Acoustic Simulation for Loudspeaker Using FEM/BEM

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Abstract: This paper studies the problem of computing an internal acoustic field of a loudspeaker box. The acoustic properties of walls, made of Medium Density Fibreboard (MDF), are taken into account by using admittance boundary condition. The coupling between the structure and the fluid is also considered. Both finite element and boundary element methods are used for numerical computations and the results are compared with each other and with measurements.

LOUDSPEAKER MODELING USING FINITE AND BOUNDARY ELEMENT METHODS

The loudspeaker box has especially been manufactured for experimental purposes. The material of the box is MDF-plate. The inner dimensions of the box are 25 cm x 40 cm x 60 cm. The loudspeaker element is 6.5" SEAS P17REX, which is placed in the rim of the 25 cm x 40 cm front plate so that it is centered with respect to the three walls. For simulation the inner region $\Omega$ of the loudspeaker box has been modeled using Helmholtz equation:

$$\nabla^2 P + \frac{\omega^2}{c^2} P = 0, \quad P \in \Omega. \quad (1)$$

The MDF-walls of the box are acoustically very hard and they have been modeled using an admittance boundary condition (boundary part $\partial \Omega_1$). Because the simulation is done at low frequencies, the loudspeaker element has been modeled as a simple piston by means of a velocity boundary condition (boundary part $\partial \Omega_2$):

$$\frac{\partial P}{\partial n} = -\rho i\omega A(\omega) P, \quad P \in \partial \Omega_1 \quad \frac{\partial P}{\partial n} = -\rho i\omega v_n, \quad P \in \partial \Omega_2. \quad (2)$$

Here $P$ represents pressure, $\omega$ frequency, $c$ speed of sound, $\rho$ fluid density, $A$ admittance and $v_n$ normal velocity.

Finite element method (FEM) is a popular method for solving partial differential equations (PDEs). The PDE is transformed into an integral equation, the solution domain $\Omega$ is discretized and the solution is approximated at the nodes of the mesh by means of element functions. In this case this leads to a system of linear equations:

$$KP + iwCP - \omega^2 MP = F, \quad (3)$$

from which the unknown pressure vector $P$ can be solved at all frequencies of interest.

Boundary element method (BEM) is another approach to solving (1). The PDE is transformed into an integral equation which consists of boundary integrals only. Now the three-dimensional acoustic problem is reduced to two-dimensional one. When the problem is discretized, a system of linear equations is obtained. In addition to boundary nodes, BEM can be used to calculate a solution for (1) in an arbitrary point of $\Omega$. The direct BEM method, used in this paper, leads to the following matrix equation:

$$HP = GQ. \quad (4)$$

Here $P$ represents pressure and $Q$ normal velocity at boundary nodes.

When the coupling between the structure and the acoustic field is taken into consideration, the situation becomes more complex. FEM can be used to simulate the vibration of walls under acoustical excitation and this structural model can be coupled with acoustical FEM/BEM-model. In practice the coupling is described with a coupling matrix. Details of both FEM and BEM in acoustic simulation are treated in reference (1).
SIMULATION RESULTS

In this paper the internal acoustic field of the loudspeaker box has been simulated using both finite and boundary element methods. All the calculations have been made using vibro-acoustic software SYSNOISE rev. 5.3 and a 300 MHz DEC Alpha workstation. FEM-models have 702 nodes and BEM-models have 394 nodes. Both the models use the same mesh, but for BEM all internal nodes have been removed. It is often required that an element mesh should have at least six nodes per wavelength. In this case the models used are valid up to 1100 Hz. In Table 1 there are some details about numerical calculations. It can be seen that coupled models take significantly more time to solve. In this case it seems that uncoupled FEM-models are larger but faster to solve than uncoupled BEM-models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Calculation Time (s)</th>
<th>Used Memory (Mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEM</td>
<td>0.7</td>
<td>4.5</td>
</tr>
<tr>
<td>BEM</td>
<td>3.9</td>
<td>6.0</td>
</tr>
<tr>
<td>Coupled FEM</td>
<td>56.5</td>
<td>50.5</td>
</tr>
<tr>
<td>Coupled BEM</td>
<td>51.2</td>
<td>31.8</td>
</tr>
</tbody>
</table>

Figure 1 shows the calculated frequency responses at a point, which is located 40 mm from the back plate, 22 mm from the side plate and 23 mm from bottom of the box. For verification the measured frequency responses have also been plotted. The measurement system is explained in reference (2). The picture on the left represents the uncoupled problem and the right one the coupled problem. It should be noted that the curves have been plotted so that they do not cover each other. This means that the decibel scale gives only relative information. Curves from top to bottom represent FEM, BEM and measurements, respectively.

FIGURE 1. Frequency responses.

REFERENCES