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Test Signal Selection for Determining the Sound Scattering Coefficient in a Reverberation Chamber

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The paper focuses on the problem of test signal selection in determining the sound scattering coefficient in accordance with ISO 17497-1. Research shows that the use of MLS signal is preferred in this procedure. The sine sweep signal, despite its advantages, presents certain limitations if the sample is moving during measurement. An attempt has been made to develop a method that allows for minimization of error, demonstrating the dependence of the obtained values of the sound scattering coefficient on the rotational speed of the turntable and type of test signal. Conditions for the application of the sine sweep signals in continuous and discrete measurements were defined.

Keywords: Schroeder diffusers, scattering, MLS, sine sweep.

1. Introduction

The procedure for measuring the sound scattering coefficient of a sample tested in a reverberation room is described in ISO 17497-1 (ISO, 2004). The measurement consists in determining the sound absorption coefficient α as described in EN ISO 354 and the specular reflection coefficient α_{spec}, whose measurement procedure requires the test sample to be rotated. The sample can be rotated in a continuous manner, i.e., the measurement is made while the sample is rotating with the turntable. The procedure also allows for discrete measurement, that is, the averaging of the results of measurements is made for different angular positions of the sample. In each case the reverberation time is required to be determined on the basis of coherently averaged impulse responses. Until now, no detailed guidelines have been formulated for the selection of the test signal to determine the impulse responses. The standard recommends the MLS signal, but allows also other signals, such as sine sweep. The authors noted considerable differences in the measurement depending on the test signal used, which motivated them to undertake this issue.

2. Problem description

The determination of the impulse response using a maximum length sequence (MLS) was introduced in acoustics in the nineties of the twentieth century in order to obtain a better signal-to-noise ratio by multiple averaging of an individual sequence. Measurement using a sine sweep signal (Farina, 2000) also involves the averaging of repeat sequences, but the use of a harmonic signal allows more accurate processing by the transmitting part of the system, so it is possible to obtain a higher signal-to-noise ratio.

In the case of determining the sound scattering coefficient by the continuous measurement method, the sample position is changing during each sequence. An MLS signal is very sensitive to time variations – even a small variation in a portion of the sequence causes it to be treated as noise. Therefore, in the case of sound scattering measurement, the impulse response obtained in a reverberation chamber for a rotating reflecting plane without a sample (reverberation time T3), for the turntable with a sample (reverberation time T4) are characterized by a very low signal-to-noise ratio. This prompted the leading research laboratories to replace the MLS signal with a tunable sine signal (Choi, Leong, 2011; Vorländer, Embrechts, 2004). This allows for obtaining a better signal to noise ratio of the impulse responses obtained (Cox *et al.*, 2006). However, sine sweep has a time-varying frequency structure. Consequently, the reverberation time for each frequency may depend on the position of the sample at any given time, in contrast to the MLS signal, for which the entire frequency range is generated at a given time.

To demonstrate that the adopted signal was correct, the dependence of the determined scattering coefficient on the sample rotational speed was studied. An assumption was made that sound scattering as a feature of the structure does not depend on the measurement method and should be constant regardless of the testing procedure.

3. Testing procedure

The measurement was performed in accordance with the guidelines of the ISO 17497-1 standard. The reverberation time was determined on the basis of impulse responses recorded using the B&K Dirac 4.1 software.

A round test sample was mounted on the turntable in the reverberation chamber (Felis *et al.*, 2012). The height of the measurement table was 130 mm. In order to reduce diffraction at the edges and scattering generated by the base plate, the space under the table was separated from the space of the reverberation chamber. The diameter of the sample was 2.75 m. The outer edge of the sample, like that of the table, was secured with a rigid band along the full height (Kamisiński *et al.*, 2010).

The measurement consisted in determining the sound scattering coefficient for a scattering system based on the change in the phase of the reflected wave (Schroeder diffuser, $N = 7$, Fig. 1). The maximum depth of the structure was set to 44 mm to avoid measurement error caused by an excessive absorption of the sample (Pilch, Kamisiński, 2011). The study was conducted for two types of measurement signals: a pseudo-random MLS and a sine sweep signal. For each type of the test signal an impulse response was determined for different angular velocities of the table, while conforming to the requirements of the standard with regard to the duration of measurement (ISO, paragraph 7.3). The length of the test signal was 10.92 s (Kamisiński *et al.*, 2012). Also, discrete impulse responses were determined for 72 angular positions of the sample. With full automation, it was possible to shorten the measurements and maintain constant operating conditions inside the chamber.

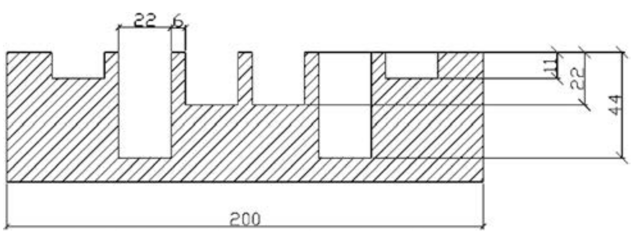

Fig. 1. Cross section of the test sample element. All dimensions given in mm.

All the measurements were performed for 6 fixed microphone positions and 2 fixed positions of the omnidirectional sound source.

4. Results

First of all, measurements using the MLS signal for different rotational speeds of the turntable ranging from 0.16 to 1.37 rpm were performed. For lower rotational speeds, lower values of the scattering coefficient were obtained, especially those above a frequency of 1250 Hz. As the studied sample operated very efficiently above 1 kHz, Fig. 2 shows the results for three rotational speeds in the 1–5 kHz band.

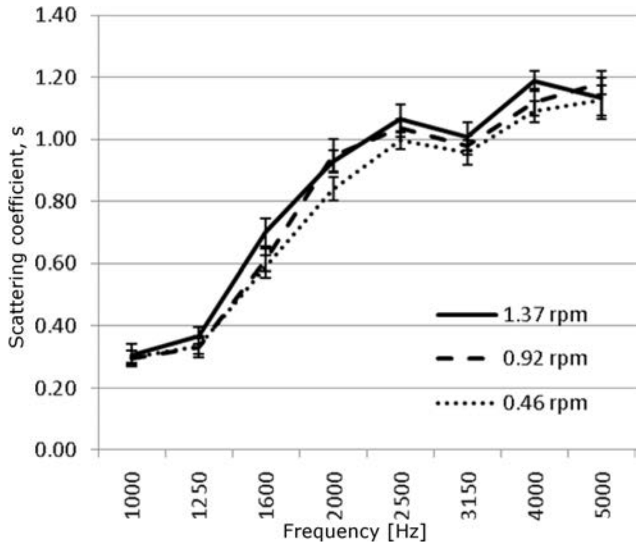

Fig. 2. Sound scattering coefficient determined using the MLS signal for different rotational speeds.

The differences are small, of the order of the standard deviation calculated in accordance with Annex A to the standard (ISO, 2004). Changes for the limiting speeds are constant for the entire measurement range. It can be assumed that the results obtained using MLS as the measurement signal do not depend on the speed of the turntable. The standard deviations of the sound scattering coefficient, calculated in accordance with the annex to the ISO 17497-1:2004 standard were up to 0.06 and did not depend on the rotational speed of the sample.

Afterwards, measurements were performed using a sine sweep signal. Figure 3 shows the scattering coefficient for the three selected rotational speeds. The study shows that the scattering coefficient values obtained from measurements using a sine sweep signal significantly depend on the turntable rotational speed. The value of the scattering coefficient decreases with the increase in the rotational speed in the interval affected by the sample. The graph in Fig. 4 shows the dependence of the scattering coefficient on the turntable rotational speed.

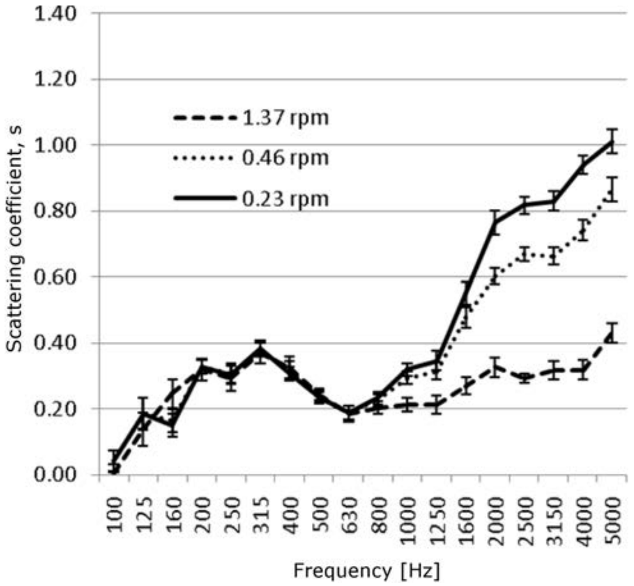

Fig. 3. Sound scattering coefficient determined using a sine sweep signal for different rotational speeds.

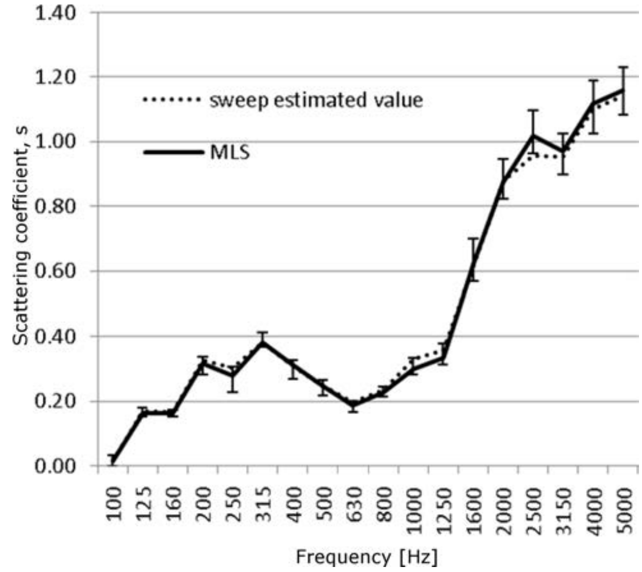

Fig. 5. Comparison of sound scattering coefficients for measurements with an MLS signal (average value for different speeds, maximum and minimum values are shown by error bars) and a sine sweep for a speed of 0 rpm (estimated).

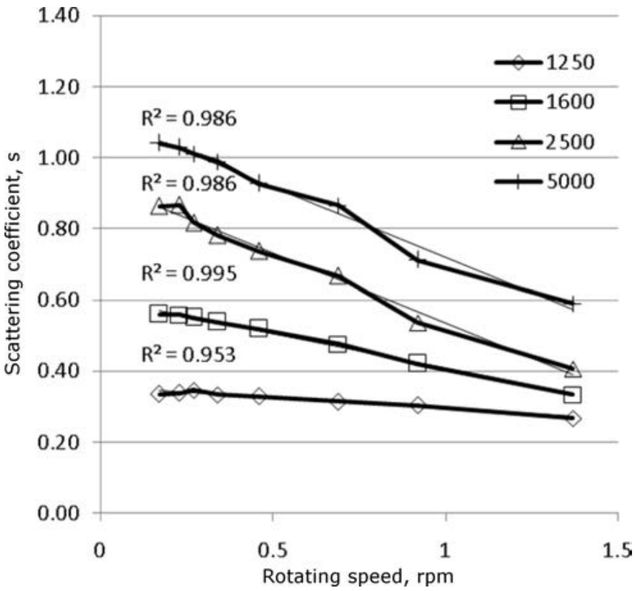

Fig. 4. Sound scattering coefficient determined using sine sweep signal as a function of turntable rotational speed for selected frequencies (R^2 is a coefficient of determination).

The increase in the value of the scattering coefficient with the decreasing rotational speed is greater for higher frequencies. A linear dependence of the scattering coefficient on the rotational speed of the sample was observed. The value of the scattering coefficient for the rotational speed equal to zero was estimated using linear regression. The calculations did not take into account the values of the sound scattering coefficient obtained for rotational speeds greater than 1.37 rpm. Figure 5 shows the values of the sound scattering coefficient measured using the MLS signal (mean values for various rotational speeds), the sine sweep (estimated values for zero speed). The values were in accord and the maximum difference was smaller than the measurement uncertainty.

On the basis of measurements, it may be concluded that the sine sweep signal is not adequate for continuous measurements of the sound scattering coefficient. The values using that type of signal are reproducible only for the same rotational speed. Correct values can only be obtained for very low speeds, i.e., for long measurement times. It can be concluded that K.U. Leuven's method presented in (Vorländer, Embrechts, 2004), where over 35 sequences of sine sweep of length 16 s were averaged (the total time of 9 min 20 s), gave values close to the actual ones. In the case of the MLS measurement signal, much smaller discrepancies of the scattering coefficient as a function of the turntable rotational speed were obtained, which allows measurement at higher speeds without sacrificing the accuracy of the results (Fig. 2). Note that the measurement time is very important because constant measurement conditions must be ensured. If measurements using a sine sweep signal are needed, it is recommended that measurements be made for several rotational speeds and the values estimated for a speed of 0 rpm.

Measurement was also carried out using a sine sweep signal of the discrete method in accordance with guidelines provided by the standard (ISO, 2004). The measurement was performed on the sample rotating in 5 degree increments, which produced 72 impulse responses for each sound source – microphone configuration. The values determined for the band above

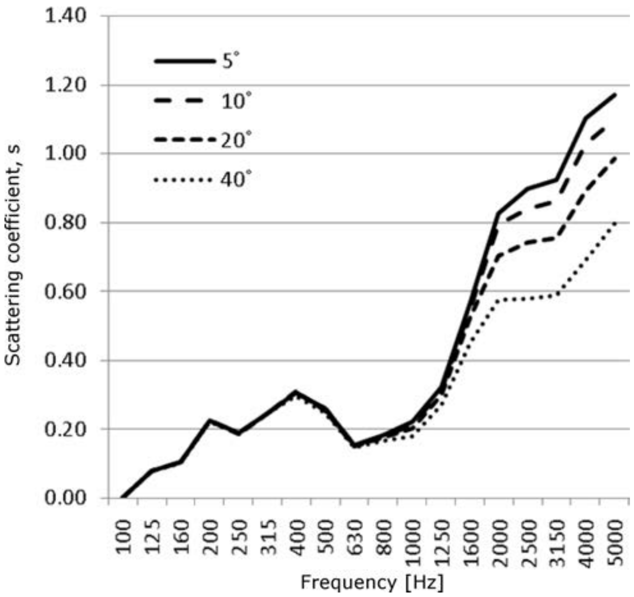

Fig. 6. Sound scattering coefficient for different angle increments in discrete measurements.

1250 Hz do not significantly differ from those obtained in measurements made using a continuous MLS signal. In the lower frequency bands the results are no longer in such good accord (Fig. 7), but still much better than in measurements presented by other laboratories (de Geetere, Vermir, 2002; Embrechts, 2002; Vorländer, Embrechts, 2004). Also analysed was the possibility of shortening the measurement time by reducing the amount of impulse responses determined. In the case of the averaging made for smaller angular resolution (e.g., at every 10 degrees), the obtained values significantly differed for high frequencies where the scattering was high. An attempt to average the impulse responses obtained for only part of the rotation (e.g., a half) did not produce good results, either. This makes it necessary to conduct measurement with 5 degree increments for full rotation of the sample, in conformity with the guidelines specified in the standard.

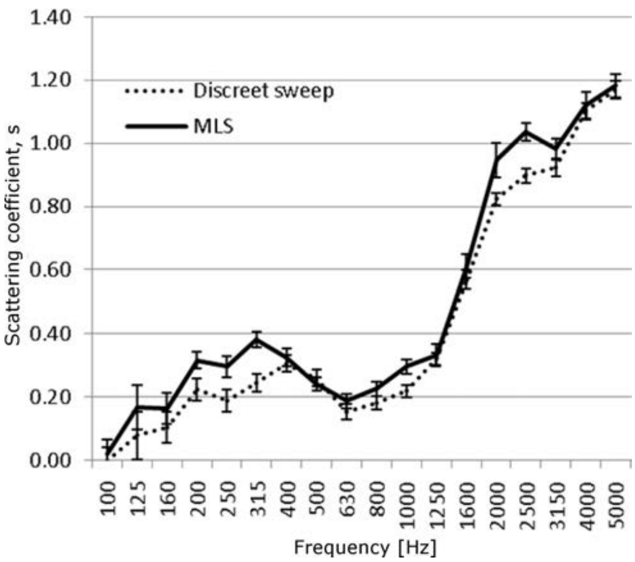

Fig. 7. Sound scattering coefficient from the measurement with a MLS signal (average value) and from discrete measurement using a sine sweep signal.

5. Summary and conclusions

Based on the study, the following conclusions can be drawn:

- The scattering coefficient values determined using the MLS test signal depend weakly on the turntable rotational speed and the differences obtained do not exceed the tolerances;
- The scattering coefficient values determined in continuous measurements using the sine sweep test signal depend linearly on the turntable rotational speed; when the coefficient value is estimated for rotational speeds tending to zero, the results are very close to the average obtained for the MLS signal;
- Measurement for discrete angular positions of the sample is possible, but only for a fully automated measurement set up that allows for measurement time to be reduced to a maximum of one hour, as recommended by (Vorländer, Embrechts, 2004);
- Measurements with an angular resolution lower than 5 degrees recommended by the standard (ISO 2004) give significantly different results of the sound scattering coefficient;
- Averaging the impulse responses of an incomplete rotational of the turntable gives too low values of scattering coefficient and cannot be used.

Acknowledgment

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