# Structure-borne Sound in Automotive Structures:

# High Frequency Boundary Element Method (HFBEM) vs.

# Statistical Energy Analysis (SEA)

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## Introduction

Sound and vibration prediction at high frequencies has been a challenging task for a lot of years. When Statistical Energy Analysis (SEA) was developed, it was possible to obtain averaged subsystem energies of a coupled structure which has to meet the requirements of SEA. However, there has been a demand to overcome some simplifications and problems SEA is rising. One out of the SEA-alternative methods, the High Frequency Boundary Element Method (HFBEM) which has been originally developed by Le Bot [1], will be tested for its usability of vibration predictions of automotive structures. Considered are three reference structures: a floor panel of a vehicle, a generic plate and a high-floor model of a train carriage.

## Theory

Starting from Huygens principle, energy density w at a certain point M inside a domain can be interpreted as the superposition of primary sources from inside the domain and of secondary sources located on the boundary. After solving a system of equations, the source strengths $\sigma_i$ of all i boundary elements are known [3]. An equation for the energy density w(M) is obtained

$$w(M) = \int_{\Omega} \rho(S)G(S,M)dS + \int_{\partial\Omega} \sigma(Q)f(\mathbf{u}_{MQ},\mathbf{n}_Q)G(Q,M)dQ, \tag{1}$$

where $\rho(S)$ specify the magnitudes of the primary sources, G(S,M) and G(Q,M) are the fundamental function values at M caused by S resp. Q; while $\Omega$ resp. $\delta\Omega$ are the domain resp. its boundary. $f(\mathbf{u}_{MQ},\mathbf{n}_Q)$ is a boundary element directivity function, which is either uniform or equals the cosine of the angle between emission direction and the normal vector of the boundary element [1]. Equation (1) and its theory based on are implemented in a code using the Python programming language. This code has been expanded to more domains, based on the boundary conditions as described in [1].

## Description of Structures

To validate the predictions of HFBEM, three structures are defined where reference measurements will take place. The first structure consists of a vehicle's floor panel with two attached wheelhouses. The dimensions of the steel panel as seen in Figure 1 are 2.50m x 1.22m x 1mm (length x width x thickness). For vibration measurements, the panel is mounted to soft springs.

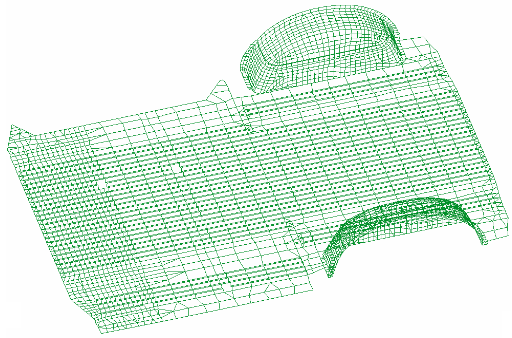

**Figure 1:** Floor panel with two attached wheelhouses

The second construction shows a generic commercial vehicle structure. It consists of an aluminium panel of dimensions 2m x 0.8m x 2mm (length x width x thickness). Two longitudinal double-T-beams and five transversal T-beams are attached to the plate as shown in figure 2.

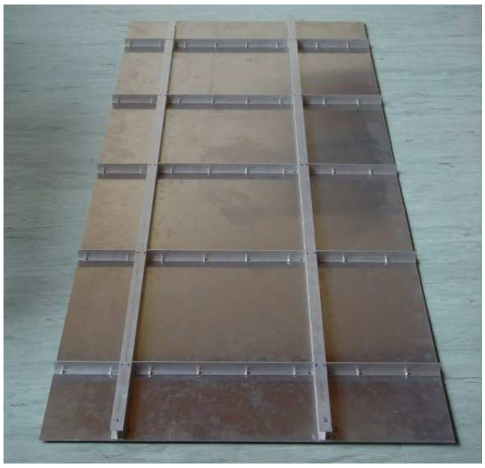

**Figure 2:** Generic commercial vehicle structure

The high-floor region (floor of a carriage) of the train AGC is modelled in structure three. It consists of 4 rectangular plywood panels with a thermoplastic core which are laid on two double-T beams. For a better vibration isolation, *Sylomer* strips (polyurethane-elastomers) are fixed between panels and beams. The panels are 16mm in thickness and have dimensions of 3.50m x 1.40m (length x width).

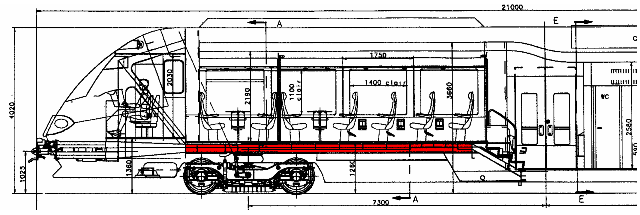

**Figure 3:** High-floor region of the AGC train. Drawing by courtesy of Bombardier Transportation

## Convergence

To compare HFBEM to SEA, a simple test case was defined which consists of two square steel plates of 2m x 2m x 1mm dimensions. Both plates had the same material properties and were coupled at an angle of 180°. Plate 1 has been driven with a point source of magnitude 1W. Obtaining the energy density w(M) from equation (1) and integrating over all area elements of the two plates structure will result in the total energy of the structure $W_{HFBEM}$. The energy received this way is compared in Figure 4 to $W_{SEA}$, the sum of the energies that SEA calculated for both plates. The smaller the element length of the mesh is, the better both energies correspond. Plotted is the relative error e:

$$e = \frac{W_{HFBEM}}{W_{SEA}} - 1 \qquad (2)$$

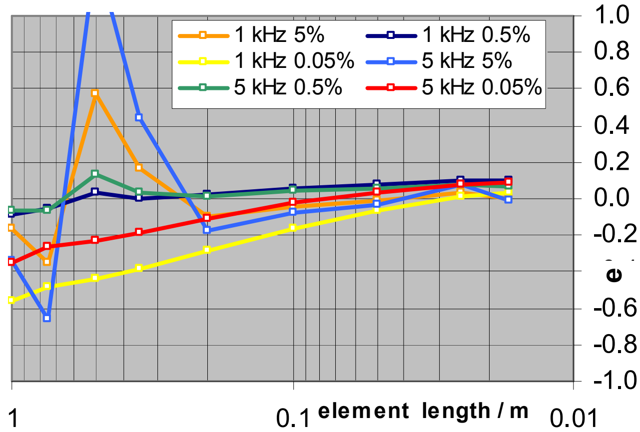


**Figure 4(a):** Convergence for uniform directivity

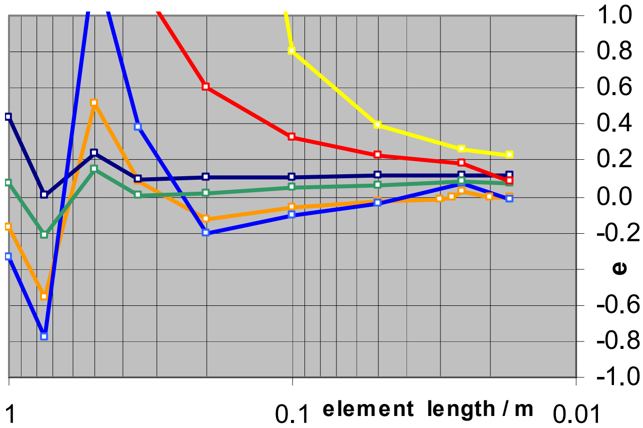


**Figure 4(b):** Convergence for cosine directivity

## Measurements

For one domain, vibration measurements on aluminium plates having different damping values were performed. Figure 6 illustrates the velocity level $L_v$ of the response path of a damped plate (damping loss factor 1 %). The dimensions of the plate can be seen in Figure 5.

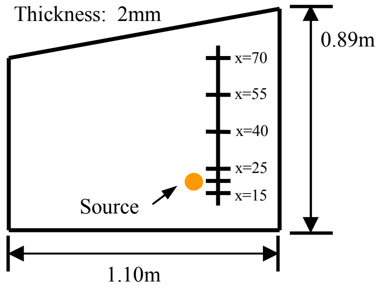


**Figure 5 :** Trapezoid damped aluminium plate with one source and one response path for acceleration measurements

The vibration prediction with the HFBEM is closer to the measurements than SEA, which predicts an averaged velocity level for the entire plate. The HFBEM also points out the velocity maximum (where the source is located) and the decrease in the far field.

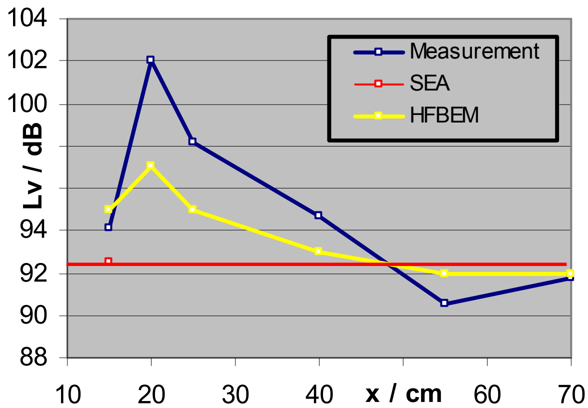


**Figure 6:** Velocity level $L_v$ as a function of the distance

## Summary:

It can bee seen, that HFBEM can provide more information than SEA. Especially for higher damping, the HFBEM predictions are of better quality than the SEA predictions. The smaller the boundary element length becomes, the better the structures total energies calculated from HFBEM and from SEA match together. For more domains, the HFBEM code will be expanded including the calculation of transmission efficiencies at domain interfaces. Measurements on the above presented reference structures will then be performed.

## References

[1] Le Bot, A.: A Vibroacoustic Model For High Frequencies. 1998, JSV 211 p.537-554

[2] Sarradj, E.: Randintegralmethode für hohe Frequenzen. in: Fortschritte der Akustik 2003 p. 578-579

[3] Sarradj, E. High Frequency Boundary Integral Method as an Alternative to Statistical Energy Analysis. 2003, Tenth International Congress on Sound and Vibration Stockholm, 2003, p.1131-1138