Boundary Element Energy Method for the acoustic prediction of vehicle external and interior noise – Validation on a mockup and industrial application

B. Betgen[1], M. Thivant[1], A. Cloix[1], P. Bouvet[1], A. Bocquillet[2]
[1]VIBRATEC, 28 chemin du Petit Bois, 69131, Ecully cedex, France, E-Mail: michael.thivant@vibratec.fr
[2]BMW Group, E-mail: arnaud.bocquillet@bmw.de

Introduction

In the context of more and more drastic noise regulation and increasing customer demand for lower noise annoyance, acoustic shields and cab insulation become essential for a wide range of vehicles. Due to reduced development times, the acoustic design must start in the early stage of industrial projects and follow the whole development phase, requiring precise and reactive prediction tools.
Classical methods based on Helmholtz's equation are quite accurate in low frequencies and for simple geometry, but they are limited for industrial problems by their computing time and their lack of robustness. To overcome these difficulties, a method based on energy boundary elements is proposed here. Absorbing materials are characterized by diffuse absorption and transmission coefficients. The frequency based meshing criterion is relaxed: only the description of the geometry must be considered.
This energy method is dedicated to acoustic issues in the mid and high frequency range, preferably with complex geometries, broadband and distributed sources. The acoustic resolution is carried out by recently developed software SONOR. Successful comparisons with measurements are presented, concerning external noise prediction for the mock-up of an automotive engine bay.

Theory

The model proposed here uses surface boundary elements to describe sources, absorbing and reflecting surfaces. Theoretical details can be found in references [1] to [4], however, the basic theory is recalled in the following.

Model assumptions:

Uncorrelated waves are assumed. Interferences between waves are neglected. This assumption is valid for acoustic problems at high frequencies, with broadband sources and complex environments.

Sources are described by their emitted power. Sound power is uniformly distributed on the source surface and radiates diffusely in all directions.

The incident field on each element is diffuse.

Diffuse absorption, reflection and transmission: if an element i receives a power $w_{\text{incident}}(i)$ from the other elements it will absorb part of the incident power depending on its diffuse absorption coefficient α_i (equation (1)):

$$w_{\text{absorbed}}(i) = \alpha_i \, w_{incident}(i)\,, \qquad (1)$$

Diffuse reflection is governed by the reflection coefficient r_i :

$$w_{\text{reflected}}(\text{i}) = \text{r}_i \, w_{incident}(i) \qquad (2)$$

The power transmitted from face k to face i of an element is given by equation (3), where τ_{ki} is the transmission coefficient in diffuse field.

$$w_{\text{transmitted}}(\text{i}) = \tau_{\text{ik}} \, w_{incident}(k) \qquad (3)$$

Coefficients α_i, r_i :, and τ_{ki} are related by equation (4), deriving from the power balance on element i.

$$1 = \alpha_i + \tau_{ik} + r_i \qquad (4)$$

View factors computation

The energy exchanged by a couple of boundary elements depends on their mutual "view factors". These factors are only related to geometry (elements area, orientation, presence of obstacles between the 2 boundary elements). In the absence of obstacles, the „view factor" can be obtained analytically.
To account for the presence of obstacles, the computation of "view factors" is performed using a numerical solver dedicated to thermal radiation.

Solution of the boundary element problem

To derive the system of equations to be solved, the power balance is written on each boundary element. For acoustic problems, the power w(i) emitted by the element i is the sum of reflected, transmitted and source powers:

$$w(\text{i}) = w_{reflected}(i) + w_{transmitted}(i) + w_{source}(i) \qquad (5)$$

Reflected and transmitted powers are expressed in terms of incident powers using equations (2) and (3). The incident power w_{incident}(i) is the sum of the powers w(j) emitted by the other elements j, weighted by the view factors F_{ji}:

$$w_{incident}(i) = \sum_{j \neq i} F_{ji} w(j) \qquad (6)$$

Introducing equations (2), (3) and (6) in equation (5) gives

$$\text{w(i)} = (1 - \alpha_i - \tau_{ik}) \sum_{j \neq i} F_{ji} w(j) + \tau_{ki} \sum_{j \neq k} F_{jk} w(j) + W_{Source}(i) \qquad (7)$$

One obtains a system of n equations (with n the number of boundary elements), with n unknowns *w(i)* being the powers emitted by each element *i*.

Post-processing

The incident power at each boundary element can be derived from the emitted powers using equation (6). Absorbed, reflected and transmitted powers can be derived from the incident power using equations (1), (2) and (3). Any power balance can then be computed on groups of boundary elements, summing either absorbed, reflected, transmitted or incident powers. Insertion Loss can be computed from the results obtained in two configurations (with and without shields).

Boundary elements model

The boundary elements must describe the geometry accurately enough, but no frequency criteria related to the wavelength is required. The mesh of the engine mock-up and compartment is shown in Figure 1.

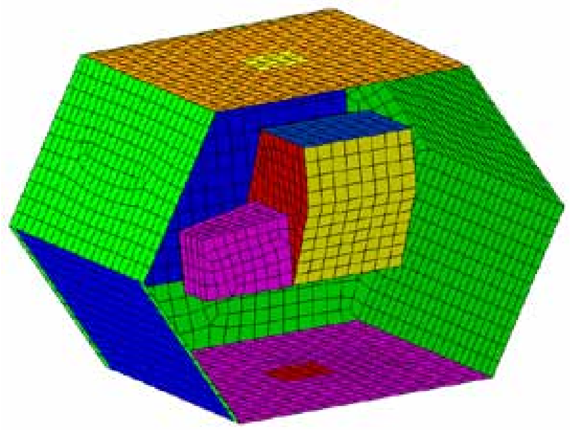

Figure 1: Surface mesh oft the power train inside the compartment

Results on engine bay mock-up

Output power is measured by BMW in a reverberant room for different enclosure configurations. Measured and predicted total output power are compared on Figure 2. In the frequency band of interest (ie middle / high frequencies), the computed acoustic output power levels are very close to the measured levels - especially for the configuration with apertures (C5 – orange lines). Output power ranking versus material configuration is well-predicted. The under-estimation of emitted power in the high frequency range is caused by the over-estimation of the transmission losses (TL) of the upper und lower plates (initially measured with coupled reverberant rooms). In fact, the use of TL values measured in-situ clearly improves the results.

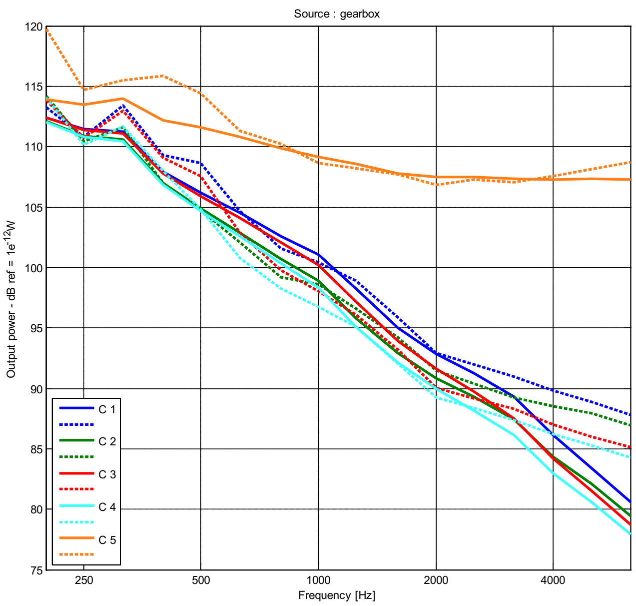

Figure 2: Total output power with gearbox source; dashed lines: measurement, solid lines: computation.

The radiated power for different source configurations is shown in Figure (3) for a given porous material configuration and with a small aperture. Besides the very low frequency range where modal behaviour occurs, the ranking of the different configurations is correct and results are quantitatively satisfying. Such kind of test clearly shows the extended possibilities of the Boundary Element Energy Method in respect to classical Statistical Energy Analysis (SEA).

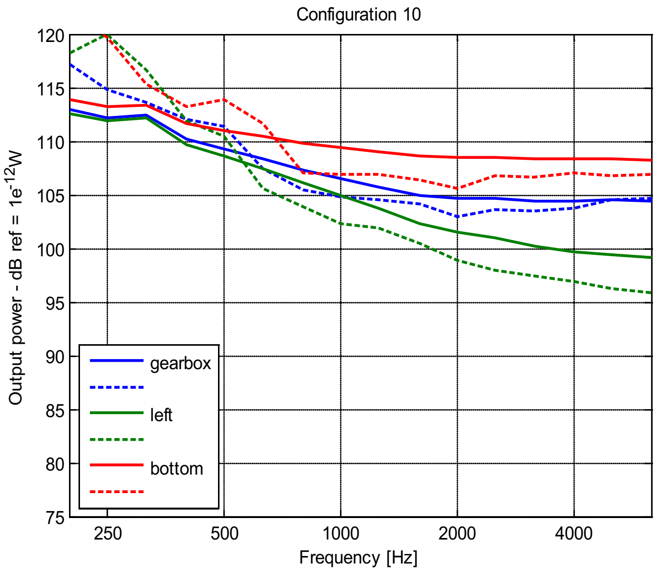

Figure 3: Total output power with open aperture on the bottom side and different source regions switched on. Dashed lines: measurement, solid lines: computation.

Conclusion

The Boundary Element Energy Method is capable of modelling the effect of different acoustic shielding configurations with a very low computational cost. Calculated output powers are predicted within a few dB, and the ranking between configurations is correctly predicted. Therefore the method can be used for acoustic shields design and validation all along the conception phases.

References

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