Reverberation chamber and its verification for acoustic measurements

Pavel Drabek[1,a] and Martin Zalesak[1]

[1]*Tomas Bata University in Zlin, Faculty of Applied Informatics, Department of Automation and Control Engineering, Nad Stranemi 4511, Czech Republic*

Abstract. Reverberation rooms are useful for measurement of the acoustic quantities of machines that operate in long cycles, however, current reverberation chamber design practices often lead to known issues with reproducibility and repeatability of measured data. The problem is that construction process of these laboratories is performed according to the relevant standards requirements which are mainly focused on the volume of the room or on the absorption coefficient value of the boundary surfaces. Nevertheless, the inner-laboratory reproducibility of acoustic data is very difficult to achieve even when these diffusivity quantifiers are satisfied. This paper presents a verification process of an acoustic laboratory which proportions, shape and construction material of boundary surfaces are not in compliance with standards in every detail.

1 Introduction

One of the most fundamental factors affecting the inside enclosures is an excessive noise generated by equipment of environmental engineering [1]. From this perspective, it is necessary to approach the issues from the viewpoint of the entire chain of noise transmission into the buildings. It includes features of the sound source in terms of temporal, spectral and spatial aspects, of the sound propagation, and of individual sound transmission paths, and furthermore with noise receptiveness of individual humans. However, these features are not easy to measure; moreover, with respect to all requirements of gripping and placing, in case of the sound source. To determine acoustic parameters of these machines with higher accuracy, such as sound power, is requisite to perform the measurements in the acoustic laboratory. Certain types of acoustic measurements can be carried out in an environment which is free of reflections or environment which uses reflection in many directions as reverberation rooms. Reverberation rooms are useful for measurement of sound power, in particular, the sound power of machines that operate in long cycles, since the alternatives, the sound intensity method, and the free field method, are not very suitable for such sources [2]. However, the round robin evidence has shown that inter-laboratory reproducibility of acoustic data is difficult to achieve and high levels of measurement uncertainty remain even when design and construction process was carried out in accordance with recommended practices [3] [4].

The paper presents some aspects and results of the verification the newly build Laboratory of Environmental Engineering at Tomas Bata University in Zlin, Faculty of applied Informatics. This laboratory consists of Universal Compensate Calorimetric chamber which also serves as Reverberation chamber.

This chamber is used among other things to measure energy parameters and sound power level of equipment commonly used in buildings.

2 Reverberation chamber

The design of reverberation chamber is very complex concernment; moreover, when a multipurpose facility is concerned. The proposal of reverberation chamber depends on the prime purpose of usage. Acousticians use reverberation chamber to conduct various acoustical tests, including absorption and scattering coefficient measurements of acoustic materials, and determination of sound power levels of noise sources using sound pressure. European standards [5] and [6] are based on the already known facts in spatial acoustic and can be used as brief guidelines for the design of reverberation rooms. However, these standards assume diffuse field when the requirements, the volume, not rectangular shape and the sound absorption of the surfaces of the reverberant room, are satisfied. Following these assumptions could cause the sufficient diffuse sound field, but nevertheless, it is necessary to know the frequency range where the sound fields are adequately diffuse and where not. The measured data between the sound source and the diffuse sound field could be afflicted with great uncertainty in the predominantly non-diffuse section [7].

The reverberation chamber has a rectangular shape with dimensions 6,66 x 4,30 x 3,27 m and a volume of 93,66 m^3. According to the standards approach, the proportions, and shape of the chamber could appear to be a tricky problem. Its proportions should be selected so

ᵃ Corresponding author: pdrabek@fai.utb.cz

that the ratio of any two dimensions does not equal or closely approximate an integer [5]. In this case, however, the chamber dimension ratio it is almost the integer. This can result in the improper decomposition of eigenmodes from the chamber response at low frequencies. This is mostly because the acoustic energy is distributive very unevenly and direction of propagation is far from random.

The surrounding surfaces of the room consist of different materials, therefore, the sound absorbing qualities of the walls, floor, and ceiling can vary considerably within a frequency range of a few hertz. Particularly, ceiling and three walls are consists of PUR panels, remaining wall is formed by Cetris Farmacel panels and the floor is covered by an antiskid metal plate.

Figure 1. Reverberation chamber at FAI UTB in Zlin, CZ.

This multi-material concept is a rather awkward considering the fact very complicated evaluation of reverberant properties of the inner space at the design stadium. In the case of rectangular shape, the accuracy and reliability of results would be impaired by the interference of the direct sound with sound reflected from the boundaries [7]. In an attempt to avoid this regrettable phenomenon, it was applied a combination of two different geometric types of boundary diffusers (the tent and semicylinder type) and curved plexiglasses as hanging diffusers (see Figure 1). Generally, the diffusers can be used to break up the reflected wavefront and so disperse the focus while still maintaining the acoustic energy and avoiding absorption, however, it should be remembered that diffusers surface can cause significant diffraction from its edges [8]. The amount of diffraction depends on the wavelength and the size of the obstacle [9]. To minimalize the diffraction effect is recommended to accomplish an acoustic treatment. For boundary diffusers, this means using two different diffusers abreast and arranging them randomly or pseudorandomly on the wall. This will reduce periodicity and so improve dispersion [8].

3 Methods

The aim of the verification process was to specify the reverberant properties of acoustic test chambers with respect to the prime purpose of usage. This is a desirable goal of room acoustical efforts since differences in

reverberant properties can cause significant errors in measured data [7]. For example, the absorption coefficients determined in reverberation chambers are commonly exaggerated by diffraction effects and care must be taken, where it is critical, to correctly take such effects into account. The appropriate proof can be that absorption coefficient tables published in the literature often contain values greater than 1 which is meaningless.

It is possible to conduct the evaluation of the acoustical behaviour of the chamber by different ways. First one established through theoretical modeling, second one using numerical simulations and third one based on the real measurements [10]. Description of a sound field in enclosures and evaluation of their reverberant characteristics are not simple, and several theoretical methods of different complexity have been developed for this. Numerical simulations are very useful, however, the accuracy of the prediction models is highly dependent on the quality of the input data, including the absorption coefficient of surfaces which often can not be determined correctly [8]. These two ways have the advantage to be able to obtain preliminary results when it is still on the drawing-board.

The verification described in this paper is based on several series of measurements which will be evaluated by impulse response of the chamber. This method was chosen because no absorption coefficient date was available for the individual surface materials for the chamber where the verification was carried out.

Reverberation time is the main parameter determining the indoor reverberation characteristics, thus, it is primarily used to assess the acoustic quality of enclosures [11]. For the purpose of analysing the structure of the impulse response characterizing the sound transmission through the chamber, this parameter was observed.
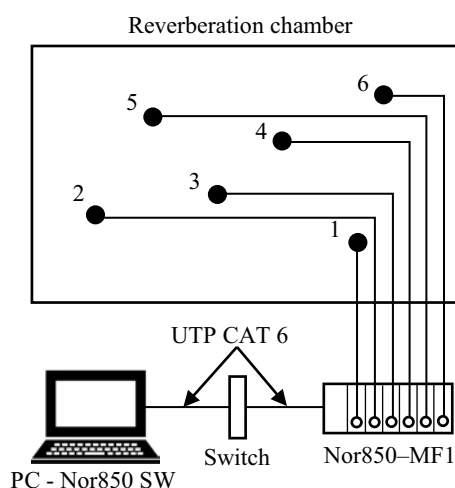

Figure 2. Scheme of measurement equipment (points 1-6 are consist of microphone GRAS GS-40AF and preamplifier Nor1209).

The standard equipment for this measurement is depicted schematically in Figure 2. The output voltage of the microphones and preamplifiers is fed to a multichannel Nor850 and then to a sound power module software which running the state-of-the-art Windows platform. This module enables connecting a number of

individual measuring units through various communication channels including both standardized LAN and USB interfaces. Wireless communication through Bluetooth or WLAN is also available. It is very important to appropriately set the value of the sampling period. This setting controls the period length of each sample along the decay. In this case was chosen the lowest one, 5 ms.

The measurement was performed under conditions which are standardly used for determination of sound power levels of noise sources using sound pressure. The chamber was maintained at a temperature of 23°C and relative humidity of 50% and the range of mid frequencies, for which all measurements, was taken, extends from about 50 to 10 000 Hz. The following procedure is not required to comply with the same order.

First of all, was measured the background noise level in the room with the all devices turned off by measuring the time-averaged sound pressure level. In the case of acoustic laboratories, it is not so frequent, however, when the room impulse response is contaminated with high-level background noise the resulting accuracy is substantially reduced because of a distortion of decay curve slope during the late decay [11]. Secondly, the determination of the impulse sound generator suitability was done. In this case, the chamber was excitation by a balloon burst. Each third-octave bandwidth was examined, more specifically, the standard deviation and the amplitude of excitation peak of a sound pressure measured in six observation points. The minimum amplitude size depends on the chosen sound pressure drop which will be evaluated, usually 35 dB [12]. Finally, the last part of the process is to obtain several different decay curves.

If the sound field were completely diffuse, the decay should be the same throughout the chamber [7]. Since this ideal condition is hardly ever met in real enclosures, it is advisable to carry out several measurements for each frequency band at different microphone positions. This is even more important if the quantity to be evaluated is the early decay time, which may vary considerably from one place to the next within one inner space [7]. For this reason, the measurements were taken at least 3 locations of impulse source and with at least 6 microphone positions. The experimental arrangement consisted of a 1/2" omnidirectional microphones and inflated balloon inside the chamber. The subsequent analysis was achieved conveniently using a multichannel as a real-time analyser (Nor850 MF-1). Usually, the sound pressure level in the measure decay curves does not fall in a strictly linear way but contains random fluctuations which are due to complicated interferences between decaying normal modes [7].

The reverberation time was calculated using a linear least-squares regression [12] of the measured decay curve, from a level 5 dB below the initial level to 25 dB below, using a linear regression of ensemble averaged decay curves. It means that the decay curve is approximated by a straight line $\hat{L}_i$ [dB], at the time t_i [s] is defined as

$$\hat{L}_i = a + bt_i \qquad (1)$$

Where is a value $\hat{L}_i$ at the time t=0 [dB],

b line tilt [dB/s].

According to linear least-squares regression method is estimation of value a and a line tilt b determine by following equations:

$$a = \overline{L} - b\overline{t} \qquad (2)$$

$$b = \frac{\sum_{i=1}^{n}\left(t_i L_i\right) - mt\overline{L}}{\sum_{i=1}^{n}\left(t_i^2\right) - mt^{-2}} \qquad (3)$$

Where

$$\overline{L} = \frac{1}{n}\sum_{i=1}^{n} L_i \qquad (4)$$

$$\overline{t} = \frac{1}{n}\sum_{i=1}^{n} t_i \qquad (5)$$

Estimation of reverberation time $\hat{T}$ is given by

$$\hat{T} = \frac{-60}{b}. \qquad (6)$$

Another method of determining the decay curve consists in the reverse-time integration of squared impulse response which is described in [13].

4 Results

The main objective of measured results presented in the following was to examine a crucial acoustic properties of reverberation chamber at FAI UTB in Zlin for acoustic measurements. In other words, it was necessary to determine whether the inter-laboratory space is able to perform acoustic data with required reproducibility and specify the frequency range in which a given reverberation chamber can be used.

The background noise was measured in several days to be eliminated any temporal noises. Results and standards requirements are shown in Figure 3. As mentioned above the supporting constructions are consists of PUR panels. In fact, the entire chamber is surrounded by another compensation chamber formed by those same panels and thus considerably reduce the noise transmission between inner and external environment. As can be seen from the Figure 3 the background noise values are predominantly below the requirement values, nevertheless, this can not be achieved at the mid frequency 630 Hz. This phenomenon is most likely caused by the fact that the sandwich structure of PUR panel acts as oscillating plate and therefore at the resonant frequency sound will pass easier through the

partitions, and so the sound insulation will be poorer [8]. Generally, it is important that the absorbing material is lightly packed, otherwise, it can form a vibration path bridging between the two partitions; this could greatly reduce the sound attenuation properties [8].
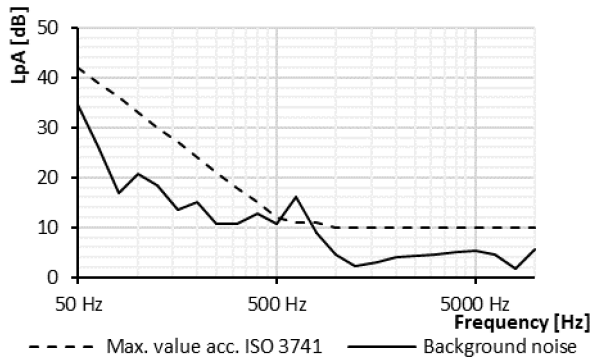

Figure 3. Graph of measured and permissible levels of background noise.

The determination of suitability of balloon burst as impulse sound source was done for three observation locations. According to the measured data can be said that the amount of energy emitted by a balloon burst depends greatly on air pressure inside a balloon, therefore, balloons do not provide repeatability results every time, especially at low frequency band. More about the comparison of different impulse sound sources is described in [14].

To properly characterize reverberant properties of the chamber, eighteen decay curves were obtained for each mid frequency band at different impulse sound source positions. Calculation results present in a clear way that in the analysed room reverberant response of the chamber and an initial amplitude of a sound decay strongly depend on the sound frequency, as indicated in Figure 4 and 5. They illustrate in each graphs only two curves because more of them would evocate confusing results.

It is obvious that a diffuse sound field will not be established in enclosures whose walls have the tendency to concentrate the reflected sound energy in certain regions [7]. For this reason, diffusers help to establish a diffuse sound field by continuously redistributing the energy in all possible directions. Upon each reflection is the fraction of energy diffusely scattered into non specular angles while the remaining energy is reflected into the specular reflection angle in the usual way. The diffuse energy is ambient energy spread throughout the room volume [8].

To assess the repeatability was very important to observe the initial slope of decay curves. In order to determine the decay times, the linear regression, according to the previous chapter, was used for finding fit lines to appropriate parts of the decay function. It is important to note that both decay times characterize a decrease in the sound energy level during the initial decay of sound. As can be seen from Figure 4, there are significant differences between each regression lines. For 50 Hz the excitation maximum peak sound pressure level was so low that the calculation could not be executed. At frequencies, 63 to 125 Hz can be observed quite wide variances of the slope of the regression lines. This indicates that it is extremely important to average over many source positions if the sound power of a source with a significant content of pure tones is to be determined in a reverberation chamber. However, this frequency range is not suitable for performing laboratory measurements with high accuracy. The frequencies 160 and 200 Hz also shows weaknesses as well though not so heavy. Nonetheless, there is no doubt that the inner space for these frequencies is not sufficiently diffuse.

Equally important was to compare the smoothness of the reverberation decay for the third-octaves from 50 Hz to 10 kHz. In general, the smoothness of the decay increases as frequency is increased, this can be seen in both Figures 4 and 5. The sound power emitted by an impulse source in a lightly damped chamber cannot be expected to be unaffected by the reverberant sound field even when it is placed far from the walls of the chamber, especially when the rectangular shape is assumed. This can be seen, for example, 50 Hz a large wave fluctuations are noted suggesting that in this case the beating effect is present. The beat information on the low-frequency reverberation decay makes possible a judgment on the degree of diffusion [11]. This effect increases the relative standard deviation of calculated reverberation times.
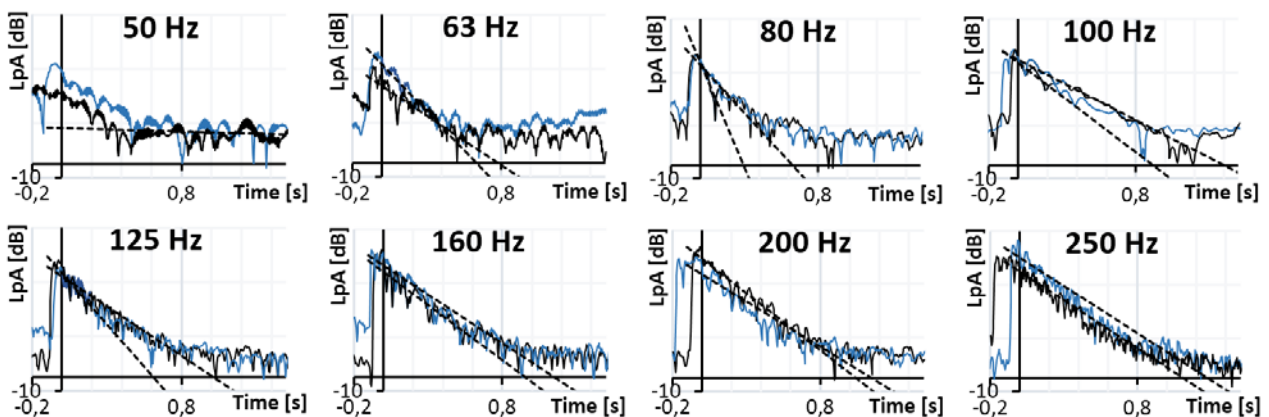

Figure 4. Temporal decay of level L_{pA} of pressure envelope for mid-frequencies of third-octave bandwidth about 50 to 250 Hz.
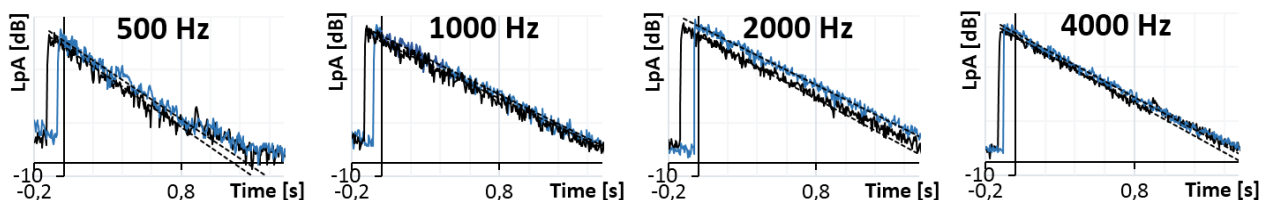
Figure 5. Temporal decay of level L_{pA} of pressure envelope for mid-frequencies of octave bandwidth about 500 to 4000 Hz.

For frequencies 63 and 80 Hz a characteristic property is a considerable different between decay times in the early and late stages of the decaying sound. A fundamental change of the response consists in a rapid decrease in a pressure in the initial stage of a sound decay. When the excitation impulse from the balloon burst energizes the inner space of the chamber, it excites one mode, and an instant later another mode. While the response shifts to the second mode, the first mode begins to decay. Before it decays very far, however, the random noise instantaneous frequency is once more back in the first mode, giving it another boost. All the modes of the room are in constant agitation, alternating between high and somewhat lower levels, as they begin to decay in between stimuli. It is strictly a random situation, but it can be said with confidence that each time the excitation noise is stopped, the modal excitation pattern will be somewhat different. These phenomena belong to the modal theory and it's well described in [8]. For the frequencies in Figure 5, the analysed time domain decreases almost linearly. These decays provide information that inner space is more stable than frequencies below 250 Hz. Within the mid-frequency 200 Hz of third-octave band will be located region where the transition boundary between the modal region where the room modes are well separated and the region of diffuse behaviour of a sound field, known also as the Schroeder region, where there is a high overlap of the room responses.

5 Conclusion

Reproducibility of acoustic data measured in acoustic laboratories is difficult to achieve for wide frequency bandwidth. For acoustic laboratories that perform measurements with high accuracy, it is necessary to know the frequency range where the sound fields are adequately diffuse and where not. In this paper were compared the decay curves obtained in several positions. These decays are not identical, and differences can be attributed to the non-uniform character of an acoustic field through the chamber. In particular, the fluctuations in the decays result from beats between closely spaced modes. Because the excitation level of the modes is constantly shifting, the form and degree of the beat pattern shift from one decay to another depending on where the random excitation happens. There is much information in each decay, and acoustical flaws can often be identified from aberrant decay shapes. The results are definitely signed by the fact that it has not been used impulse sound source which generates always the same pure-tone but balloon

burst was used. In future will be the verification process made with a pistol shot.

The work could be extended to include the effects of edge diffraction, which previously in this paper have been shown to cause significant estimation errors in measured data. The work also needs to re-derive acoustic properties of all boundary walls using alternative reverberation time formulations to get absorption coefficients.

Acknowledgement

References

1. P. Drabek, Diploma thesis, (2014)
2. F. Jacobsen, *The Sound Field in a Reverberation Room*, (2011)
3. D. Bradley, M. Muller-Trapet, J. Adelgren, M. Vorlander, Building Acoustics, **21**, 145-152 (2014)
4. W. Weise, V. Wittstock, Building Acoustics, **12**, 3 (2005)
5. CSN EN ISO 3741, Standard, Urad pro technickou normalizaci, metrologii a statni zkusebnictvi, Prague, CZ (2011)
6. CSN EN ISO 354, Standard, Urad pro technickou normalizaci, metrologii a statni zkusebnictvi, Prague, CZ (2003)
7. H. Kuttruff, Room Acoustics, **5**, (2009)
8. T. Cox, P. D'Antonio, Acoustic Absorbers and Diffusers, **2**, (2009)
9. E. Deines, Dissertation, (2008)
10. M. Meissner, Archives of acoustics, **41**, 27-41 (2016)
11. M. Meissner, Archives of acoustics, **38**, 47-54 (2013)
12. CSN EN ISO 3382-2, Standard, Urad pro technickou normalizaci, metrologii a statni zkusebnictvi, Prague, CZ (2009)
13. M. Schroeder, Acoustical Society of America, **37**, 3, 400-412 (2016)
14. M. Horvat, K. Jambrosic, H. Domitrovic, Acoustics08 Paris, **17**, 3985-3990 (2008)