

# Reverberation measurement set for the interrupted noise method

D Jun<sup>1</sup> and O Nespěšný<sup>1</sup>

<sup>1</sup> Faculty of Civil Engineering, Brno University of Technology, Veverí 331/95, 602 00 Brno, Czech Republic

E-mail: David.Jun@vutbr.cz

**Abstract.** This paper describes the methodology of measuring the sound absorption coefficient in a reverberation room. For its purpose, a measuring set was created combining professional with widely available hardware suitable for acoustic reverberation measurements. For the measurement itself, the interrupted noise method was chosen based on the standard ČSN EN ISO 354. Measurement and evaluation of data take place using scripts written in the Python programming language. An effective measuring set was developed both in terms of operation during measurement and in terms of subsequent data processing, accessing and graphical presentation.

## 1. Introduction

Several methods can be used to determine the effectiveness of acoustically absorbing structures. The sound absorption coefficient by which this efficiency is most often quantified can be measured in an impedance tube, in a free field or in a reverberation room. These measurement variants are described in more detail and compared by Cox and D'Antonio [1].

Each of the mentioned methods is suitable for a different purpose, however, for the needs of room acoustics, the most commonly used measurement is in a reverberant room, the output of which is Sabin sound absorption coefficient  $\alpha_S$  [-]. The main reason is probably a certain similarity between boundary conditions of this measurement and the placement in a real room. There, the normal incidence of sound (measured in an impedance tube) or a specific incidence angle (measured in a free field) rarely occurs. The situation in a room is more often close to a partially diffuse acoustic field, where the direction of sound impact on adjacent structures is more or less random. It is possible to simulate this situation in the free field, but it is a method demanding instrumentation and accuracy of the experiment.

The reverberation room method also has some disadvantages, which stem from the difficult-to-achieve fully diffuse acoustic field and thus the problem of non-uniform boundary conditions across different laboratories. Jeong and Chang, for example, have researched this problem [2].

The reverberation room method is based on measuring the reverberation time  $T$  [s], ie the time during which the sound pressure level drops by 60 dB after the source is switched off [3]. However, this quantity is seldom determined from the whole decrease. The most used variants and evaluated ranges of reverberation curves are summarized in table 1. It is possible to use several excitation signals for the measurement itself, but most often it is an impulse or broadband noise. These two variants are described in the ČSN EN ISO 354 standard [4], the national equivalent of the ISO 354 standard [5].

This contribution presents a measuring set and a software part of the measurement developed especially for measuring the sound absorption coefficient by the interrupted noise method. The aim was



to develop an inexpensive set that could be operated from a computer throughout the measurement and that would provide data from all steps necessary to evaluate the sound absorption coefficient  $\alpha_s$  [-].

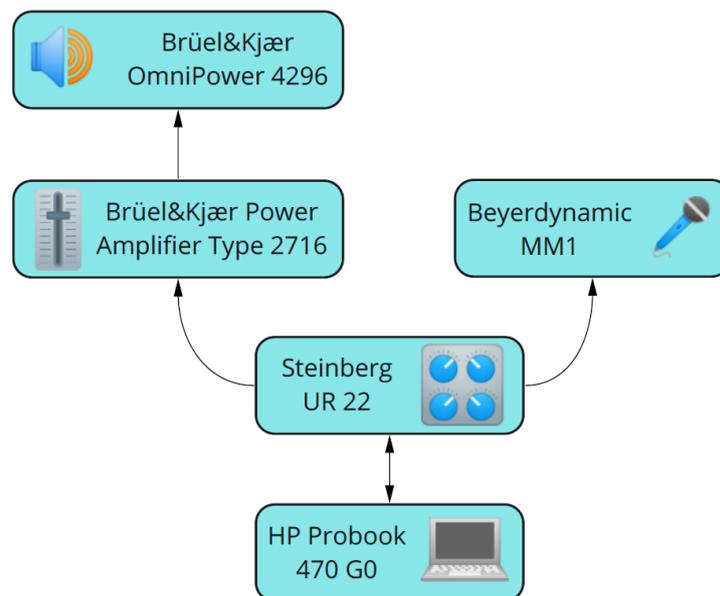
**Table 1.** The most common types of reverberation times. The level of 0 dB represents the level immediately after switching off the source, or the maximum of the impulse.

Variable [s]	Upper limit [dB]	Lower limit [dB]
$T_{30}$ [6]	-5	-35
$T_{20}$ [6]	-5	-25
$EDT$ [7]	0	-10

## 2. Measuring set and used software

A set consisting of a Brüel & Kjær OmniPower 4296 omnidirectional power supply, a Brüel & Kjær Power Amplifier Type 2716 amplifier, a Beyerdynamic MM1 measurement microphone, a Steinberg UR22 USB audio interface and an HP ProBook 470 G0 notebook was used for the measurements. The scheme of the measuring set is shown in Figure 1.

While on the one hand the professional Brüel & Kjær hardware was used, on the other hand, the omnidirectional microphone and the audio interface of a rather lower category were used. This did not have a limiting effect on the reverberation measurements, as level differences are evaluated and it is not necessary to know the exact sound pressure level.



**Figure 1.** Measuring set scheme.

The software part of the measurement used both existing software and own scripts written in the Python programming language [8] and it was operated from the interactive Jupyter Notebook interface [9].

The first software used is the JACK Audio Connection Kit [10], which is an extension of the audio driver that allows to connect virtual and physical audio inputs and outputs of the computer with low latency. In this case, JACK was supplemented by modules from the jack-tools package [11], which allows basic operations such as playback and recording from the command line environment.

The second software used is the Room EQ Wizard (REW) [12], which is an application that allows the measurement and evaluation of various parameters of room acoustics. In this case, only its pink noise generator was used.

The Python libraries used summarises in table 2. They were used to measure and evaluate the measured data and to create graphical outputs.

**Table 2.** Python libraries used for measurement and data processing.

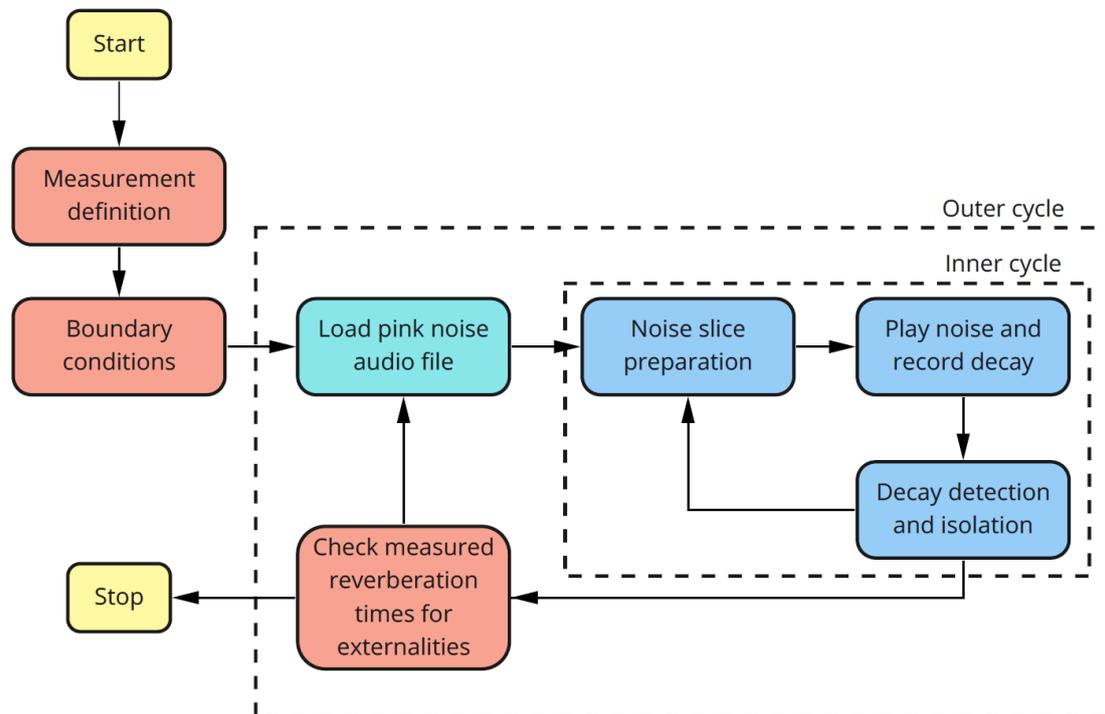
Name	Usage
NumPy [13]	Efficient work with large vectors and matrices.
pandas [14]	Data manipulation and analysis.
SciPy [15]	Extensive library for data, image and signal processing. In this work, it was used mainly for digital signal filtering.
Matplotlib [16]	Graphical output creation.
python-acoustics [17]	Acoustic measurements and calculations. In this work, the room module was mainly used, containing a function for reverberation time determination from the impulse response of the room. This function has been modified to suit the interrupted noise method and to return a larger number of outputs. Above all, it was necessary to obtain reverberation curves for further averaging.

### 3. Measurement procedure and obtained data

According to the standard, the measurement of absorption in a reverberation room is measured in at least 12 position-independent configurations of the source and microphone. In addition, in the case of the interrupted noise method, at least 3 submeasurements have to be made in each configuration to reduce the statistical error [4]. This leads to a minimum of 36 submeasurements for each specimen. Because of a large number of submeasurements, effective measurement requires maintaining a good overview of source-microphone configurations. The second requirement is the near real-time unwanted externality detection during the measurement and its repetition only for configurations where the problem occurred.

In this work, these requirements were included in a measurement algorithm consisting of the following steps, which are summarized in Figure 2:

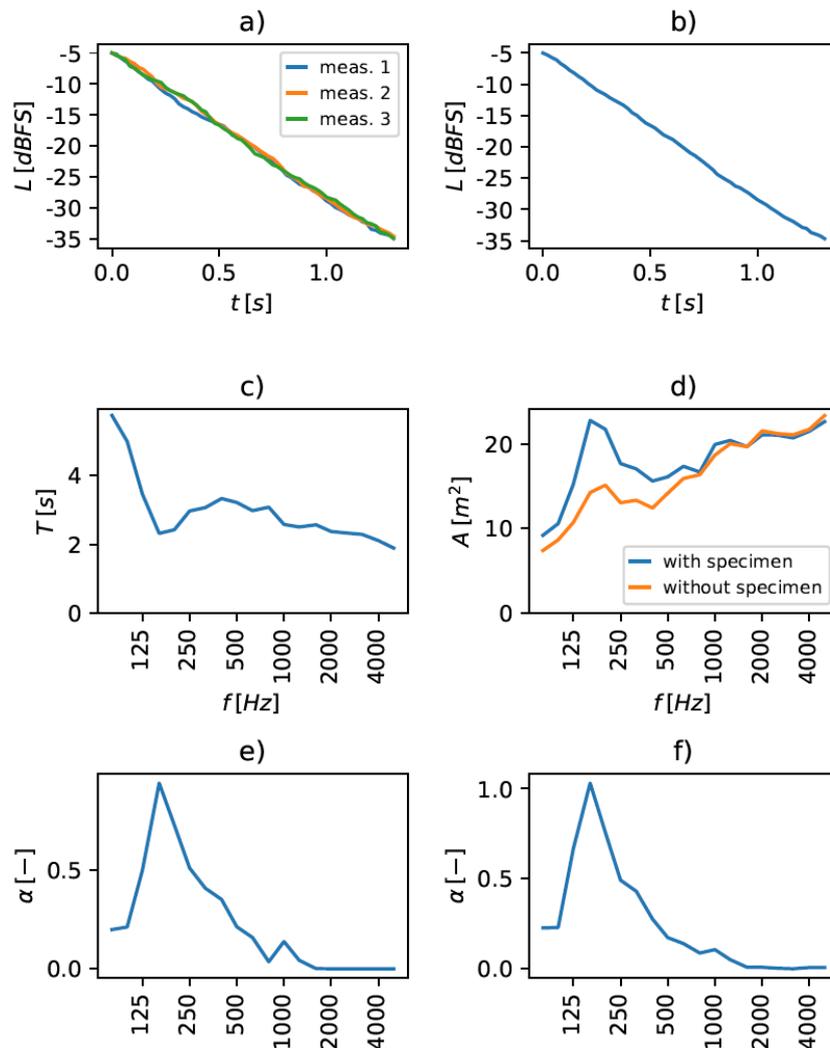
1. Selection of the number of measuring points of the microphone and the source, or the number of surveys in one configuration, if it is to be greater than 3. Based on this selection, the process of measurement is defined.
2. Saving of boundary conditions of measurement (relative humidity and temperature).
3. Entry into the measuring cycle.
4. Prompt for readiness to perform measurements for the first configuration and then prompt to leave the room.
5. Loading a noise file previously exported from REW software. For the presented work, it was pink noise with a spectrum slope of  $-6$  dB/octave.
6. Measurement in a notified configuration with a predefined number of submeasurements. (Figure 2 - Inner cycle)
  - a. Cut out a noise segment lasting 5 s at a random time.
  - b. Play noise and start recording 0.5 s before the end of playback. Recording takes 10 seconds from the start.
  - c. Power-off detection and trimming of the recorded file.
7. Audible signalization of the end of the measurement in the given configuration, which allows entering the room without the risk of disturbing the measurement.
8. Output of the measurement to CSV files.
9. Display the reverberation time  $T$  [s] graph for the current 3 submeasurements to evaluate the need for the measurement repetition.
10. Prompt for repetition of the submeasurements in the same position.
11. Repeat steps 4 through 10 for other configurations. (Figure 2 - Outer cycle)



**Figure 2.** The measurement process. Outer cycle – measuring in different configurations, Inner cycle – performing pre-set number of submeasurements in a specific configuration.

Using the described procedure, reverberation recordings in individual configurations are obtained. Subsequent evaluation of this audio data is facilitated by the previously mentioned uniform naming of source-microphone configurations. Thanks to this, it was also possible to create a unified output system in the form of CSV files. The data processing procedure was as follows:

- Calculation of decay curves for each submeasurement separately using the modified room module from the python-acoustics library. Made in 1/3-octave resolution. (Figure 3a)
- Averaging of the decay curves according to individual configurations. (Figure 3b)
- Reverberation time calculation in individual configurations. (Figure 3c)
- Total absorption calculation of the room with sample  $A_2$  [m<sup>2</sup>] according to ČSN EN ISO 354 [4]. (Figure 3d)
- Loading the total absorption of the room without sample  $A_1$  [m<sup>2</sup>].
- Calculation of the sound absorption coefficient  $\alpha$  [-] according to the formula  $\alpha = (A_2 - A_1)/S$  where  $S$  [m<sup>2</sup>] is the actual area of the measured specimen. (Figure 3e)
- Calculation of the average sound absorption coefficient course from all available configurations. (Figure 3f)



**Figure 3.** Data processing. a) decay curves in one configuration for one third octave band, b) average decay curve in one configuration for one third octave band, c) reverberation time in one configuration, d) total absorption in one configuration, e) sound absorption coefficient in one configuration, f) sound absorption coefficient averaged from all configurations.

#### 4. Conclusion

This paper described a possible approach to measure the sound absorption coefficient in a reverberant room using the interrupted noise method. Own measuring set and measurement software solution were introduced, which enable time-efficient and operator-friendly measurement with the possibility of above-standard control of the obtained data. Freely available software and libraries and the Python programming language were used for this purpose. The measuring set included both a professional power amplifier and omnidirectional source from the manufacturer Brüel & Kjær, as well as a relatively low-cost measurement microphone and a USB audio interface. The measuring set has already been used for measuring acoustic resonators formed by perforated cement fiber boards [18,19]. One of the main advantages of the measurement is the back access to audio files and CSV files with data stored in important calculation steps. Further developments should focus on the use of alternative measurement signals and methods to obtain the impulse response of the room and to eliminate the error in the processing of the measured reverberation.

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