A simple method of determining the sound absorption coefficient at oblique incidence

Xiaoru Zhou, Xueqin Zha

Fraunhofer-Institut für Bauphysik IBP, D-70569 Stuttgart, Germany, Email: zhou@ibp.fhg.de

Introduction

This paper proposes a simple method for estimating the sound absorption coefficient at oblique incidence in an anechoic environment. The frequency dependent sound pressure (direct sound) is first measured at one microphone position without any reflecting plane. In a second step a reflecting/absorbing material is inserted and the sound pressure measured again. The direct sound and the reflected sound cause interference at the microphone position. The pattern of interference is depends on the reflection characteristics of the material to be tested. By analysing the interference pattern the absorption coefficient of test object at oblique incidence can be calculated. This method can do without any complicated instruments and calculation procedures. More specifically, it yields a fast and precise estimate of the absorption ability of larger acoustic modules and linings.

Principal approach

The test setup shown in Figure 1 consists of a plane absorber sample with reflection factor r, a moveable microphone M, and a speaker L with symmetric radiation characteristics. The angles θ/2 from the speaker centre axis to the reflection point and to the microphone are made identical.

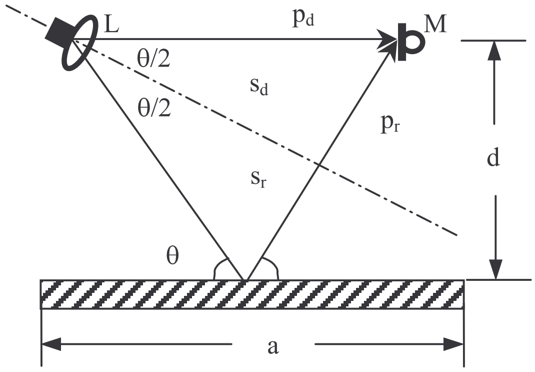

Figure 1: Schematic measurement set up.

The test room should be as anechoic as possible. The interference between the direct and reflected sound at the microphone position yields:

$$p = p_d + p_r = \frac{p_0}{s_d}\exp\left(-j\frac{2\pi f s_d}{c_0}\right) + \frac{p_0}{s_r} r \exp\left(-j\frac{2\pi f s_r}{c_0}\right). \tag{1}$$

The mean-square amplitude of the pressure at the microphone depends on the path length difference $\Delta s = s_r - s_d$, the ratio $x = s_d / s_r$ and the respective reflection factor r:

$$p^2 = p_d{}^2\left(1 + 2|r|\, x \cos\frac{2\pi f\,\Delta s}{c_0} + x^2 |r|^2\right) \tag{2}$$

If the reflection arrives at the microphone position M in phase with the direct sound, pressure maxima $|p|_{max} = |p_d|\,(1 + x\,|\,r\,|)$ occur at the frequencies $f_{max} = (n-1)\dfrac{c_0}{\Delta s}$; n = 1, 2, 3..., with the sound velocity c_0. An approximately 6 dB pressure level increase is observed, if the distance d is small and the reflection factor of the sample r is close to 1. In the measurement shown in Figure 2, the level increase

$$\Delta L_{max} = 20\,\lg\left|\frac{p_{max}}{p_d}\right| = L_{max} - L_d = 20\lg(1 + x\,|\,r\,|) \tag{3}$$

is about 5 dB, where L_{max} is measured with and L_d without a probe in the freefield (direct sound).

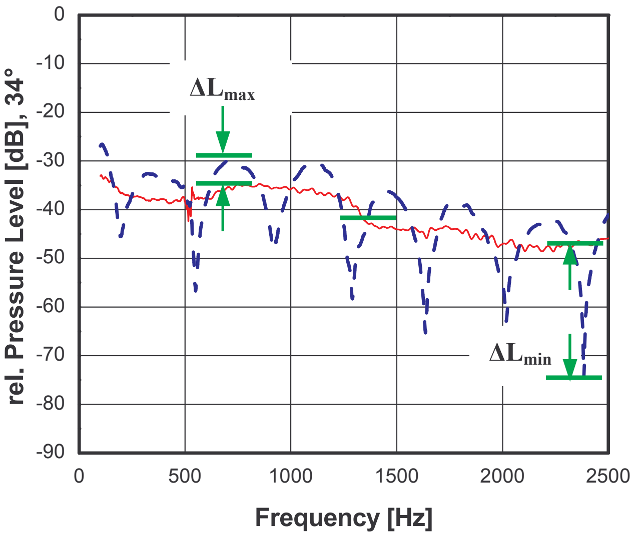

Figure 2: Sound pressure spectra, measured according to Figure 1 for θ = 34° in a freefield. —— Without test sample (direct sound), – – With a 30 mm thick chipboard.

On the other hand, if the reflection arrives at the microphone 180° out-of-phase with the direct sound, the sound pressure minima

$$\Delta L_{min} = L_{min} - L_d = 20\lg\,(1 - x\,|\,r\,|) \tag{4}$$

is observed at frequencies $f_{min} = (2n-1)\dfrac{c_0}{2\,\Delta s}$. Figure 2 shows e.g. a value of ΔL_{min} = –26 dB at 2350 Hz when the probe is acoustically hard (e.g. a 30 mm thick chipboard). The reflection factor and absorption coefficient at certain frequencies is then calculated from:

$$\alpha = 1 - \left(\frac{10^{\frac{\Delta L_{max}}{20dB}} - 1}{x}\right)^2 \;;\; \alpha = 1 - \left(\frac{10^{\frac{\Delta L_{max}}{20dB}} - 1}{x}\right)^2 \tag{5}$$

Measurement setup

The measurements are carried out with a „home made“ speaker box, hanged about 1.5 m above the metal grid in the large freefield room at the Fraunhofer IBP (Figure 3). The radiation characteristics of the speaker box is sufficiently symmetric in the frequency range between 200 and 2000 Hz for angles ± 45° around its axis, so that the amplitudes of the direct and reflected sound waves may be considered to be emitted with the same amplitude. The angle of incidence θ may be varied between 34° and 81°

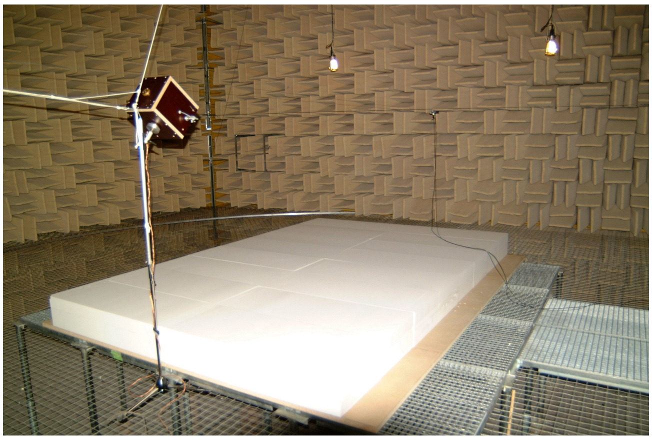

Figure 3: Measuring set up in a free field with a 25 cm thick 4 x 3 m BCA sample according to [2].

Results for 2 sound absorbers

The absorption of two types of high-efficiency absorbers (BCA and ASA after [2]) was measured to test the new method. The absorbers were developed for anechoic linings. The absorption coefficients α_θ therefore exceeds 0.9 between 200 and 3000 Hz for a wide angle. Figure 4 shows that α_θ increases with θ and the difference between the two types of absorbers is small for $34° \leq \theta \leq 40°$. For $\theta \geq 45°$ the effectiveness of BCA, as expected, falls behind that of the ASA. The latter meets the requirement of $\alpha \geq 0,99$ according to [3] for $45 \leq \theta \leq 81°$. Generally, the absorption coefficient falls continuously from close to 1 at normal incidence to lower values at oblique or grazing incidence. This is an important result of this investigation in accordance with [4]: If one takes only α_0 as measured in a standing wave tube as a design basis for a freefield room, one should be careful when estimating the response of the room, since other angles of incidence may have to be considered in a specific measuring task. The α_θ-results may, however, be incorporated in freefield simulations like those described in [5].

Summary

The absorption coefficient of anechoic linings on walls, ceilings and floors, which may obliquely hit by spherical waves, are important in the acoustic design of the anechoic rooms. A simple method was developed and tested on novel absorbers, so that different structures of porous absorbers could be compared and estimated. The interference spectrum, that arises from the superposition of the direct and reflected spherical waves, which form in an anechoic room above a test surface, is analysed and evaluated. The measurements above BCA and ASA lining show that their absorption coefficient is larger than 0.99, but strongly dependent on the angle of incidence. A reliable tool is now available for the improvement of input data for a design program for anechoic rooms and acoustic test cells [5]. The new method complements the standardized measurement with plane waves in standing wave tubes.

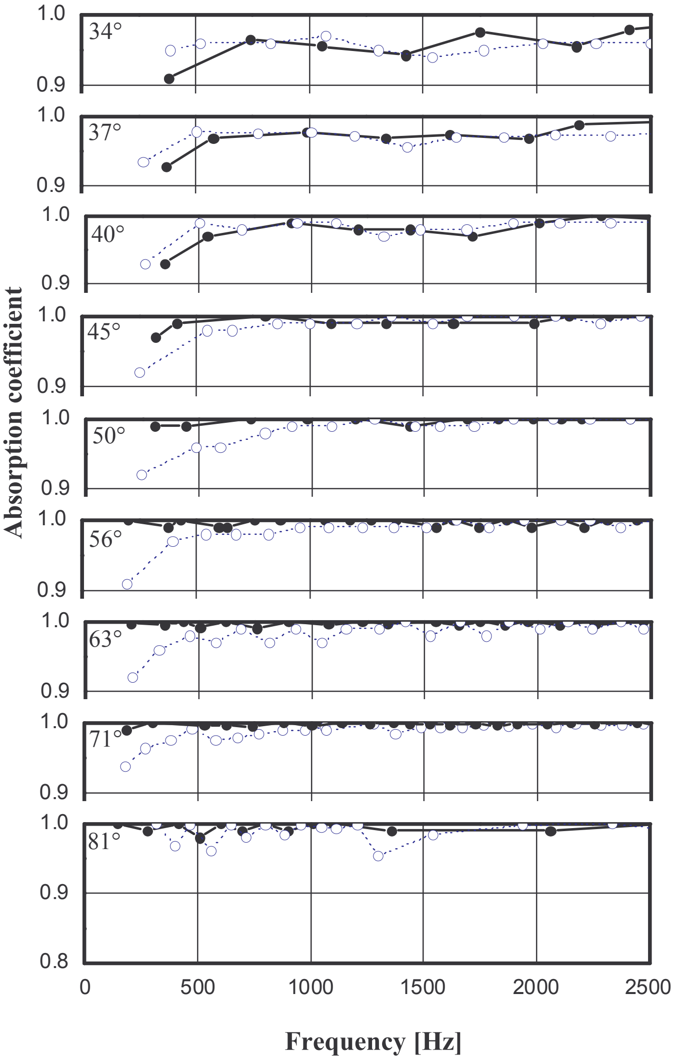

Figure 4: Absorption coefficient of ASA (●) and BCA (○) for different angles of incidence.

References

[1] Zha, X. et al.: Bestimmung des Absorptionsgrades bei schrägem Schalleinfall. Z. Lärmbek. (to be published)

[2] Fuchs, H.V. et al. Broadband compact absorbers for anechoic linings. In: CFA/DAGA 04, p. 272

[3] ISO 3745 - 2003 Determination of sound power levels of noise sources using sound pressure – Precision methods for anechoic and hemi-anechoic rooms

[4] Mommeritz, E.: Angle-dependent in-situ measurements of reflection coefficients using a subtraction technique. Applied Acoustics 46 (1995), 251-263

[5] Zhou, X. et al: Computerised planning aid for the design of anechoic chambers. In: CFA/DAGA 04, p. 58