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A Burton–Miller formulation of the boundary element method for baffle problems in acoustics and the BEM/FEM coupling

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ABSTRACT

Baffle problems, i.e. radiation problems from objects mounted behind a hole of an infinite hard reflecting wall, can be simulated as a multi domain problem consisting of a finite interior domain around the object, and two infinite half spaces in front and behind the baffle plane. A formulation of such problems is presented in the context of the Burton–Miller boundary element method. Additionally, the coupling of the acoustic boundary element method and the structural finite element method in the context of the Burton–Miller-formulation of the baffle problem is discussed.

1. Introduction

It is well-known, that for certain critical frequencies the integral representation formula for an exterior Helmholtz problem does not have a unique solution. The CHIEF-point method presented by Schenck [1] is widely used to guarantee a unique solution also at these irregular frequencies. However, particularly at higher frequencies, it is difficult to select appropriate CHIEF-points, because they must not be located near the nodal surfaces of an associated eigenvalue problem which are unknown (see also [2–4]). Moreover, the large condition number of the coefficient matrix, which is caused by improperly selected CHIEF-points, makes the application of iterative solvers almost impossible. However, for large scale problems, especially when fast numerical methods such as the fast multipole method [3,5–11] are used, iterative solvers are preferred or even inevitable, thus a high condition number caused by badly selected CHIEF points should be avoided. The Burton–Miller method [12] is free from the above difficulties. In [13] an algorithm for a symmetric Galerkin-type boundary element method (BEM) with CHIEF-points was formulated. Based on the equations derived in that work, we formulate equations for a Burton–Miller BEM for acoustic radiation and scattering in a similar manner.

The baffle problem, i.e. the acoustic radiation problem including an apparatus mounted behind a hole of a large, hard reflecting wall, is of practical importance for developing electrical devices such as high frequency loudspeakers. To simulate the reflections from the baffle, the baffle can be discretized directly, but this approach is not efficient, because the baffle is generally seen as being infinitely large compared to the apparatus. Alternatively, in our approach an interface that encloses the considered apparatus is chosen, so that the whole space is subdivided into three domains: a finite one around the apparatus and the hole in the baffle, and two infinite ones in front and behind the baffle, respectively (see Fig. 1). The three-domain approach was chosen to correctly model situations, when the apparatus is mounted behind a hole in the baffle. The apparatus may lie partly in front of the baffle and partly behind it. The advantage of our approach is that only the interface and the surface of the apparatus need to discretized, but not the baffle itself. Thus the dimension of the problem can be reduced drastically compared to the direct method. Multi domain approaches were already used for coupled interior/exterior acoustic problems (see for example [14]) or for modeling seismic wave propagation [15].

In Section 2, we derive the boundary integral equations (BIE) for baffle problems in the context of the Burton–Miller BEM and derive the linear system of equations. Naturally, the boundary integral equations for problems without baffle can be seen as a special case of that for the baffle problem. In Section 3, the coupling between the Burton–Miller BEM for the baffle problem and the structural finite element method (FEM) will be treated using the similar approach as in [16,17]. In Section 4, results for three examples are shown. In the first example, a baffle problem is solved using the direct method (i.e. direct discretization of a large part of the baffle) and the indirect method (i.e. using a multi domain model without discretization of the baffle itself). The second example shows the results for the sound radiation from a high frequency loudspeaker mounted on a baffle. The third example is the simulation of sound

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