Calibration of reverberation chambers – ideas and suggestions

Christian Nocke[1], Peter D'Antonio[2]

[1] *Akustikbüro Oldenburg, Oldenburg, E-Mail:nocke@akustikbuero-oldenburg.de*

[2] *RPG Diffusor Systems, Inc., Upper Marlboro, E-Mail: pdantonio@rpginc.com*

Introduction

Many (standardised) measurements such as the classical ISO 354 [1] reverberation chamber method procedures for sound absorption rely on geometrical approximations or statistical approaches. They fail whenever the limit of geometrical acoustics is reached. It is well known that the measurement of the same sample in different reverberation chambers yields different results for the sound absorption coefficient.

Within the discussion about the present revision of ISO 354, the idea came up to calibrate the reverberation chamber. This might help to exclude all of the possible reasons for the deviations between different rooms as described above.

In this paper, an approach will be presented that uses a well-defined sound absorber as a reference, as well as an analysis of the sound field in the room. The analysis of the decay of the sound field in the room follows the idea given by Maa and [2] and [3]. A micro-perforated sound absorber is suggested as a reference material, because the angular dependence of the normal specific surface impedance can be calculated for this sound absorber. Using the modal approach of the sound field, this calculation will give a chamber coefficient that can then be used to calibrate the reverberation room.

Sound absorption coefficients

Ever since, different approaches to measure the acoustic absorption or acoustic surface impedance of a material have been used. According to certain requirements, the quantity to measure has been the impedance or absorption coefficient. As Morse et al. [4] pointed out the complex quantity impedance is rather used in a scientific context, whereas the real quantity absorption is found in practical applications. The specific surface impedance Z might be used to calculate some of the absorption coefficients quoted in the following.

The acoustic behaviour of a boundary between two materials can be described by the change of the characteristic impedances. For porous sound absorbers, various models to describe the acoustic properties with wave number and characteristic impedance have been developed, see [5], [6], [7] [8].

Sound absorption coefficients Since an early discussion on "the sound absorption problem" in 1939 [9] many different definitions of sound absorption coefficients have been introduced. This leads to a remark by Mechel about too many sound absorption coefficients (see [5], p. 275).

Plane wave absorption coefficient For a plane wave at normal incidence the formula

$$\alpha_0 = 1 - \left| R_p(Z) \right|^2$$

can easily be deduced, with the plane wave reflection factor $R_p(Z) = (Z - 1) / (Z + 1)$ and specific surface impedance Z. For oblique incidence at angle θ, this absorption coefficient can be calculated according to

$$\alpha_\theta = 1 - \left| R_p(Z,\theta) \right|^2$$

with $R_p(Z,\theta) = (Z \sin\theta - 1) / (Z \sin\theta + 1)$ [5]. For small angles of incidence, e.g. near grazing incidence this description with plane waves is not valid [10].

Statistical absorption coefficient For statistical incidence of plane waves, the well absorption coefficient, α_{st}, can be calculated according to

$$\alpha_{st} = \int_0^{\pi/2} \alpha(\theta) \sin 2\theta \, d\theta$$

.

For locally reacting absorbers this integral can be solved and the corresponding formulae might be found in [5].

Sabine absorption coefficient In room acoustics, the so-called Sabine absorption coefficient, α_s, is used very often describing the average absorption in a room. Some requirements have to be fulfilled to apply the formula of Sabine.

Micro-perforated sound absorbers

The theory of the micro-perforated panel absorbers as initially presented in [11] is based on the classical treatment of sound propagation in short tubes. The derivation by Maa [11] first delivers an approximation for the specific acoustic impedance Z_{MPP} for a micro-perforated panel of thickness t with holes of diameter d spaced at a distance b apart in front of an air cavity with a depth D, see Figure 1 for principal set-up.

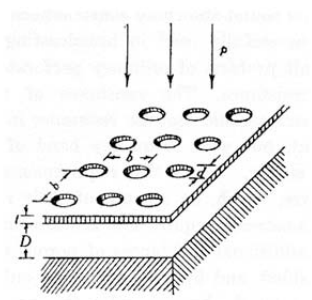

Figure 1: Sketch of micro-perforated panel absorber (MPA) from [6] with d diameter of orifice, b spacing between orifices, t thickness of panel and D air cavity depth between panel and backing wall.

The angle-dependent impedance Z_{MPP} of the micro-perforated sound absorber can easily be calculated by Maa's approximation [11, 12]. From this impedance, the sound absorption coefficient for normal and random incidence of sound on the micro-perforated sound absorber can be easily calculated [13], using well-known principles, see above. As the angular and frequency dependence of the surface impedance of the micro-perforated sound absorber can be calculated from purely geometrical data of the structure, the statistical sound absorption coefficient, α_{st}, shows good agreement with the diffuse/Sabine absorption coefficient, α_s, see figure 2.

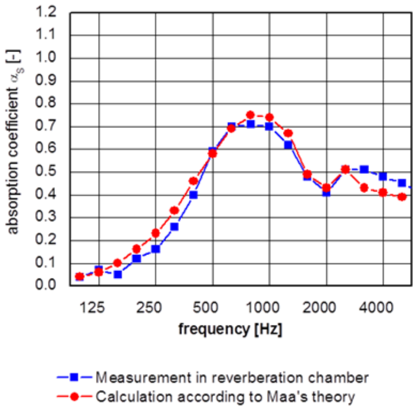

Figure 2: Comparison of measured and calculated sound absorptions coefficient in diffuse sound field.

Sound field in a room

The decay of a sound field in a rectangular room can analytically be described as shown by Maa in [3]. In figure 3 an example from [3] is shown for a comparison between analytically deduced and measured decay constants.

TABLE I. *Decay constant in room 2.17×1.24×1 feet, one wall absorbing.*

Arrangement (Celotex, wood)	(1,0,0) 259.5~ Obs.	Calc.	(2,0,0) 519~ Obs.	Calc.	(1,0,1) 622.5~ Obs.	Calc.
	30	31	151	152		
	183	173	60.5	60	127	123
	86	80	97	102	76	74
	105	107	101	104	95	85
	13.7	14.4	39	47	114	103
2.17	2.9	2.9	21	21	66	66

Figure 3: Different decay constants for various arrangements of the same (porous) absorber sample from theory and measurement, see [3].

Further analysis of the sound field, on the basis of statistical distribution of normal modes, gives an exact description of the number of modes per frequency band and the corresponding angular distribution of normal modes. An example from [13] is shown in figure 4 for the 160 Hz 1/3 octave band in a 195 m³ room. A difference between the often used random assumption, diffuse field assumption and the exact distribution of angle of incidence can be seen.

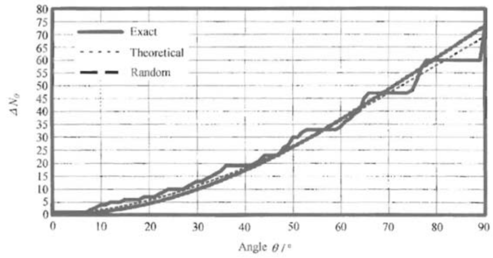

Figure 4: Angular distribution of 74 normal modes in 160 Hz one-third octave band in 195 m³ reverberation chamber, see [13].

Suggestions on calibration of reverb chamber

With a well-defined and physically deduced model for a sound absorber (such as the micro-perforated panel absorber according to Maa [11]) and an analytical description of the sound field in the room, the deviations between the measured and calculated absorption coefficient can be used to deduce a "room correction" factor. This room-dependent factor will help to calibrate the reverberation chamber so that the deviation between different rooms can be reduced. A physical absorber model has advantages compared to an empirically deduced absorber model (e.g. various models for even more porous absorbers). Further investigations might concentrate on scattering or edge effects of the finite sample.

Literature

[1] ISO 354 Acoustics – Measurements of sound absorption in a reverberation room, 2003
[2] Hunt, F.V., Beranek, L.L., Maa, D-Y., Analyses of Sound in Rectangular Rooms, JASA 11, p. 80, 1940
[3] Maa, D.-Y., Non-Uniform Acoustical boundaries in Rectangular Rooms, JASA 11, p. 39, 1940
[4] Morse, P. M., Bolt, R. H., Brown, R. L. JASA 12(2), 217 – 227, 1940
[5] Mechel, F. P., Schallabsorber, Vol. I, Hirzel, 1989
[6] Allard, J. F., Propagation of sound in porous media, modelling sound absorbing materials, Elsevier Science Publishers LTD, 1993
[7] Zwikker, C., KOSTEN, C. W., Sound absorbing materials, Elsevier, 1946
[8] Attenborough, K. , Models for the acoustical properties of air-saturated granular media, ACUSTICA / ACTA ACUSTICA 1, 213 – 226, 1993
[9] Hunt, F. V., JASA 11, p. 38 – 40, 1939
[10] Morse, P. M. , Vibration and sound, ASA, 1981
[11] Maa, D.-Y. Theory and design of microperforated panel sound-absorbing constructions. Scientia Sinica, 18(1):55-71 (1975).
[12] Hilge, C., Nocke, C. Properties and application of micro-perforated stretched ceilings, Proc. Institute of Acoustics, Vol. 25, Pt. 5, 2003
[13] Nocke, C., Liu, K., Maa, D.-Y. Statistical absorption coefficient of microperforated absorbers. Chinese Journal of Acoustics, 19(2):97-104 (2000).
[14] Liu, K., Nocke, C., Maa, D.-Y. Experimental investigation on sound absorption characteristics of micro-perforated panel in diffuse fields, Acta acustica (in Chinese), 25(3): 211-218 (2000)