Guimarães - Portugal

Determining the Wall Sound Absorption Coefficient of Assessed Anechoic and Semi-anechoic Rooms

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ABSTRACT: This work shows how the results from measurements made to assess the anechoic performance of anechoic and semi-anechoic rooms may be used to estimate the average sound absorption at the walls of these rooms and the room average absorption coefficient. An image model of the room anechoics has been made with which to predict the standard deviations from anechoic and semi-anechoic behaviour in a room of know absorption. Methods of assessing the acoustic performance of anechoic and semi-anechoic rooms have been implemented together with the image source model in order to process the data from measurements in a semi-anechoic chamber. Predictions of standard deviation and wall absorption were made for a semi-anechoic room of known characteristics. Room properties and measurement conditions are responsible for the relationship between the variability of sound pressure level and the wall average absorption coefficient. The agreement between numerical results and measurements is fairly good.

1. INTRODUCTION

Anechoic and semi-anechoic rooms have their acoustic performance assessed according to the international standard ISO 3745[1] procedure or the carousel method introduced by Moreland[2]. Although each method measures a different variability of sound pressure level (SPL) and so different qualifying figures are obtained, both are accounted by the ISO 3745 standard. Results from either measurement procedure may then be used to estimate the average sound absorption at the walls of these rooms, using an image source model. Room properties and measurement conditions will be responsible for the relationship between the variability of SPL and the wall average absorption coefficient. Information about the variability of the SPL and the average wall sound absorption in anechoic and semi-anechoic rooms will assist users selecting measurement positions with lowest STDs for making sound power measurements and other testing and estimate the errors incurred by the rooms' weaknesses.

2. THEORETICAL BACKGROUND

2.1 Procedures for anechoic and semi-anechoic room testing

According to the international standard[1], the acoustic performance of anechoic and semi-anechoic rooms must be measured as the deviation from inverse square law behaviour by measuring the SPL decay from a test sounce. However, in the case of semi-anechoic rooms, there will be strong interference effects caused by the floor image source, which will be greater the higher the position of the acoustic centre of the test source above the floor. Furthermore, this method does not describe the performance of anechoic and semi-anechoic rooms in meaningful terms. A qualification of rooms in terms of measurement precision and accuracy is much more meaningful to the engineer using the room. The carousel method, as reported by Moreland[2], Nelson[3] and Agren[4], does this and overcomes the problems caused by the floor image source. Instead of measuring the SPL decay with distance, this method assesses the rooms by measuring the variation of the SPL with the angular position of a receiver at a fixed radius from the source. This variation is then quantified by computing the sample standard deviation (STD) $\Delta\sigma$ of the SPL about the mean value averaged over the receiver angle θ,

$$\Delta\sigma = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}\left(L_{p_i} - \bar{L}_p\right)^2} \tag{1}$$

where L_{p_i} is the SPL at the i^{th} position around the test source, $\bar{L}_p$ is the mean SPL at the same radius and n is the number of measurement positions. With the carousel method, the floor interference effects are equally accounted at all measurement positions around the test source. Hence, only the lateral walls will influence the variation of SPL. Since maximum STDs of mean values are also specified in ISO 3745 (as measurement uncertainty) the carousel method is also valid to assess these rooms. Analysis usually starts at 1m away from test source because measurements are only valid in the far-field.

2.2 Image source model

An image source model is used to predict the relationship between the variation of sound pressure level and the average sound absorption coefficient at the walls in anechoic and semi-anechoic rooms. Consider a rectangular room with an omni-directional source and a receiver located inside. Since these rooms are highly absorptive, it can be assumed that only first order reflections have a significant contribution to the sound field inside the room. Assuming plane wave propagation and normal sound incidence, the acoustic pressure at a receiver point is given by,

$$\tilde{p}_t \simeq p_o\left(\frac{1}{r_d}\cdot e^{-jkr_d} + \sum_{i=1}^{6} R_i \frac{1}{r_i} e^{-jkr_i}\right) \tag{2}$$

where p_0 is the source strength, r_d is the direct sound path, r_i and R_i are respectively the reflected sound paths and the reflection coefficients of the walls, ceiling and floor (in the case of semi-anechoic rooms the floor is hard reflective instead of absorbent). The individual sound paths may be determined by geometry, as described in standard textbooks. In practice the source strength p_0 is usually the acoustic pressure measured at the distance of 1m from the test source.

3. PREDICTING ANECHOIC PERFORMANCE

The rectangular semi-anechoic room investigated by Agren[4] and listed in Table 1 is taken as example. Absorption coefficients were assumed 0.99 above cut-off frequency for the walls and ceiling, and 0.05 for the hard floor. Test source and receiver positions had the same height z_0=1.6m.The variation of SPL is analysed around test source and with distance from test source using the image source model. Since, several analyses can be made to the variation of SLP inside the room, only those that seamed most relevant are discussed in this section.

3.1 Angular variation of SPL and standard deviation with distance

The variation of the SPL versus receiver angle θ was predicted. As shown in Figure 1, the SPL fluctuates about a mean value with a deviation that varies with the reflectivity of the walls. Since the room is symmetric about the centre, the variation of SPL around test source at a fixed radius tends to repeat after 180º. The variability increases with increasing frequency and also with increasing radius.

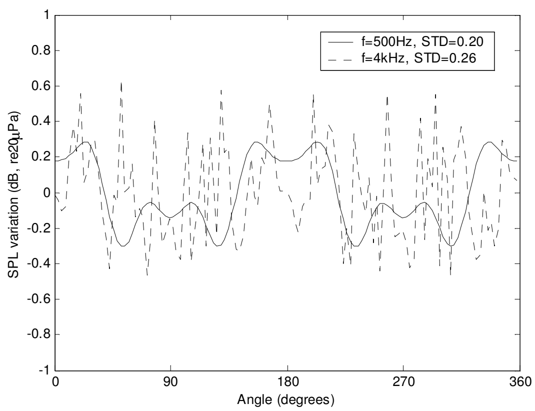

Figure 1 - Angular variation of SPL around test source at 2m.

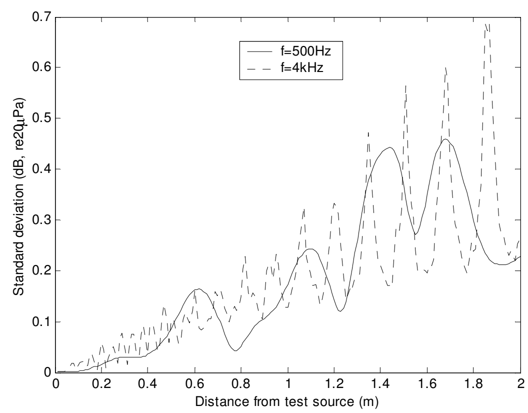

Figure 2 – STD up to 2m from source of octave band centre frequencies versus frequency.

The STD of the angular variation of SPL is basically obtained by combining the image model with Eqn. (1). This was computed with increasing radius from the test source. The results at some frequencies are plotted in Figure 2. The STD increases with increasing radius, mainly because the direct field contribution becomes progressively weaker and the reflections from the walls stronger due to proximity of receiver to the walls. A highly correlated pattern of deviations is clear at 4kHz, especially after 1m away from test source. Maxima and minima are separated by half wavelength (4.3cm) and the STD is smallest at distances of around multiples of the wavelength. This pattern is generally verified at frequencies that fit two wavelengths between the test source and the receiver, but only after 1m away from test source (far-field condition). Hence, this measurement may provide guidance to the engineer using the room to choose the measurement radius with smallest STDs when making use of anechoic and semi-anechoic rooms. It was also verified that the increasing trend of STD is about the same at these frequencies, STDrms≅0.24dB.

3.2 Standard deviation versus frequency

The STD of angular SPL versus frequency is investigated. Figure 3 illustrates the predicted STDs of the semi-anechoic room at 1.4m from test source. The dashed-line represents the maximum allowable STD specified in the ISO 3745. The absorption coefficient of the walls was assumed the same at all frequencies (0.99). Note that the STD peak density increases in the same fashion of room modal density. This suggests the influence of standing waves between parallel walls, which originate room modes, on STD measurements.

For measurements beyond 2m from test source, the room is expected fail the ISO standard requirements at many frequencies. The comparison of predictions with experimental results from Agren[4] show good agreement at many frequencies. Slightly higher deviations at low and mid frequencies are verified. The discrepancy at low frequencies is acceptable due to the image model breakdown. However, in order to obtain a better estimate from the image source model, one should use the absorption coefficient data of tested samples of absorptive material as input to the prediction model, rather than assuming α=0.99 for all frequencies of interest.

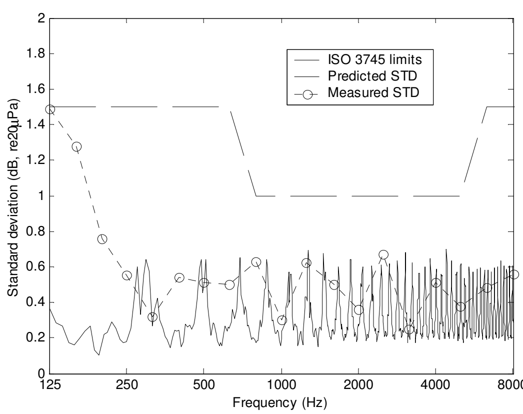

Figure 3 - STD as a function of frequency at 1.4m from test source.

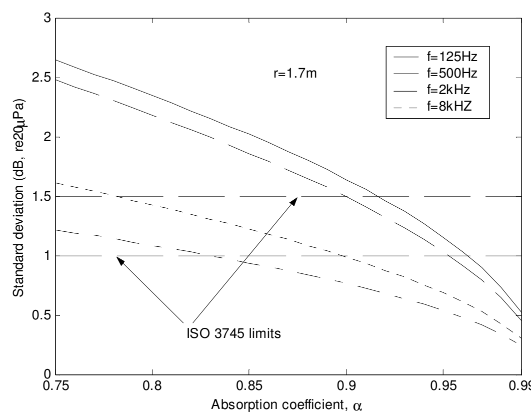

Figure 4 – STD as a function of wall average absorption coefficient at several frequencies.

3.3 Standard deviation versus absorption coefficient

It is possible to predict by how much the room acoustic performance will deteriorate with a decrease in absorption coefficient. This is illustrated as the variation of STD with wall average absorption coefficient over incidence angle and over surface. Figure 6 shows an example at 1.7m from test source and a number of different frequencies. For instance, at 125Hz, the room would need an absorption coefficient of at least 0.97 to produce a STD below 1dB in order to perform measurements up to 2m. Naturally, this process must then be repeated for all frequencies of interest and at more than one radius to help identifying measurement radii with inferior room performance. In addition, once known the wall average absorption coefficients at different radii, these can be averaged to obtain a room average absorption coefficient. Modelling rooms before construction can be useful to choose the necessary wall absorption treatment to meet design requirements, while before practical assessments it can be useful to choose measurement radii to quantifying the room.

4. ANECHOIC PERFORMANCE OF TESTED ROOMS

4.1 Standard deviation measurements

Measurements of standard deviation in semi-anechoic rooms reported in some studies, Moreland[2], Agren[4] and Ballagh[6], are analysed and the average wall absorption coefficients are estimated. Table 1 summarises room characteristics and the radii used for measuring the SPL variation around test source.

	Wall treatment	Material + air gap [m]	wedge-tip-to-wedge-tip [m]	mic radius [m]	source/mic height [m]	cut-off freq. [Hz]
1	SPF1® absorptive wedges	0.81 + 0.10	6.5x6.2x4.7	0.5 to 2.0	n.a.	90 (expected)
2	V-folded glass-wool sheets	0.56 + 0.10	10.6x4.5x6.8	1.4	1.6	100 (expected)
3	Absorptive wedges with wire mesh	0.30 + 0.25	9.3x9.3x5.5	4.21	1.77	100 (expected)
4	Resonators / glass-fibre facing	0.23 + n.a.	5.8x4.8x3.3	1.52	1.52	100 (expected)
5	Mineral wool / Tectum® / fibre-glass	0.30 + 0.28	7.3x7.0x6.7	1.59	1.75	100 (expected)

Table 1 – Summary of semi-anechoic chamber characteristics.

In room 1, the author strictly followed the procedure described in ISO 3745. For comparative reasons, of a range of measurements with distance from test source is analysed in terms of STD. In rooms 2 to 5 the STDs were measured using the carrousel method and different radii depending on the room size. A comparison of the measured STDs of these rooms is shown in Figure 5. The dashed line is the STD limits specified in ISO 3745. A “U-shaped” plot of STD as a function of frequency is usually expected, because rooms are usually more sensitive at lowest and highest frequencies. This is in fact verified in the case of rooms treated with acoustic wedges. In rooms 1 and 3, the STDs tend to greatly increase above 4kHz, most likely because of the blunt wedge tips and covering wire meshes, whilst the remaining rooms offer better anechoic performance at high frequencies.

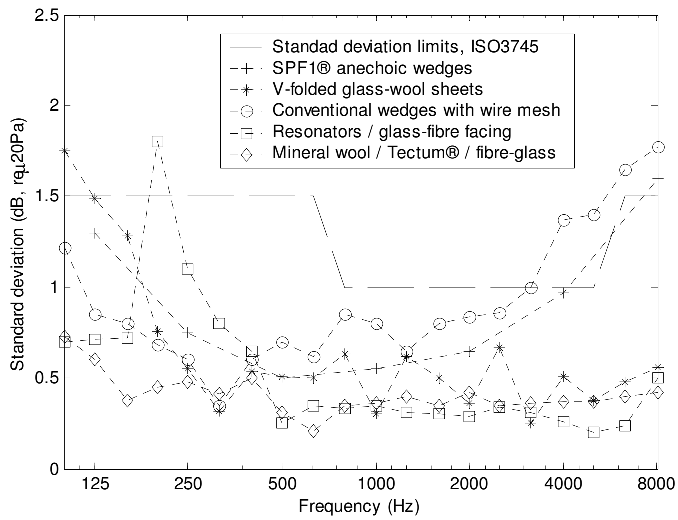

Figure 5 – Measured STD of investigated rooms (listed Table 1).

In room 3 for instance, the higher STDs at low frequencies are due to the proximity of measurements to the walls. Low frequency room modes, which cause strong modal responses, may be responsible for punctual increase of STDs. This effect is clearly identified in room 4 at around 250Hz. Room 5 shows the lowest variability of STD, but it must be noted that this is probably due to the small measurement radius in comparison to the large dimensions of the room. In general, the increase of STDs at low frequencies is influenced by the cut-off frequency of absorptive treatment and at high frequencies by the stronger reflections from the walls.

4.2 Average wall sound absorption coefficient

The angular measurements of SLP can be used as input to a reverse image model in order to find the average absorption coefficient of each wall – by solving simultaneous equations to find R_i from Equation (2). For one measurement radius, this must be done for all receiver angles and at each frequency. Then, the absorption coefficients obtained for all receiver angles must be averaged to find the wall average absorption coefficient. Another process, consists in plotting a prediction of the STD versus absorption coefficient of the semi-anechoic room, and then cross the measured STD data at the same radius to find the corresponding wall average absorption coefficient. The results obtained for the rooms in Table 1 are shown in Figure 6.

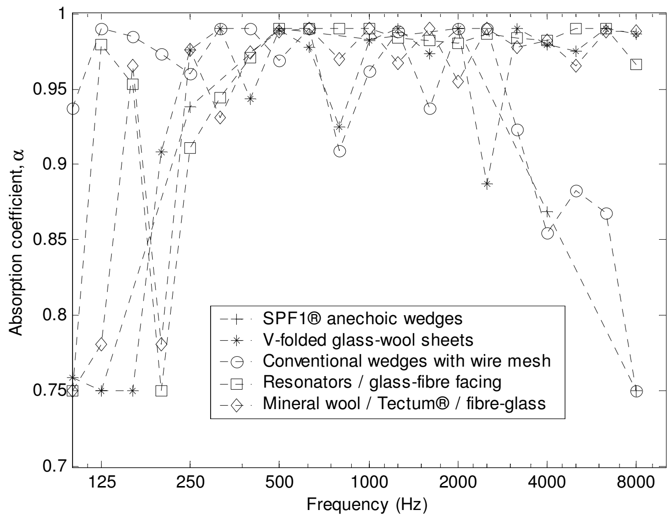

Figure 6 – Estimated wall average absorption coefficient of investigated rooms.

In general, the highest absorption coefficients are verified in the mid frequency region. Rooms 2, 4 and 5 also show very high absorption at high frequencies and the least variation from 500Hz onwards. By analysing Figure 5 and Figure 6, it can be seen that an increase in STD is generally attributed to a reduction in the wall sound absorption. However, a lower STD result may occasionally correspond to a lower absorption coefficient at a specific frequency, when compared with neighbour frequencies or with other rooms. The wall average absorption coefficient in the mid frequency region is always above 0.90. This is important to keep low STDs in order to satisfy the standard stricter requirement in this frequency range. Although the wall average absorption coefficient reaches considerably low values at high and low frequencies, these are not lower than 0.75 for all investigated rooms. In most cases, the wall average absorption coefficient should be above 0.95 at most frequencies in order to meet ISO 3745 requirements. In addition, Moreland[2] suggests that semi-anechoic rooms should be at least 75% absorbent to really be in the class of rooms with anechoic performance.

4.2.1 Comparison with tested samples of absorptive material

Although it may be measured that the absorptive materials have normal incidence absorption coefficient equal to 0.99 above cut-off frequency (from impedance tube measurements), the estimated wall average absorption coefficient is at many frequencies below 0.99. Such reduction in absorption is mainly due to the same factors influencing the variation of SPL. The absorption coefficient, from impedance tube measurements, of the wedges used in room 1 was available. These could be compared with the estimated wall average absorption coefficients plotted in Figure 6. The results were relatively different, primarily at mid and high frequencies. It suggested the strong influence of the reflecting floor and the measuring conditions, as the proximity of measurements to the walls, upon the wall absorption characteristics of each room. This behaviour can be generalised and so also expected in the other rooms. Results can eventually be used to estimate the necessary absorption corrections so that the room complies with the standard requirements.

5. CONCLUSION

A way to determine the average wall absorption of anechoic and semi-anechoic rooms was described and applied to experimentally assessed rooms. The influence of the rooms on SPL measurements was in general found to increase with decreasing wall sound absorption and with the proximity of measurements to the room walls. The variation of STD is dependent on the relationships between test wavelength, measurement distance from test source and from the walls. In the case of semi-anechoic rooms, the wall averaged sound absorption coefficient should be equal or greater than 0.75 over the complete frequency range of interest, so that the room can be classified as semi-anechoic. Information about the variability of the SPL and the wall average sound absorption in anechoic and semi-anechoic rooms will assist users selecting measurement positions with lowest STDs for making sound power measurements or other kind of testing and also to estimate the errors incurred by the rooms' weaknesses.

6. REFERENECES

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