Applied Acoustics 93 (2015) 9–14

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Technical Note

Influence of enclosure wall vibration on the frequency response of miniature loudspeakers

Xuan Zhong *, Qunli Wu, Xiaodong Li

Institute of Acoustics, Chinese Academy of Sciences, 21 Bei-Si-huang-Xi Road, Beijing 100190, China

ARTICLE INFO

Article history:
Received 18 April 2014
Received in revised form 6 January 2015
Accepted 14 January 2015
Available online 4 February 2015

Keywords:
Miniature loudspeaker
Loudspeaker back cavity
Frequency response
Loudspeaker directivity
Structural vibration

ABSTRACT

The miniature loudspeaker is widely used in consumer electronic products. The unwanted vibration of the enclosure wall of the loudspeaker could add to the overall acoustic output and cause distortion of the frequency response. An experimental miniature loudspeaker model with a low-damping enclosure wall was constructed. The vibration of the enclosure wall plate was simulated with an acoustical analogous circuit, in which the wall plate was modeled as a separate branch in parallel with the back cavity air volume. The acoustic frequency response of the enclosure wall was simulated with combined finite element method and boundary element method (FEM–BEM). The vibration and acoustic measurements validated the effectiveness of the simulation methods. Finally, the frequency response of a production type miniature loudspeaker was measured before and after modification. Distortion up to ±15 dB on the frequency response curve was observed around 7.8 kHz. With damping material applied to the enclosure wall, the distortion was largely suppressed.

1. Introduction

The miniature loudspeaker is widely used in consumer electronic products, often as a sub-system in applications such as hands-off telephone calls and music playing [1]. A smooth and flat frequency response is commonly required by telecommunication standards and is favorable for perceived sound quality [2]. The acoustic part of a loudspeaker system consists of the loudspeaker unit and the back cavity. When the loudspeaker unit plays sounds, the enclosure walls also vibrate and may distort the frequency response [3]. However, it is common engineering practice to simply generalize the whole back cavity as a volume of air [4], and the enclosure wall vibration problem was seldom documented in the context of miniature loudspeaker designs.

The thickness of a miniature loudspeaker unit is typically 2–3 mm, and almost always under 10 mm. Its diameter is typically 10 mm, and almost always under 50 mm. To save space and lower manufacturing complexity, the two suspension parts on a normal-sized loudspeaker unit (the roll surround and the spider) are combined into a single one, i.e. the outer part of the membrane. The structure of miniature loudspeaker units and systems has been discussed in greater detail in [4]. The miniature loudspeaker enclosures are often made of low-damping materials such as plastic or metal, which cannot easily suppress the resonance of plates compared to the commonly used wood materials for the normal-sized loudspeaker [3]. Thus, some higher modes of enclosure wall resonance may also be excited to such an extent to affect the loudspeaker's frequency response. In another aspect, the miniature loudspeaker systems in handheld/desktop/car audio applications do not always point to the user's listening position with their main axis [5].

If the problems of enclosure wall vibration could be simulated in an early phase of the acoustic design process, they could be fixed at a lower cost. A straightforward way of modeling is the analogous circuit method. Tappan [3] modeled the enclosure wall with an analogous circuit and observed distortion on the frequency response curve of the wooden-box loudspeaker systems. The distortion had a shape in the form of a combination of a peak and a valley on the frequency response curve. It was concluded that only the first structural resonant mode of the loudspeaker wall with the largest dimension should be controlled. Iverson [6] discussed the resonance of loudspeaker cabinet boards in general. Such lumped parameter methods could predict the wall vibration up to the first resonance mode.

Another simulation option is to use computational models. The task of simulating the frequency response from loudspeaker enclosure walls consists of two parts, a structural part and an acoustic part. The structural part is to accurately calculate the enclosure

* Corresponding author at: 975 S Myrtle Ave., Lattie F Coor Hall 2211, Tempe, AZ 85287, United States.

E-mail address: xuan.zhong06@gmail.com (X. Zhong).

http://dx.doi.org/10.1016/j.apacoust.2015.01.012
0003-682X/

wall vibration based on the parameters of the loudspeaker unit, the back cavity and the wall structures. Historically, with the finite element method (FEM), Karjalainen et al. [7] measured and simulated, the vibration of the loudspeaker enclosure walls, but did not calculate the frequency response. So the problem of the second acoustic part is, given the vibration pattern, how to calculate the acoustic response at a certain point in the sound field. Bastyr and Capone [8] measured the enclosure wall vibration with a laser vibrometer. Based on the measurement, they predicted the acoustic radiation from loudspeaker enclosure walls with the boundary element method (BEM) with success. But they did not attempted modeling the back cavity and the enclosure wall itself. The structural and acoustic simulations were seldom discussed together in the simulation of enclosure walls, so a more complete study based on an integrated model is needed.

The current study investigated the influence of loudspeaker wall vibration on the frequency response of the miniature loudspeaker systems. Both an analogous circuit model and a FEM–BEM model were used to calculate the enclosure wall vibration and the acoustic frequency response. Simulations were validated with the vibration measurement and the acoustic frequency response measurement. Finally, a real design model of a production type loudspeaker was measured before and after modifications of the enclosure wall to show how the distortion could be reduced.

2. Theory and calculation

An experimental loudspeaker model was constructed as shown in Fig. 1. A miniature loudspeaker unit was mounted at the front of the model. The front and side enclosure walls were made of 5 mm thick steel which can be considered as a rigid boundary in the model. A 5 mm deep back cavity was left open at the back side with clamps on all the edges. The back enclosure wall was a 31 mm ∗ 31 mm ∗ 0.34 mm aluminum plate mounted with the clamps. The boundary condition could be regarded as clamped on all the four sides of the plate. The acoustic signal measured at a certain point in the space would be the addition of the sound from the loudspeaker unit and that from the back enclosure wall.

The main design consideration of the experimental model was to demonstrate the worst case of enclosure wall vibration. In real acoustic engineering cases, a square shaped back cavity is often avoided to reduce the combined modes in the back cavity. However, the outcomes of the research on the simplified model could still be suggestive of the considerations in actual designs.

2.1. The analogous circuit modeling

The acoustical analogous circuit method combines the electrical, the mechanical and the acoustical parameters of the loudspeaker system in a unified model [9]. The first resonance of the enclosure wall plate and vibration velocity frequency response of the plate were simulated. The effect of the back plate vibration on the vibration of the loudspeaker membrane could also be derived from the model, as suggested by Tappan [3].

In the model, the electrical and mechanical domains were reflected to the acoustic domain. As shown in Fig. 2, several groups of the components were used to represent the three parts of the experimental model, (a) the loudspeaker unit, (b) the back cavity, and (c) the enclosure back wall plate.

For the loudspeaker unit branch, the total acoustical impedance was given by:

$$Z_{AS} = R_{AT} + j\omega M_{AS} + \frac{1}{j\omega C_{AS}} \tag{1}$$

where

Z_{AS} – total acoustical impedance of the loudspeaker unit.
R_{AT} – total acoustical resistance of the loudspeaker, including voice coil resistance and damping of the membrane suspension.
M_{AS} – acoustical mass of the loudspeaker unit.
C_{AS} – acoustical compliance of the loudspeaker unit.

The loudspeaker unit parameters were derived from T–S parameter measurement [10]. The loudspeaker unit was type Ra miniature loudspeaker from the former Philips Sound Solutions (presently a part of Knowles) and its size was 15 mm ∗ 11 mm ∗ 3 mm. The parameters of the unit were: the effective radiation area S_D = 2 cm^2, force factor Bl = 0.7 T m, C_{AS} = 1.025 ∗ 10^{-10} m^5/N, M_{AS} = 247.4 g/m^4, and R_{AT} = 47,430 kg s^3/m^4.

For the back cavity branch:

$$Z_{AB} = R_{AB} + \frac{1}{j\omega C_{AB}} \tag{2}$$

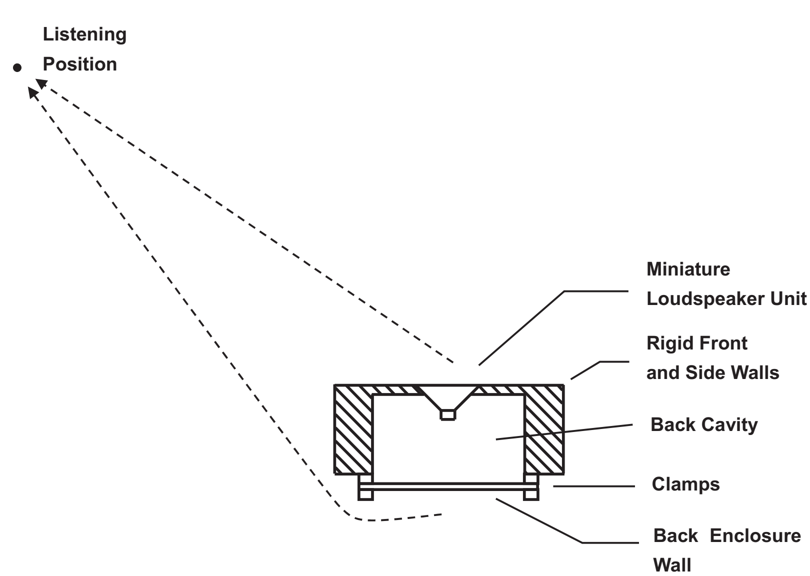

Fig. 1. The miniature loudspeaker experimental model under test. The size of the cavity was 31 mm ∗ 31 mm ∗ 5 mm.