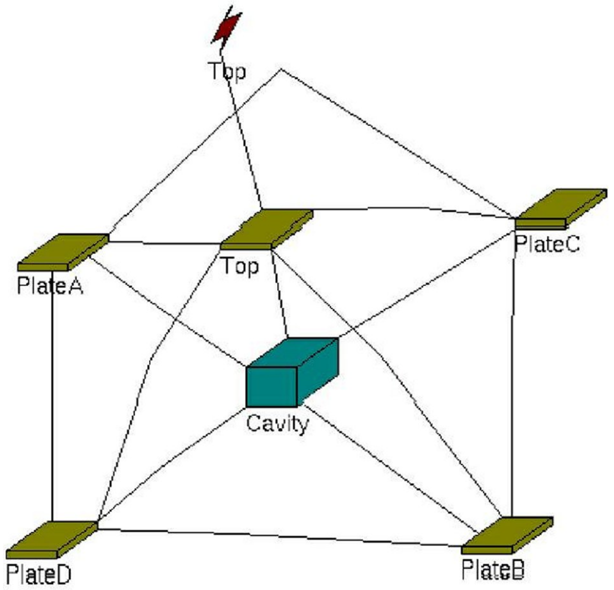

Figure 4: SEA model of the testbox.

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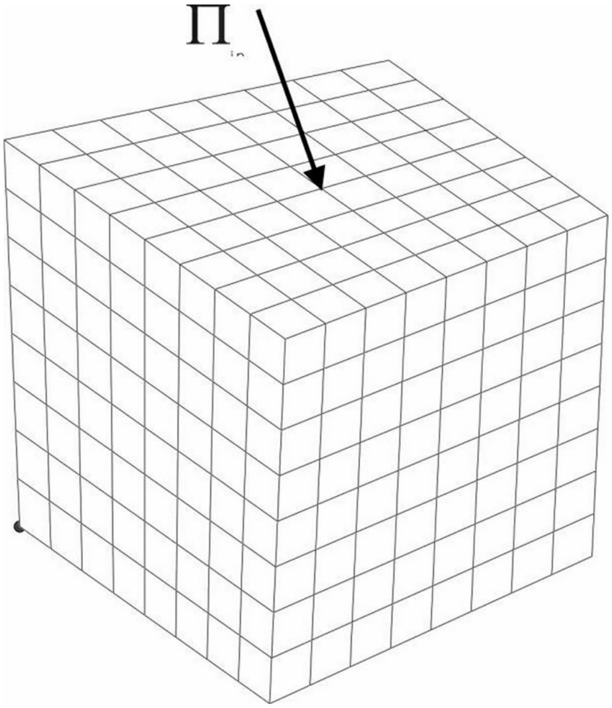

Figure 5: EFEM model of the testbox.

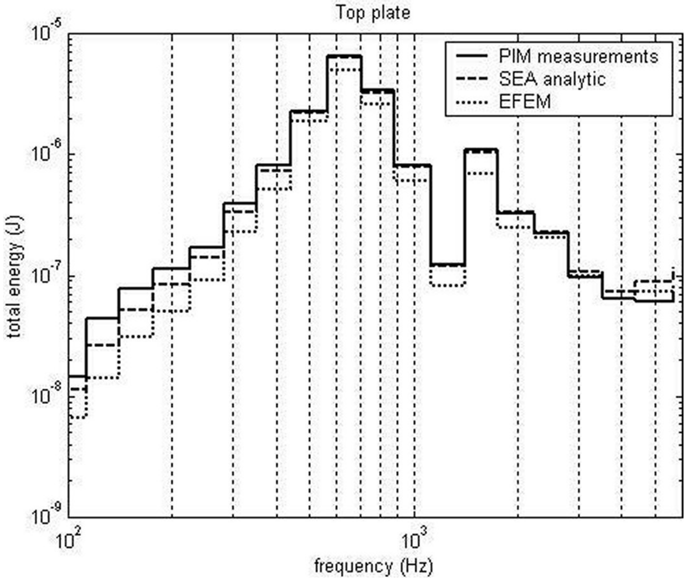

Figure 6: Total energy of the top plate.

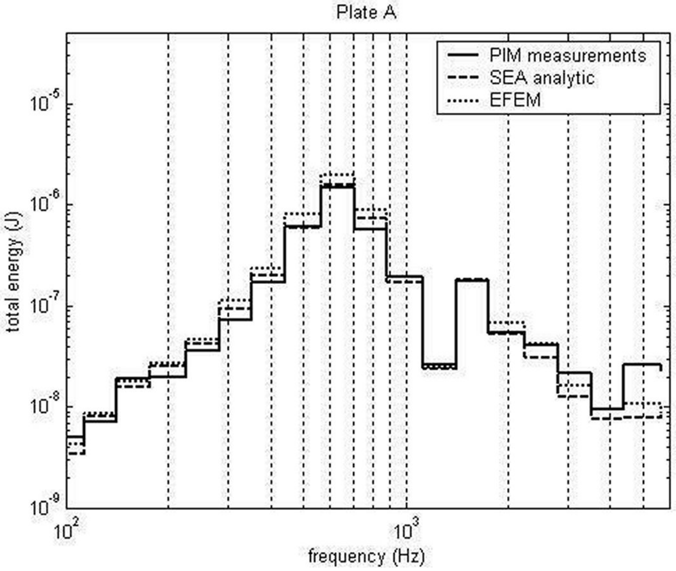

Figure 7: Total energy of plate A.

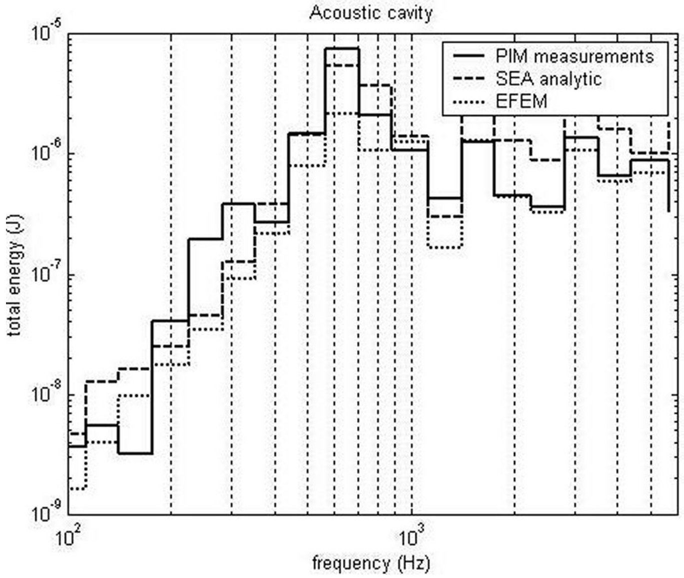

Figure 8: Total energy of the acoustic cavity.

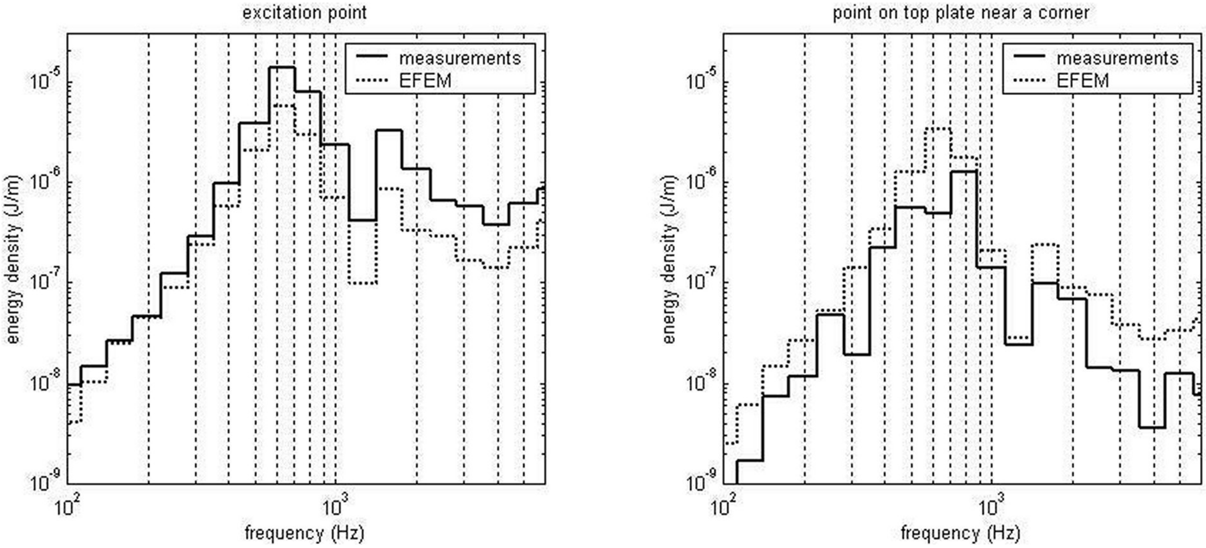

Figure 9: Energy density for 2 points on the top plate: the excitation point and a point near a corner of the top plate.