Determination of Loudspeaker Characteristics by Numerical Modeling and Measurements

André L. Goldstein and Samir N.Y. Gerges

Federal University of Santa Catarina, Department of Mechanical Engineering, Acoustic and Vibration Laboratory, Cx.P. 476, Florianópolis, SC, Brazil

The frequency response prediction of loudspeakers has a closed-form analytical solution only for low frequencies and simple geometries. This paper presents the use of the finite element method and the boundary element method to extend the prediction of loudspeaker response to higher frequencies to allow consideration of the flexible behavior of the diaphragm. The modeling of a commercial loudspeaker is performed considering the axisymmetry of the system, and its frequency response and directivity are calculated. The procedure used to obtain the material properties is also presented. The computational results were compared with measurements made in a hemi-anechoic chamber and show good agreement. The FEM modal analysis of a three-dimensional model was performed and compared with results from an experimental modal analysis. The comparison gives some insight into the validity of the simplifications assumed in the axisymmetrical model adopted to predict the sound pressure response.

1. INTRODUCTION

The prediction of the acoustic response of loudspeakers is a problem that has a closed-form mathematical solution restricted to low frequencies, when the acoustic wavelengths involved are larger than the dimensions of the system. Such a problem can be solved using lumped parameters. In this case, the loudspeaker is modeled using dynamical analogies and by formulating an equivalent electrical circuit, with the cone of the loudspeaker being considered to behave like a rigid piston (Beranek, 1993). However, in general, the loudspeaker is used at higher frequencies, where the cone no longer vibrates as a rigid body and the propagation of structural waves modifies the surface velocities of the cone and alters its frequency response. Therefore, until recently, the design of loudspeakers for the complete frequency range of operation was made in an empirical way, by trial and error and by the construction of a great number of prototypes.

Today, with the advance in computational resources and the widespread availability of numerical methods, the prediction of the vibro-acoustic behavior of loudspeakers is technically possible. The finite element method (FEM) can accomplish the prediction of the vibratory behavior, as presented, for example, in the work of Shepherd & Alfredson (1985). However, FEM is not efficient for the evaluation of the sound radiation and so approximate methods are normally used; see for example the simple source method (Kyouno & Kagawa, 1983; Shindo et al, 1980 and Suzuki & Nomoto, 1982); or more recently, the boundary element method (BEM), as shown by Henwood & Jones (1987) and Geaves (1996).

In this paper the prediction of the vibro-acoustic response of loudspeakers is accomplished, including the flexible behavior of the cone, by using FEM and BEM. The modeling of a commercial loudspeaker with a paper cone and foam surround suspension was performed and its sound pressure level response computed. A procedure to measure the cone and surround material properties necessary to formulate the finite element model is discussed. The Thiele-Small parameters (Small, 1972; Thiele, 1980) and an empirical model for the impedance at higher frequencies, as proposed by Wright (1990) were used to obtain the force values necessary in the FEM forced response simulation. The validation of the results obtained from the computational model was made by comparing the results with those from sound pressure measurements in a hemi-anechoic room.

The modal analysis of a three-dimensional model was performed and compared with the results of an experimental modal analysis done by using a non-contacting laser transducer. This comparison gives information about the validity of the simplifications assumed in the axisymmetrical model adopted to evaluate the sound pressure response, when it is compared with the more realistic 3-D model with real loudspeakers.

2. DETERMINATION OF MATERIAL PROPERTIES

To formulate the finite-element model of a loudspeaker, it is necessary to have knowledge of the material properties of the cone and surround, in particular the Young's Modulus and the structural damping. These have been shown to have a great influence in loudspeaker sound pressure response calculations.

In this work the method adopted is described in the ASTM standard E756 — "Measuring Vibration Damping Properties of Materials". This method is suitable to measure the vibration damping properties of materials over a frequency range of 50 Hz to 5 kHz and over a useful temperature range of the material.

In this method, also known as the Oberst bar test method, the material to be tested is bonded to a specific size of steel bar and the system is excited in its various modes of vibration under a cantilevered configuration. The dynamic complex modulus properties of the elastomeric material can be calculated from the natural frequencies and the corresponding modal loss factor of the homogeneous and composite beams. These are obtained from the transfer function of the system.