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PRACTICAL VALIDATION OF THE LOCAL PLANE WAVE METHOD USING A SPHERICAL MICROPHONE ARRAY

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ABSTRACT

In most environments, the Local Plane Wave (LPW) method estimates the amplitude and phase of the incident and reflects sound waves without making assumptions regarding the global sound field. This study compares the results of standardized ISO tests and LPW tests in some practical cases of airborne sound insulation and acoustic absorption.

The first step in the validation consisted of performing laboratory measurements for all target applications in reverberant or anechoic rooms according to the corresponding ISO standards. Subsequently, the same samples were tested using the LPW method in regular non-laboratory rooms. The results of the LPW method showed reasonable agreement with the ISO results, despite the simplified test environments.

Keywords: *Local Plane Wave, Acoustic measurement, Airborne sound insulation, Sound absorption*

1. INTRODUCTION

In situ measurements of acoustic parameters are crucial for various applications, including the automotive industry and architecture. Traditionally, the determination of acoustic absorption, transmission loss, and sound power has been performed according to ISO standards in controlled laboratory environments. However, these conditions do not always accurately reflect the behavior of materials in real-world applications. Therefore, in recent years, methods have been developed to assess these parameters without prior assumptions about the global sound field.

In this context, the University of Twente and the company Soundinsight (Demcon group) have developed new techniques and devices (Sonocat) to measure the incident sound energy and, separately, the reflected sound energy in any sound field. In doing so, the Local Plane Wave (LPW) method allows the in situ absorption and emission coefficients as well as the transmission loss and radiated power to be estimated. There is no need for a predefined sound field or restrictions on the configuration of the environment [1] [2].

This study compares in situ measurements made with the LPW probe against traditional methods based on ISO standards, intending to validate the accuracy and reliability of the LPW method as an effective alternative for acoustic characterization in practical and in situ applications, which shows good correlation with laboratory-controlled and standardized tests.

2. THEORETICAL BACKGROUND

The LPW method is a novel approach for measuring sound absorption, transmission loss, and sound power in situ, without relying on the assumptions of the global

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sound field. This method is particularly useful in practical applications where the sound field is complex and cannot be easily replicated in laboratory settings. The LPW method is based on the assumption that the sound field can be approximated as a combination of incoming and reflected plane waves, that is, the pressure and particle velocity in the normal direction to the surfaces of interest (absorber/partition). By measuring the sound pressure, P, and the normal particle velocity to the absorbing surface, U_n, the complex amplitudes of the incoming wave, A, and the reflected wave, B, can be determined using Eqn. (1) and Eqn. (2). [3]:

$$A = \frac{1}{2}(P + \rho_0 c_0 \overrightarrow{U} \cdot \overrightarrow{n}), \quad (1)$$

$$B = \frac{1}{2}(P - \rho_0 c_0 \overrightarrow{U} \cdot \overrightarrow{n}), \quad (2)$$

where ρ_0 is the density of the medium, c_0 is the speed of sound, and $\overrightarrow{n}$ is the normal vector, with direction pointing into the absorbing surface.

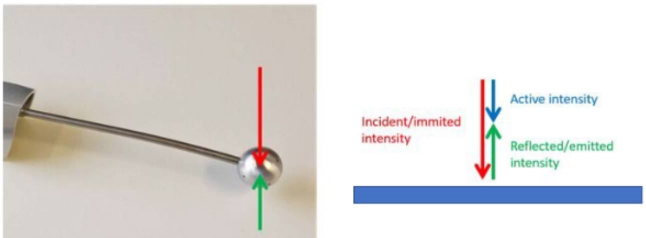

Figure 1. Diagram illustrating the incident, active, and reflected/emitted intensities in the LPW method.

The incident sound intensity I_{in} can then be calculated as in Eqn. (3):

$$I_{in} = \frac{A \cdot \overline{A}}{2 \cdot \rho_0 c_0}, \quad (3)$$

Both, the active and incident power are obtained by spatial integration of the active and incident intensity, respectively. Note that this is an essential part of the LPW method; similar to the active intensity, the incident intensity is now a local quantitative measurement in situ, where $\overline{A}$ denotes the complex conjugate of A. The absorption coefficient α is defined as the ratio of the active power P_{ac} (net acoustic power) to the incident power P_{in}, as shown in Eqn. (4):

$$\alpha = \frac{P_{ac}}{P_{in}}, \quad (4)$$

As illustrated in Figure 1, the LPW method distinguishes between an incident, active and reflected/emitted intensities, which are crucial to accurately determine the absorption coefficient and transmission loss. This distinction allows for more precise measurement of sound energy interactions with surfaces under real-world conditions.

The LPW method can also be applied to measure in situ sound transmission loss. Transmission loss (TL) is defined as the reduction in sound power when a sound passes through a partition, as in Eqn. (5):

$$TL = -10 \log_{10}(\frac{P_{tr}}{P_{in}}), \quad (5)$$

where P_{tr} is the transmitted power and P_{in} is the incident power. Using the LPW method, the incident and transmitted powers can be measured by scanning the pressure and particle velocity on both sides of the partition. This allows for the determination of transmission loss under real conditions, even when the sound field is not diffuse or anechoic [4].

Figure 2. Measurement of incident sound power, scanning the surface approximately at 3 cm of partitions, using Sonocat probe.

3. EXPERIMENTAL PROCEDURES FOR THE ACOUSTIC CHARACTERIZATION

3.1 Evaluation of airborne sound Insulation

3.1.1 Experimental setup

Airborne sound insulation was measured on a separating wall between two dwellings in a building block, following the methodology established in ISO 16283-1 [5]. A pink noise source, dodecahedron (IAG DD5), was used for the test. For data acquisition and processing following the ISO standard procedure, a 01 dB SONO 1/3 octave band analyzer and DB BATI software were used. For the alternative LPW method, the Sonocat probe was used.

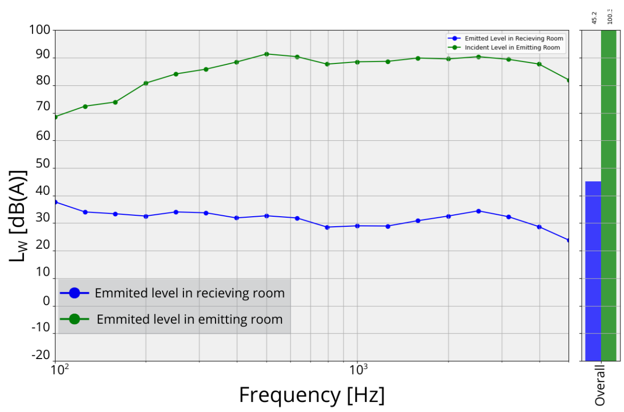

Figure 3. Incident and radiated sound power levels for the partition measured as shown in Figure 2.

3.1.2 Measurement procedure

Measurement of incident sound power. In the emitting room, a diffuse sound field was generated using a pink noise source. The incident sound power on the separation wall was measured by scanning the surface approximately 3 cm from the separating wall (partition) using a Sonocat probe.

Measurement of emitted sound power. In the receiving room, the sound power emitted by the separating partition was measured by scanning the surface again at 3 cm using a Sonocat probe.

Measurement of background noise. The background noise level was recorded by scanning the partition noise radiation in the receiving room once more, but the noise source was turned off to evaluate its influence on the measurements.

Figure 2 shows the scanning of the separating wall using a Sonocat probe. Figure 3 shows the values of the incident (sound power in the emitting room) and radiated (sound power in the receiving room) levels captured by Sonocat. Remarkably, background noise measurements were not performed using the Sonocat probe.

3.1.3 Calculation of acoustic parameters

Calculation of R' (apparent sound reduction index) The apparent sound reduction index R' was calculated in the frequency domain for all frequencies in the 1/3-octave band test range (100 Hz–5 KHz), according to ISO 16283-1, we applied Eqn. (6):

$$R' = L_1 - L_2 + 10log_{10}\left(\frac{S}{A}\right), \qquad (6)$$

where S is the area of the wall and A is the equivalent absorption area of the receiving room.

3.1.4 Comparison with the ISO 16283-1 Standard

The spectrum value of the transmission loss (*TL*) obtained experimentally using the LPW method was compared with the spectrum values obtained following the ISO 16283-1 standard. Deviations were analyzed, and potential sources of variation were discussed.

3.2 Determination of the sound absorption coefficient

3.2.1 Sample selection

The absorption coefficient, measured using the LPW method, was evaluated for various material samples. The method was compared with the absorption coefficients, as characterized by the manufacturer. These samples included several materials that are representative of applications in building acoustics. In addition, the behavior of the absorption coefficient was studied under various conditions, including different sample sizes, different sound incident angles over the sample, and different placement locations.

3.2.2 Experimental setup

An omnidirectional sound source consisting of a dodecahedral loudspeaker (IAG DD5) powered by a pink noise amplifier (IAG DD400A) was used to measure the absorption coefficient. The experimental setup was designed not only to validate the LPW method using the Sonocat probe against manufacturer-provided data, but also to analyze the influence of sample size and placement location on the measured absorption coefficient.

3.2.3 Measurement procedure

Sample Size Variation. To study the effect of sample size on the absorption coefficient, measurements were taken using four different surface areas of the same material.

Placement configuration variation. The absorption coefficient was measured under three different conditions to analyze the influence of the placement configuration. The sample was placed directly on the floor, placed on a table, and surrounded with another absorbent material. Figure 4 shows the setup for the 45° incidence sound test.

Figure 4. Setup for the measurement of the absorption coefficient with 45° incidence sound.

Measurement with Sonocat probe. Multiple measurements were taken using a Sonocat probe, and the surface of the sample was systematically scanned to capture the necessary levels to calculate the absorption coefficient. Figure 5 shows the in situ absorption measurements for Ecophon Akusto One and Ecophon Master Eg.

Data recording. The absorption coefficient values were recorded in one-third octave frequency bands ranging from 100 Hz to 5 KHz.

Figure 5. Example of measurement setup of the sound absorption using Sonocat.

4. ANALYSIS OF RESULTS

4.1 Airborne sound insulation

4.1.1 Comparison of experimental and reference data

In Figure 6 shows the experimental direct transmission loss of the separating partition (TL), using Sonocat, compared with the in situ R' measurement (according to ISO 16283-1 standard).

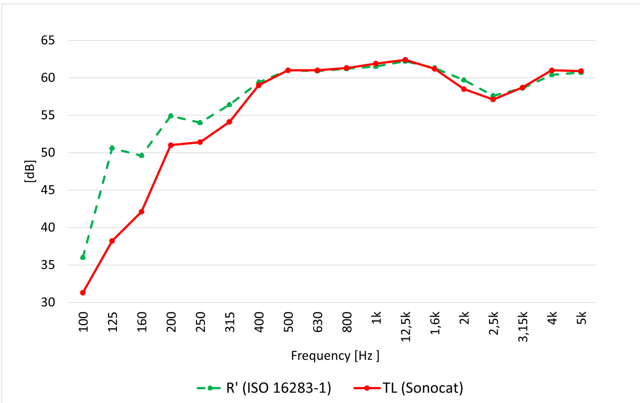

Figure 6. Comparison of TL Values using Sonocat and R' ISO 16283-1.

4.1.2 Discussion of results

Low Frequencies (100 Hz - 250 Hz). Deviations were observed between the experimental and reference values. These deviations can be attributed to the difficulties in generating a true or ideal diffuse sound field at low frequencies and the influence of uncontrolled flanking paths (sound transmission through adjacent structures in the wall or receiving room).

Mid and High Frequencies (250 Hz - 5000 Hz). The values calculated using the LPW method were in excellent agreement with reference values. This confirms the accuracy of the LPW method using the Sonocat probe in this frequency range.

4.1.3 Validation of the Method

Despite the deviations observed at low frequencies, the experimental results showed a good correlation with the theoretical values in the mid- and high-frequency ranges. This validates the methodology and confirms the usefulness of the LPW method, helping to separately analyze the radiation for different room partitions (floor, walls, and roof) to evaluate the sound insulation in practical applications.

4.1.4 Recommendations for future studies

To improve the accuracy of ISO measurements, it is recommended to ensure a completely diffuse sound field, especially at low frequencies. The LPW method does not rely on the diffusivity of the sound field because it directly measures the incoming sound intensity. Hence, it can also be used in non-diffused sound fields. For optimal test accuracy according to the ISO method, a perfectly diffuse sound field was required in both rooms. However, this condition is not necessary when the Sonocat method is used. Consequently, diffuse field conditions are not properly achieved in various scenarios, and variability in the sound pressure levels may occur, particularly at low frequencies. This may lead to higher values than the actual performance when the ISO standard is followed. The LPW method can also be used to evaluate the influence of flaking paths on the sound transmission. Additional measurements must be conducted at lower frequencies to better understand the reasons for these deviations.

4.2 Sound absorption coefficient

4.2.1 Experimental validation and analysis of measurement conditions

Behavior of the absorption coefficient in various situations:

Sample size. The area of the sample significantly influenced the measured absorption coefficient, particularly at low frequencies. The results for the different sample sizes are presented in Figure 7. We measured samples of different sizes (e.g. 2400 mm × 1200 mm and 2400 mm × 1800 mm). Analyzing the results, it is observed that if the sample is larger, the effect of the sample size decreases and converges to a value that is also measured by the laboratory ISO 354 absorption test.

Placement configuration. The placement of the samples also affected the measurements. The results for the different placement configurations (table, floor, and surrounded by another absorbent material) are summarized in Figure 8. Samples placed directly on the floor exhibited higher absorption coefficients at low frequencies than those placed on a table, likely because of the interaction with the floor surface and resonances of the table. The similarity between the sample placed on the ground and that surrounded by absorbent material proved that the Sonocat method measures the absorption coefficient of the scanned material regardless of its surroundings.

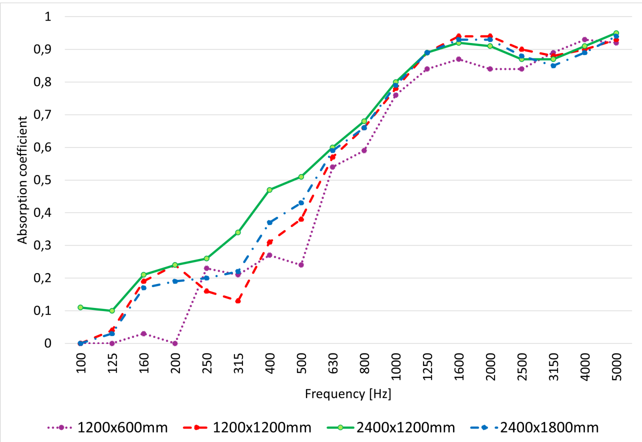

Figure 7. Values obtained by measuring a sample of Geopannel PYL of different dimensions.

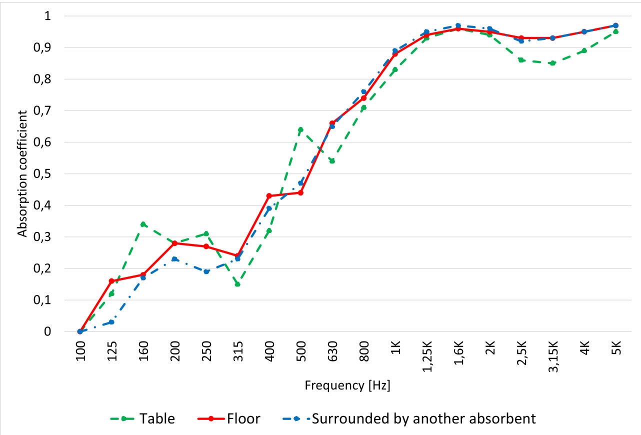

Figure 8. Values obtained by measuring a sample of Basotec G+ of different placement configuration.

Comparison with Manufacturer-Provided Data: The sound absorption coefficient (α) was measured using the Sonocat probe (LPW method) for the same material (Basotec G+) in different configurations. It was concluded that the best way to measure α, such that the LPW method closely resembles the ISO method, is to place a sufficiently large sample (in the experiments, a surface of 1200 mm x 1200 mm was used) on a surface that ensures a fixed position, such as the floor. The results were compared with the α values provided by the manufacturer, which were measured using a reverberation chamber and impedance tube according to the ISO 354 and ISO 10534-2 standards [6] [7].

4.2.2 *Discussion of results*

Low frequencies (100 Hz - 200 Hz). In this range, the values obtained with the Sonocat method were higher than those obtained with the impedance tube and close to those obtained with the reverberation chamber.

Mid frequencies (200 Hz - 1 KHz). In this frequency range, the values obtained were between those provided by the reverberation chamber and those obtained using an impedance tube.

High frequencies (1 KHz - 5 KHz). In this range, the Sonocat method demonstrated excellent reliability, with absorption coefficients very close to those of both the reverberation chamber and impedance tube.

4.2.3 *Validation of LPW method*

Currently, there are two standardized test methods for measuring the sound absorption coefficient: the reverberation chamber method and the impedance tube method. Both methods are based on different sound field assumptions (diffuse and normal incident, respectively), different calculation criteria, different sample sizes, and different test environments, the absorption coefficients are different for both methods.

As shown in Figure 9, we compared the spectrum absorption coefficients of the three methods. Sonocat led to intermediate values with respect to the values obtained in the impedance tube and those obtained in the reverberation chamber.

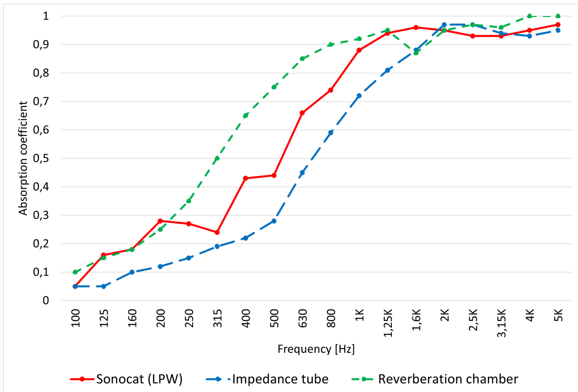

Figure 9. Comparison of α values using Sonocat (LPW method), impedance tube and reverberation chamber.

4.2.4 *Recommendations for future studies*

To obtain good results, it is recommended that a sample surface of at least 1200 mm x 1200 mm. Measurements should be conducted in a solid basement without radiated sounds.

To obtain results similar to those of the standard methods, future tests should consider the perpendicular incidence of sound waves. A Previous experiment, as shown in Figure 10, showed results that were closer to those in Figure 9, performed with an incidence of 45º. Therefore, it is suggested that a perpendicular sound field impinges on the surface of the sample to compare the standard's results with those obtained using the LPW method,

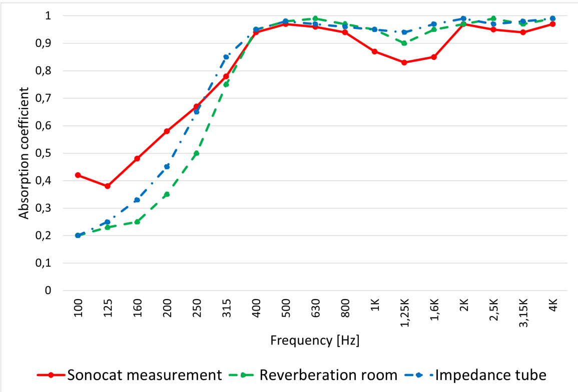

Figure 10. Comparison of α values using Sonocat (LPW method) with normal incident sound field, impedance tube and reverberation chamber.

This type of scenario occurs only when we want to evaluate the manufacturer's samples. However, this fact is not relevant when we perform in situ measurement tests; for example, when we measure complete construction solution areas, such as ceilings, walls, or floors, each covered with different absorption materials, allowing the absorption coefficient of each surface to be measured with this LPW method.

Additional applications can focus on the in situ measurement of the absorption coefficient inside a moving vehicle, where the noise source is the noise generated by the vehicle itself.

5. CONCLUSIONS

In conclusion, it is important to highlight the difference between the in situ method and the ISO method. ISO standards rely heavily on a true diffuse field; however, the reality is different, and the results depend on the diffusivity of the sound field, which we never obtain in real measurements. Therefore, we can conclude that by using the LPW method, we will obtain in situ insulation and absorption values with reliable results that can never be obtained with currently standardized methods. The LPW method is an ideal representative method for determining the acoustic behavior of materials at locations where they are installed.

6. ACKNOWLEDGMENTS

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