Simulation of the acoustical behavior of reverberant rooms by means of the fast multipole BEM

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Introduction

Determination of sound transmission loss often takes place in a measuring facility that is composed of a reverberant room and anechoic chamber. Those experimental studies are usually very time-consuming and expensive. It has been shown, however, that such experiments can be simulated with sufficient accuracy by numerical methods.

Reverberant rooms often exhibit a large volume, which can be hardly modeled by finite element methods (FEM) or conventional boundary element method (BEM). In this paper the fast multipole boundary element method (FMM) is used to calculate the acoustical field in a reverberant room. Furthermore, since the sound field in the reverberant room can be regarded as diffuse field, the results will also be verified by an analytical model of the diffuse field, a so-called “plane wave model” [1].

Computational model of sound transmission loss

The measuring facility is shown in figure 1. It consists of two rooms, a reverberant and an anechoic one, separated by a massive wall with an open window, where the considered specimen is placed. The reverberant room is used to generate an acoustical diffuse pressure field exciting the specimen. On the other side of the specimen the absorbing materials of the anechoic chamber prevent reflections of radiated sound, such that only transmitted sound energy is measured.

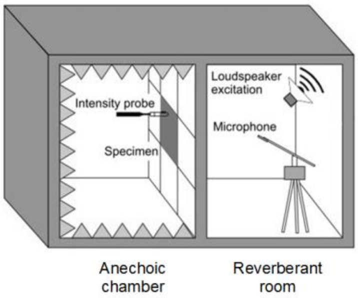


Figure 1: Sketch of the window measuring facility for the investigation of sound transmission loss.

The computational model of sound transmission loss is designed accordingly. It contains three parts as shown in figure 2: structural elements, a layer of elements for the acoustical fluid, and absorbing boundary condition. The structural elements are used to simulate the dynamic behavior of the specimen. Then the acoustical elements are coupled to the structure, so that its sound radiation can be calculated. Finally the infinite element method is applied as the absorbing boundary layer around acoustical fluid. As for the excitation of the system, the diffuse fields obtained from both FMM and the plane-wave-model are applied to the structure.

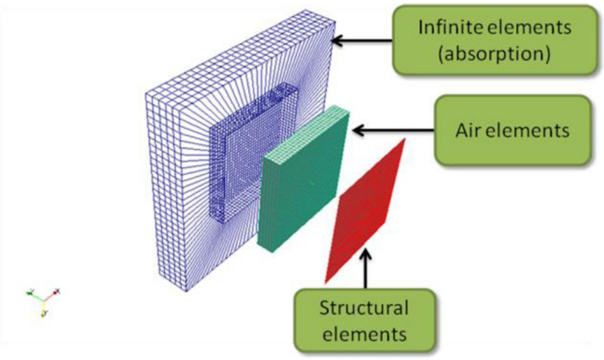
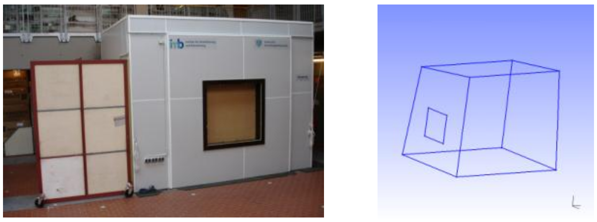


Figure 2: The basic structure of the computational model for sound transmission loss investigations.

Simulation of the reverberant room by means of the fast multipole BEM (FMM)

The system matrix of the conventional BEM approach is a nonsymmetric and fully populated matrix, which requires plenty of computational resources for its computation. In fact, the solving of such a system needs $O(N^3)$ and $O(N^2)$ operations by means of direct and iterative solvers, respectively. Hence, for large-scale problems the usage of the conventional BEM is limited. On the contrary the FMM does not explicitly assemble the entire system matrix. Instead, by hierarchically dividing the whole system into different cells, direct integrations like the conventional BEM are only needed in the near field. The interactions between those cells are further used for the far field calculation [2].



(a) (b)

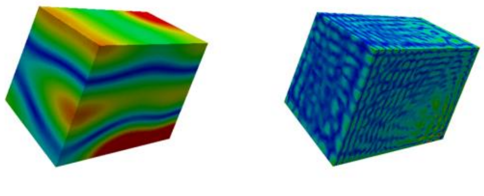
Figure 3: The reverberant room (a) and its CAD model (b).

The employed reverberant room is illustrated in figure 3(a). It has the size of about 4m×4m×3m, where the specimen window is 90cm×90cm. The internal surfaces of the room are regarded as rigid walls and meshed by 94572 elements. A 90-days evaluation version of the program “FastBEM” [3] is used to carry out the calculation with the configurations listed in table 1.

Table 1: Configurations of the fast multipole BEM calculation of the reverberant room

Max. number of elements in a cell	100
Max. number of tree levels	10
Order of fast multipole expansions	6
Convergence tolerance of the iterative solver	5.0E-4

Some of the results are shown in figure 4, the sound field generated in the simulation shows certain patterns at each frequency. The sizes of those patterns are inversely proportional to the frequencies. Such sound fields are actually not really diffuse, but this effect will be discussed in more details in the next section.



(a) 100Hz (b) 1000Hz

Figure 4: The simulation results of the reverberant room at different frequencies calculated by FastBEM. (a): the result at 100Hz. (b): the result at 1000Hz.

Verification with plane wave model

The plane wave model [1] is a stochastic model, where the diffuse field is calculated by sound sources which are equally distributed around the field. Each sound source creates a plane wave; the amplitude and the initial phase of those plane waves are randomly assigned. Then the diffuse field is calculated by a superposition of all the plane waves. It is obvious that each realization of the diffuse field is incorrelated to the others. The problem of using such a stochastic model in a transmisson loss calculation is that several realizations of the diffuse field have to be applied as excitations, and for each excitation the whole system must be solved repeatedly. Then the average value is considered as the final result.

In figure 5 two realizations of the diffuse field, obtained by means of the plane wave model at 500Hz, 1000Hz, and 2000Hz, are compared with the respective results of the FMM simulation. At each frequency the diffuse fields of the plane wave model contain similar patterns as the FMM model, therefore the sound field in the reverberant room can be regarded as one realization of a diffuse field.

The transmission loss curves are shown in figure 6. For the plane wave model 5 realizations of diffuse fields are applied as excitations at each frequency, whereas the FMM model only requires one excitation obtained by simulating the reverberant room. Although both predicted transmission loss curves fit the measurement well, it is to notice that the result of the averaged plane wave model is smoother than the other. However, with the help of FMM approach, the actual sound field in the measurement can be represented, and instead of 5 only one excitation has to be solved for the whole system.

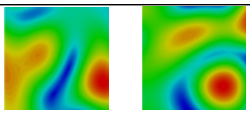
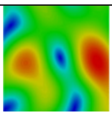
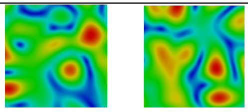
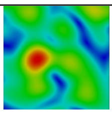
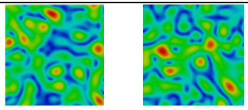
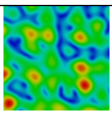
	Plane wave model	**FMM simulation**
500Hz		
1k Hz		
2k Hz		

Figure 5: Diffuse fields calculated by both plane wave model and fast multipole BEM (FFM).

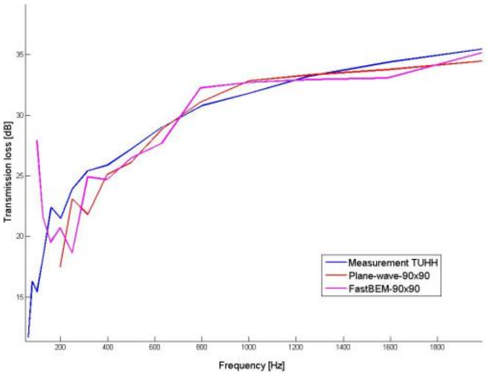


Figure 6: Comparison of the measured transmission loss with the results predicted by the numerical model, whose excitations are calculated both by plane wave model and FMM.

Conclusion

The simulation of the sound field in reverberant room by FMM is comparable to the diffuse field excitation. It consumes more time in the preprocessing phase, but is more efficient in sound transmission calculations.

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Literature

[1] Rafaely, B.: Spatial-temporal correlation of a diffuse sound field. J. Acoust. Soc. Am 107(6), 2000.

[2] Liu, Yijun: Fast multipole boundary element method, theory and applications in engineering, 2009

[3] FastBEM Homepage, URL: `http://www.fastbem.com`