APPLICATION OF BEAMFORMING AND SONAH TO AIRBORNE NOISE INSULATION MEASUREMENTS

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ABSTRACT

According to ISO 140-4, pressure level measurements are usually carried out to evaluate the airborne noise insulation. This standard provides no information about parts of the element under test that present a reduced insulation. To solve this problem, intensity measurements based on ISO 15186-2 can be taken. Nevertheless, this solution implies a long time due to the high number of measurement points required.

This paper introduces different tests to assess the in-situ airborne noise insulation through SONAH and Beamforming techniques. This makes it easier and quicker the calculation of the insulation of these parts of interest.

In these experiments, the intensity magnitude has been obtained through SONAH or Beamforming measurements to derive the airborne noise insulation of a separating element, or a part of it, applying the calculation procedure indicated by the ISO 15186-2 for that.

The experiments have been carried out for four constructive elements: a double-wall and three doors made up of common materials (wood, glass, sheet).

To determine the accuracy obtained with these experiments, the insulation of the tested elements has been determined in advance by the standardized procedures of pressure and intensity, so that a valid comparison with the results given by SONAH and Beamforming could be established.

1 INTRODUCTION

Standardized methods stated in the ISO 140 [4], through sound pressure measurements, and in the ISO 15186 [5], through sound intensity measurements, are commonly used to determine the noise insulation of a separating element or a constructive element.

Specifically, the method in the ISO 140-4 [4] establishes that the sound field generated in the emitting room and received in the receiving room must be space sampled and timely averaged. The apparent sound reduction index R' can be calculated from the equation (1) after taking the former measurements.

$$R' = L_1 - L_2 + 10\log\frac{S}{A} \qquad \text{dB} \tag{1}$$

L_1 is the mean sound pressure level emitted, L_2 is the mean sound pressure level received, S is the area of the separating element between the two rooms and A is the equivalent sound absorption area of the receiving room derived by the Sabine's equation:

$$A = \frac{0.16V}{T} \tag{2}$$

being V the volume of the receiving room in m^3 and T its reverberation time in s.

Focusing now on the measurement procedure through sound intensity [3], not only the insulation of the separating element can be determined through it, but also the areas with fewer insulation can be identified. ISO 15186 [5] indicates that, on the one hand, the incident sound pressure in emission must be averaged when this procedure is applied. On the other hand, the separating element under test must be sampled in the receiving room with a measuring grid dense enough so that sound leaks or weaknesses could be characterized. The measuring time in each one of the points must be at least 10 s. After taking these two measurements, the apparent sound reduction index through intensity R'_I can be calculated through the equation (3):

$$R'_I = \left[L_{pI} - 6 + 10\log\left(\frac{S}{S_0}\right)\right] - \left[\bar{L}_{I_n} + 10\log\left(\frac{S_M}{S_0}\right)\right] \qquad \text{dB} \tag{3}$$

where L_{pI} is the mean sound pressure level in the emitting room, S is the area of the separating element, $\bar{L}_{I_n}$ is the normal sound intensity level measured in the receiving room over the measuring surface, S_M is the area of the measuring surface and $S_0 = 1\ m^2$.

After the examination of the measurement procedures, it is noticed that the main advantages of the pressure method [4] are its standardization and the reduced time required to take the measurement; its main disadvantages are the incapability of detecting leaks and areas with a poor insulation level and, additionally, it does not reject the possible indirect transmissions. On the other hand, the intensity procedure [5] has the advantages of identifying areas with the weakest insulation and a less influence of the indirect transmissions; its disadvantages come from the higher measuring time required, which increases depending on the density of the number of points in the measuring grid.

A new measurement procedure is proposed to unify the advantages of both methods mentioned above: quickness and detection of leaks. This new procedure is based on Beamforming and accompanied by SONAH; its main aim is the identification of the areas with weak insulation in one shot measurement and the approximation of R'_I from the evaluation of the acquired intensity.

2 METHODOLOGY

2.1 Selection of Elements

A double-wall and three doors made up of common materials have been selected as the contrasting or separating elements to evaluate the measurement tests using Beamforming and SONAH to determine the sound insulation.

The wall has been selected because this is a uniform separating element. Furthermore, this item is acoustically well-known and studied, so that its insulation can be accurately determined theoretically by the mass law and prediction equation, and experimentally according to the standard methods of pressure and intensity [4, 5].

The selection of the doors [3] comes from the fact that they, together with the windows, are the items with the weakest insulation within a separating element (usually a wall). Consequently, the global insulation of the separating elements is highly constrained by the insulation of these partial items. Different types of doors have been selected to study their influence depending on its material; particularly, wood, glass and sheet doors have been tested. Moreover, the sheet and wooden doors tested are non-homogeneus, as they included glass parts; therefore, the insulation of heterogeneous separating elements can also be evaluated.

2.2 Measurement procedure

Recommendations of the standards mentioned above [4, 5] are followed to determine the apparent sound reduction index through Beamforming and SONAH.

First, the emitting and receiving rooms are defined. Next, the omnidirectional sound source is placed in the emitting room in a location where the best sound difussion could be established [4, 5]. The source will emit white noise properly equalized to achieve a flat spectrum and of enough level so that a high signal to noise ratio could be obtained in the receiving room. The measuring array must be placed in the receiving room; specifically, an 18-channel pizza-array by B&K linked to a Pulse acquisition system, see figure 1, has been used in the tests carried out.

The frequency range of interest for the standardized measurements [4, 5] is defined by the third-octave bands from 100 to 3150 Hz; it can also be widened to 50 Hz at low frequency and up to 5000 Hz at high frequency if a broader analysis is required. With just one of the techniques proposed, Beamforming and SONAH, the whole frequency range mentioned cannot be covered. Beamforming presents a low resolution at low frequency [1] and SONAH would require a huge number of microphones to achieve a proper resolution at high frequency spanning the total surface under test [2]. Therefore, a combination of both techniques seems the best option: third-octave bands among 500 and 5000 Hz can be taken from Beamforming, whereas

Figure 1: 18-channel pizza-array

SONAH can be used for the third-octave bands among 50 and 1600 Hz. The measurement procedure for each case is the following:

1. **Beamforming:** This technique specifies that the measuring distance between the transducer and the source can be medium-long [1]. Considering this and despite a possible resolution loss, the distance chosen has been the minimum to cover the whole area of interest of the separating element. This distance is defined by the equation (4):

$$L = 1.15z \tag{4}$$

   where z is the measuring distance and L is the sound source length. Consequently, the measuring distance has been set to 2 m for the doors and 5 m for the wall.

2. **SONAH:** This technique requires only near-field measurements [2], so a distance of 10 cm has been chosen. This close distance to the element under test makes that one measurement can cover a surface just like the size of the array. Hence, measurements over different parts of the element under test must be taken to compare afterwards the results with the partial insulation obtained from the intensity method. The results obtained from SONAH cannot be compared with those from the pressure method, as this one evaluates the whole insulation and not insulation of parts of an element.

According to the equation (3), the apparent sound reduction index can finally be calculated once the measurements are taken and the intensity maps over the separating element and its total radiated intensity are obtained.

3 RESULTS

This section presents the intensity maps obtained from Beamforming and SONAH for each of the four separating elements analyzed.

Figure 2 shows the results through Beamforming for the whole wall in the third-octave band of 1 kHz and through SONAH in the central point of the wall in the third-octave band of 250 Hz. It can be observed in both images that the wall is a homogeneous separating element without leaks and, as a consequence, the intensity maps are uniform over all the surface of the element.

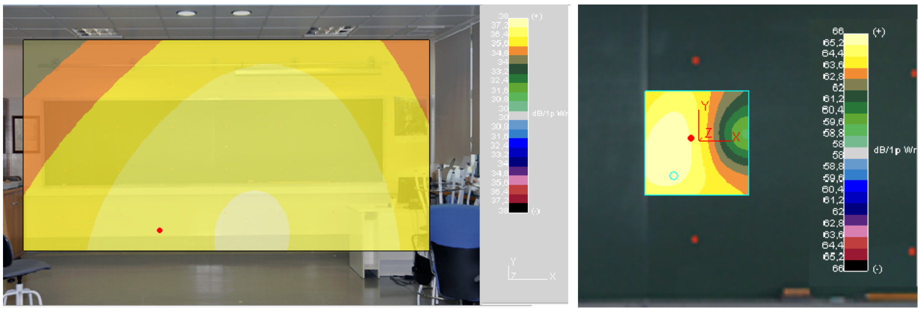

Figure 2: Results for the wall. Left: Beamforming at the third-octave band of 1 kHz. Right: SONAH at the third-octave band of 250 Hz.

Results for the glass door appear in figure 3. Beamforming mapping at the third-octave of 4 kHz is shown on the left; highest intesity levels are concentrated in the lower part due to the existing chink of door.In addition, the influence of the sidelobes of the array at this frequency can be observed in the rest of the door.

The image on the right of the figure 3 shows the results for SONAH over the glass surface at the thid-octave band of 160 Hz. Here the calculated intensity is quite uniform in the whole considered area.

Left side of figure 4 includes the map with the results for the sheet door through Beamforming at the third-octave band of 2 kHz. Again, the greatest part of sound radiation is located in the lower chink of door. The levels in the central part are due to the influence of the sidelobes of the array, which become significant from that frequency on.

The right part of figure 4 shows the results through SONAH at the third-octave band of 250 Hz in the central point of the door and the glass. The levels achieved in the glass are quite homogeneous and higher than those obtained in the sheet part of the door, where there is a greater variation.

Figure 5 on the left presents the results for the wooden door, which includes a glass ornament, through Beamforming at the third-octave band of 500 Hz. Reiteratively, the higher levels are

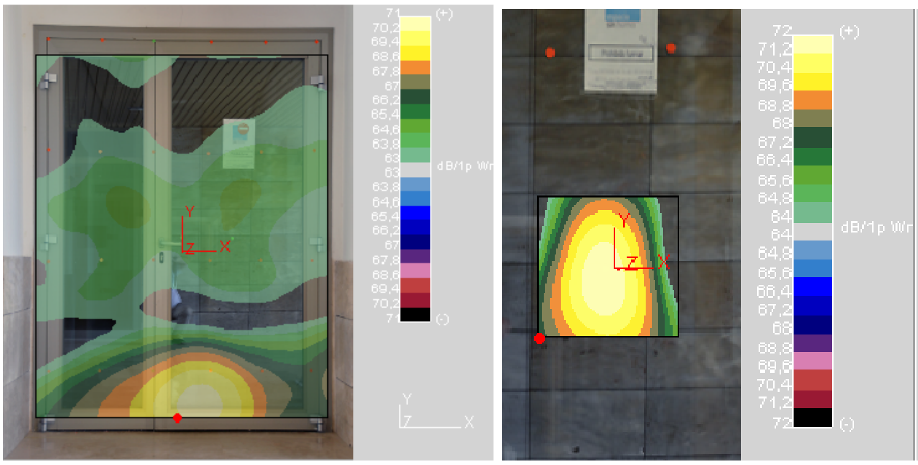

Figure 3: Results for the glass door. Left: Beamforming at the third-octave band of 4 kHz. Right: SONAH at the third-octave band of 160 Hz.

Figure 4: Results for the sheet door. Left: Beamforming at the third-octave band of 2 kHz. Right: SONAH at the third-octave band of 250 Hz.

in the lower chink. For SONAH, (figure 5 right), the map is quite uniform, as the measuring surface is homogeneous.

4 DISCUSSION

Next, the results for the apparent sound reduction index R'_I obtained from the standardized methods and the combination of Beamforming and SONAH are analyzed and compared.

The charts of the figure 6 reflect that the results for the wall from the standardized method

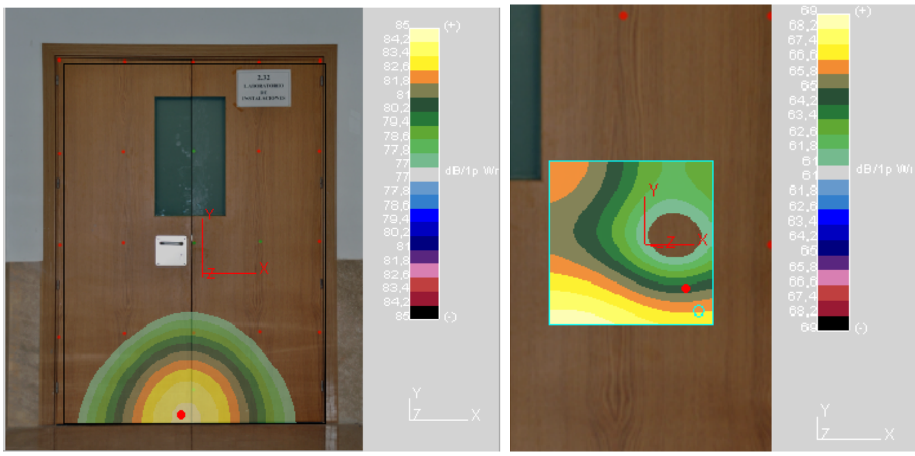

Figure 5: Results for the wooden door. Left: Beamforming at the third-octave band of 500 Hz. Right: SONAH at the third-octave band of 250 Hz.

match almost perfectly, given that the wall, as it has been mentioned, constitutes a reference element for the insulation analysis.

The results for the wall through Beamforming (figure 6 left) follow the trendline marked by the standard methods, but the numerical values obtained are slightly lower. This difference might be due to an overestimate of the sound power of the sound field in the receiving room, what would lead to an underestimate of the insulation, as the chart shows.

Regarding the SONAH measurement, the values obtained in comparison with the partial insulation values, considering only the intensity measured at that point (figure 6 right), are very similar. Nevertheless, the numerical values of insulation through SONAH are slightly higher (among 4-6 dB) to the partial insulation values.

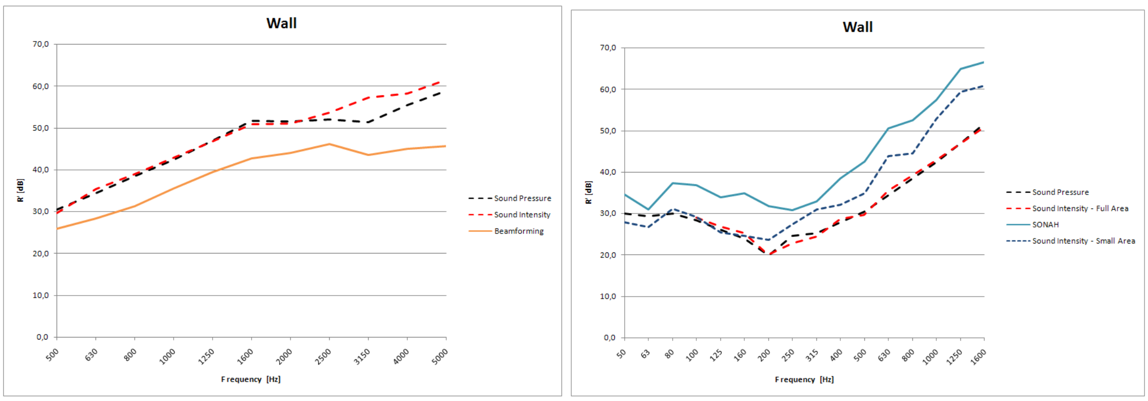

Figure 6: Comparison of sound reduction indexes for the wall. Left: Beamforming. Right: SONAH.

In the case of the glass door (figure 7) the trendlines for the sound reduction index are similar among the standard methods and Beamforming. In spite of that, the insulation decreases through Beamforming beyond 1600-2000 Hz in respect of the two other methods. This is due to an overestimate of the sound power caused by the contribution of the sidelobes of the array, what leads to a decrease in insulation.

For the SONAH measurement, the footprints of the glass surface through SONAH and the partial insulation through intensity are very closed in the whole frequency range of interest. The most important difference between the two methods is located beyond 160 Hz, as the partial insulation through intensity is 3-6 dB higher than that obtained through SONAH.

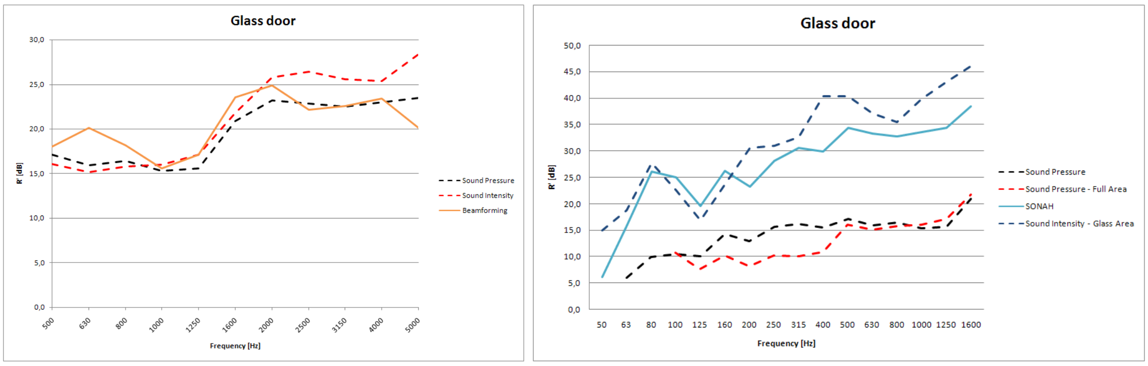

Figure 7: Comparison of sound reduction indexes for the glass door. Left: Beamforming. Right: SONAH.

Study of the sheet door (figure 8) reveals that the results through the standard methods match almost exactly, but with scarce numerical values differences. Moreover, those results compared with those obtained through Beamforming are very similar in the frequency range analyzed: they present the same trendline with slight numerical differences due to the sound field contribution again.

The results through SONAH are very close to those obtained through intensity, together for the sheet surface and the glass surface of the door.

Results for the wooden door (figure 9) present the higher differences among the standard methods and Beamforming at the frequency range between 500 and 5000 Hz. This is due to the fact that the receiving room was a narrow parallelepipedic corridor, what implies that the sound pressure becomes increased by the energy reflected in the nearby walls and this leads to an underestimate of the insulation.

The results through SONAH and intensity are very similar, given that the measurement is taken very near the separating element and, consequently, the effect of the room drops.

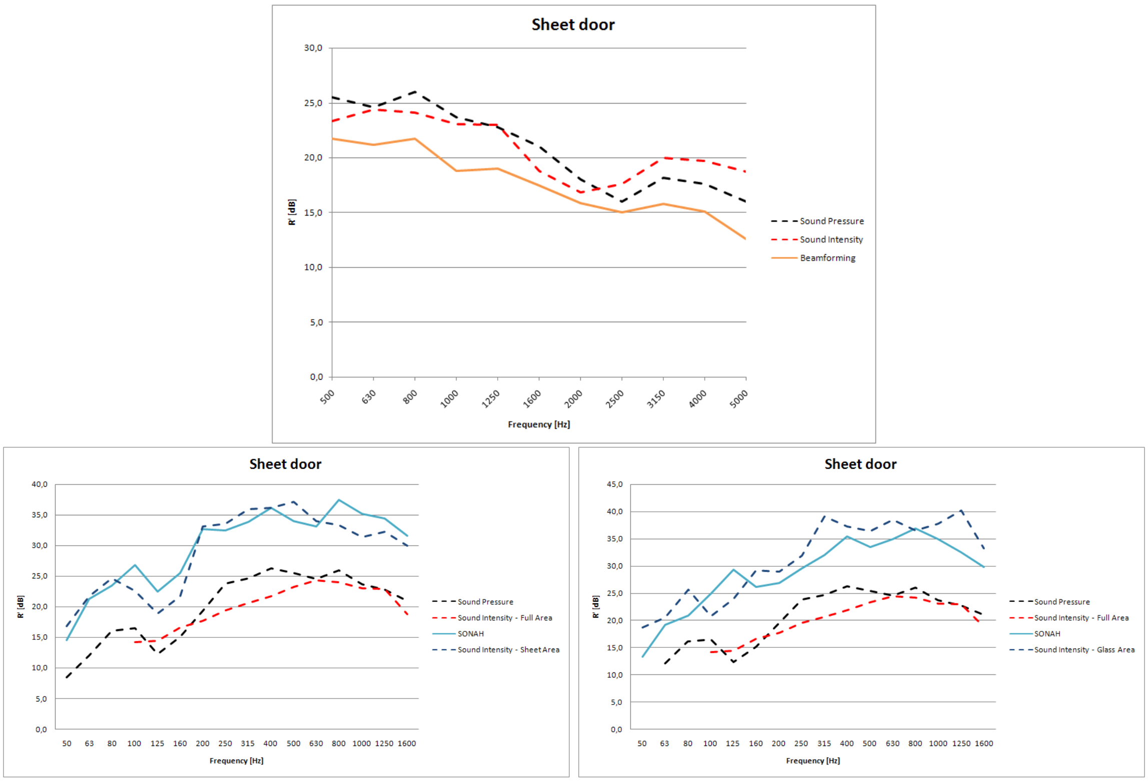

Figure 8: Comparison of sound reduction indexes for the sheet door. Up: Beamforming. Bottom Left: SONAH in the sheet surface. Bottom right: SONAH in the glass surface.

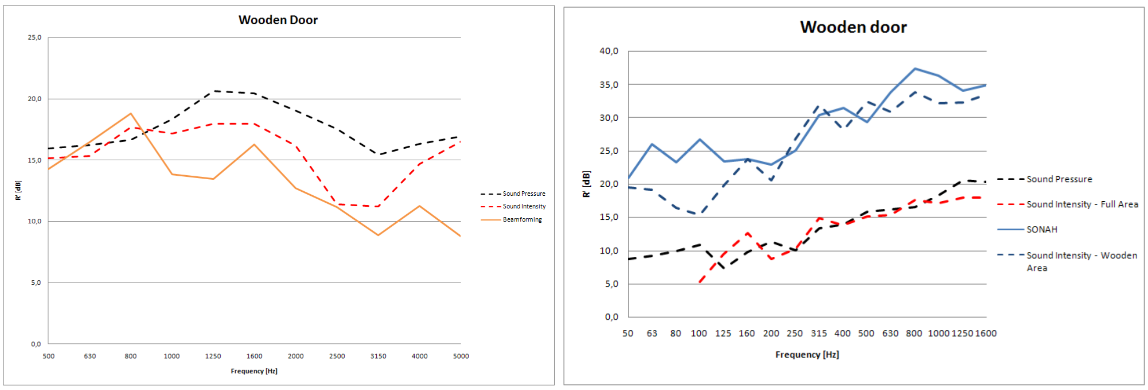

Figure 9: Comparison of sound reduction indexes for the wooden door. Left: Beamforming. Right: SONAH.

5 CONCLUSIONS

A combined measurement method through Beamforming and SONAH has been presented in the former sections to determine rapidly the sound insulation of separating elements that would make it possible also the assessment of areas with weaker insulation as well.

The following conlusions can be remarked for this study:

- Beamforming makes it possible to locate the points with the weakest insulation rapidly. Afterwards, SONAH can be used for a detailed analysis over those specific areas.
- The frequency range through Beamforming analysis is limited to approximately two octaves for applications based on insulation according to ISO standards. Therefore, its combination with SONAH becomes indispensable to increase the frequency range of interest.
- SONAH can only be properly applied over surfaces dependent on the size of the array. As a consequence, the use of this method for separating elements of big surface is difficult and complicated. Standard intensity method is more adequate for those cases.
- Beamforming overestimates the pressure due to the sound field contribution in case of narrow receiving rooms or big surfaces close to the array and hence, the insulation is underestimated. Because of that, Beamforming can be used as a valid method to assess the insulation in wide rooms, in the outside or where the edge receiving surfaces are very absorptive or are located far from the array position. This problem does not affect SONAH given the proximity to the surface under analysis.

Taking into account all the former, it can be stated that the proposed procedure is useful as an initial control method for a rapid preliminary evaluation of the insulation. If problems are detected, the standard methods of pressure and intensity have to be used, as despite being slower, they are more accurate in the determination of insulation.

Acknowledgements

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