Design of an Acoustic Anechoic Chamber for Application in Hearing Aid Research

MARC S. RESSL[1]
PABLO E. WUNDES[2]
GEDA (Grupo de Electrónica Digital Aplicada)
Buenos Aires Institute of Technology (ITBA)
Av. E. Madero 399, Buenos Aires
ARGENTINA
mressl@itba.edu.ar[1], pwundes@alu.itba.edu.ar[2]

Abstract: - An acoustic anechoic chamber is a shielded room designed for performing sound measurements under conditions close to free space. This short paper summarises the design and construction of a low cost anechoic chamber, with a focus on hearing aid research. Under these conditions, small scale and a predominant axis of measurement are the major factors of consideration. Insulation, absorption and construction issues are detailed and addressed, preliminary results and proposals for future work are included.

Key-Words: - anechoic chambers, sound insulation, sound absorption, sound measurements, hearing aids

1 Introduction

Acoustic anechoic chambers are environments with a high acoustic insulation from the nearby environment, used to measure systems under conditions close to free-space. Due to the generic requirements of these measurements, anechoic chambers tend to be of considerable size, in order to attain an acceptable response. This leads to high construction and maintenance costs, and the requirement of an appropriate physical space.

However, if an anechoic chamber is designed for a specific set of applications, many of these limitations can be overcome. In the context of the hearing aid project our group is engaged in, a chamber was required for measuring the response of two, possibly mismatched, microphones from a directional source.

In this context the physical size of the chamber can be kept within constraints, since the frequency range of interest is 250 Hz - 4000 Hz, small scales are predominant and a predominant axis of measurement is involved. The insulation of the chamber to external sources of sound and the reflective behaviour of the walls can also be given special consideration. It is even possible to comply with parts of ISO 3745 [1], a standard for performing sound pressure level measurements in anechoic rooms.

2 Chamber Design

2.1 Shape

Large anechoic chambers are usually constructed in the shape of a rectangular cuboid, mainly due to architectural limitations. Even though this set-up is prone to standing waves, the fundamental frequency of resonance is usually low enough to be disregarded.

In the case of a smaller chamber this effect is not negligible, thus a non-regular shape is preferred. In spite of this recommendation a rectangular cuboid was chosen as the shape of the design, as it simplifies simulation and construction.

2.2 Dimensions

The dimensions of the chamber are a critical design factor. If chosen wisely, the standing wave problem can be mitigated and certain parts of ISO 3745 can be observed.

For determining the internal width, height and length, a common scale was multiplied by three small prime numbers. This achieves a mix of standing wave modes that do not overlap in the frequency range of interest.

The chosen dimensions led to a volume of 1.103 m^3. ISO 3745 recommends a chamber volume (V_c) of at least 200 times the volume of the sound source (V_s), thus devices of up to 5515 cm^3 can be measured.

In order to find the chamber's cut-off frequency, the source is assumed to be directional, facing the major *d* dimension. In this case the geometric cut-off frequency can be obtained as [2]:

$$a + 4a + \lambda/2 + 2l_w = d \tag{1}$$

a represents the size of the sound source in the *d* dimension, and l_w is the wedge height (see 2.4 Absorption).

The sound source used in the set-up has $a = 0.1$ m. Solving for λ, the geometric cut-off frequency in the *d* direction is found to be 211.7 Hz. This falls below the lower frequency of interest.

2.3 Insulation

To determine the necessary acoustic insulation, the maximum SPL level at the site of our sound lab was determined with a Brüel&Kjær 2250 sound level meter. It was determined that the maximum SPL is 60 dB(A) in the frequency band of interest.

Simulations were initially carried out with a single wall insulation. If it is assumed that wave-fronts are flat, interfaces infinite and there is no dissipation, the transmission loss at the interfaces can be calculated as

$$TL = -10 \log_{10}(|T|^2) \tag{2}$$

T being the quotient of two phasors that represent the complex amplitude of the incident and transmitted pressure waves, respectively [3]. The wall width was varied in order to comply with the noise criteria curve NC-10.

The resulting width was unacceptably large, thus a double wall insulation was considered. Simulations were repeated for this configuration, and wall widths and separation were varied. Best values for these parameters were determined by constraining the first high frequency transmission zero above the maximum frequency of interest, and forcing the low-frequency zero to a low as possible value (Figure 1). The values found were 30 mm thickness for both walls, and 50 mm for the air gap.

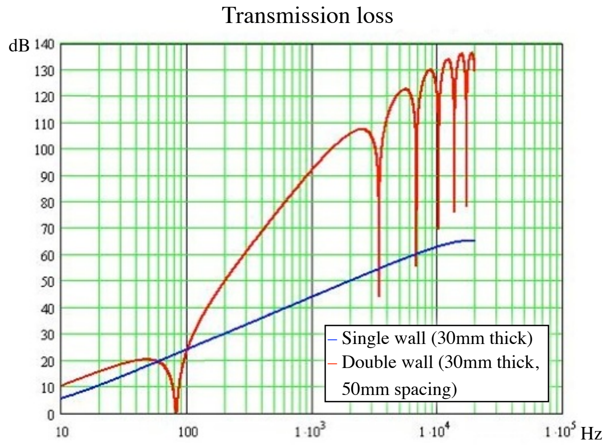

Fig. 1 - Single and double wall transmission loss

Transmission loss is also highly dependant on the wall material's density, increasing with materials of higher density. A survey of available materials was realised, and MDF (Medium Density Fibreboard) was determined to be the best material matching our constraints.

The choice of a double wall insulation results in a chamber that consists of a box inside a box (Figure 2).

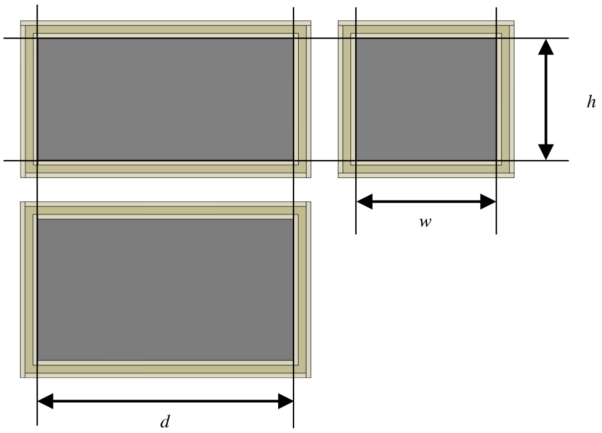

Fig. 2 - Chamber structure

In order to improve the characteristics of the chamber even further, glass wool was added to the air gap between the walls. The quality factor of such zeroes is quite high, thus a small amount of absorption is capable of mitigating the effect of these zeroes.

2.4 Absorption

To minimise echoes inside the chamber, an internal wall lining is necessary.

At first a survey of anechoic wedges was produced. Several factors were considered: absorption cut-off frequency, absorption coefficients, material, dimensions, shape and safety. None of the materials found on the local market was suitable, and importing foreign material was determined to be prohibitive. It was thus decided to design and construct our own anechoic wedges.

The design is based on Beranek's wedge structure *A* [4]. A very important design factor is wedge height, as it is directly correlated to the wedge's lower cut-off frequency. This frequency can be approximated by the following expression:

$$f_c = c / 4h \qquad (3)$$

where c is the speed of sound in the chamber, and h the height of the wedges [2].

In order to meet the lower frequency of interest, the value of h has to be at least 0.34 m. This, along with the geometric cut-off frequency and the requirement of a working space, imposes constraints on the smallest dimensions of the chamber.

Unfortunately the space in our lab was not sufficient for a larger chamber, so it was decided to lower the wedge height to 0.15 m. This raises the cut-off frequency of absorption to 571.6 Hz, and is above the lowest frequency of interest for our research. Even though a certain level of absorption is expected in the 250 Hz - 571.6 Hz region, the effect of this decision has yet to be evaluated.

A second design factor is the wedge's angle, a parameter related to base area. A small angle leads to a better acoustical gradient, yet a larger angle simplifies manufacturing, handling and mounting. It also reduces the total number of wedges necessary in the chamber.

Low-density polyurethane (25 kg/m^3) of low-stiffness was chosen as the material for the wedges. This material is commonly used for the purpose of absorbing sound, is easy to cut, easy to adhere to surfaces, and automatically fills voids, avoiding sound leakage. Fibreglass-based wedges were determined to be too expensive and difficult to manufacture. Melamine foam was also disregarded for being too costly.

The design is presented in Figure 3.

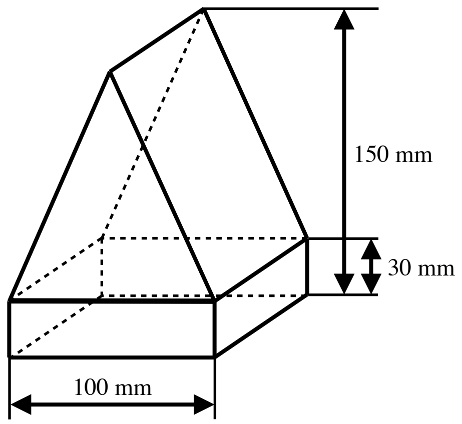

Fig. 3 - Anechoic wedge

The response of the wedges is yet to be evaluated. The intended method of measurement is the impedance tube method. A loudspeaker is located at one end of the tube, and the material at the other. Sound waves travelling down the tube are reflected on the material to be studied. By moving a microphone inside the tube, the pressure differences of the standing wave pattern inside the tube can be measured and used to calculate the amount of sound reflection.

For the purpose of a preliminary simulation of the chamber, the response of a commercial absorbing material resembling our design was used.

3 Simulation

The distribution of sound power inside the chamber was simulated in MATLAB with the source-image method. The method consists of replacing the chamber's walls with phantom sources, located at the equivalent geometric points from where the echoes of the walls would originate.

Only first reflections were considered in this work, thus six phantom sources were used.

The pressure distribution of a single source of frequency f is [5]:

$$p(r) = A \sin(\omega t + kr) \qquad (5)$$

where r is the distance to the source, and A follows the inverse square law.

It is very easy to calculate the power distribution by evaluating the pressure field at some arbitrary time t and at time $t + 1/(4f)$.

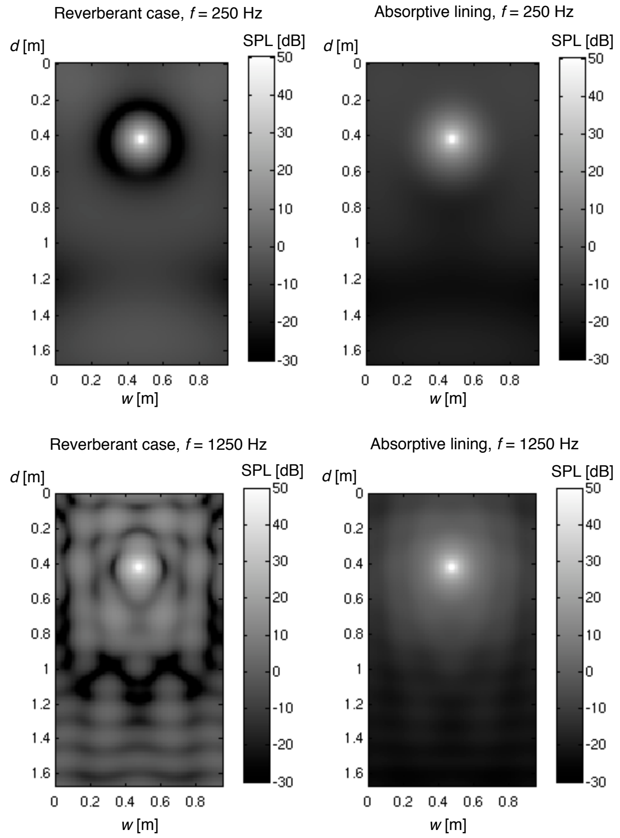

Fig. 4 – SPL simulations

The simulations were carried out for a source located at mid-width, mid-height and at a length of 0.44 m. Perfectly reflective walls (the reverberant case), and walls treated with our absorptive lining were compared. The frequency was swept within the range of frequencies of interest, and the horizontal distribution of power for different values of *h* (height) was calculated. The resulting power distribution was also compared to the distribution of the inverse square law.

It was determined that the best location for measurements is in the area close to the opposite corner of the chamber. There, variations in frequency response are minimal.

4 Construction

4.1 Structure

The parts of the structure were cut from industrial MDF panels with a computer controlled saw fence to 0.5 mm precision. The inner box was constructed on top of the base of the outer box, and properly sealed.

In order to isolate the inner box from the outer box, and to keep the necessary air gap of 50 mm, four double-deflection neoprene mounts of rated capacity 136-272 kg were used (the inner box's weight being 220 kg). Cork mounts were considered, but they did not match the working conditions.

The outer box was constructed last. Glass wool was added to the boxes' air gap.

4.2 Interface

In order to access the inside of the chamber some interface is necessary, both for physical access to the working area, as well as for transmitting power and signals.

For the purpose of physical access, a double door was devised for the front of the chamber. The inner door consists of a rectangular cut to the inner box's front panel, a rubber seal and a rectangular panel. This panel can be screwed tightly on top of the inner box, in order to guarantee a good seal. The outer door is constructed likewise but larger, so the inner door can pass through. Due to the larger weight of the outer door, a sliding mechanism was required (Figure 5).

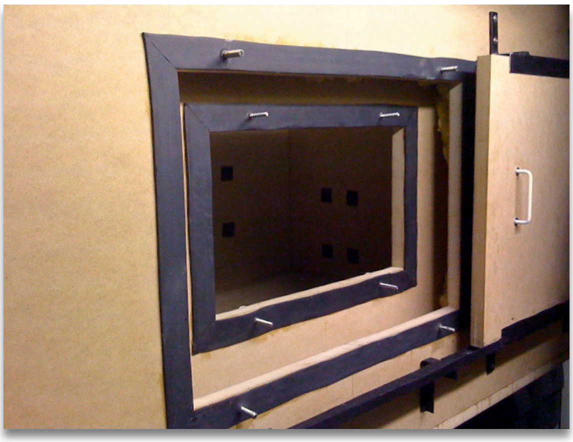

Fig. 5 – Access door

The electrical interface consist of power and shielded signal cables that were routed through sealed holes in the inner and outer boxes. Standard BNC connectors were used for signals.

4.3 Anechoic Wedges

The 450 wedges of polyurethane required for lining the inside of the chamber were fabricated using a pantograph hot-wire cutter.

Modules of 2x3 wedges were constructed by placing wedges in alternating orientations on top of a plywood base. The modules are fastened to the walls through Velcro. It is thereby easy to convert the anechoic chamber to a reverberant one.

Special care was given to covering the corners as well as possible. Where necessary, strips of polyurethane were applied. The wedges were also slightly compressed, in order to avoid sound leakage.

4.4 Stands

Small wooden stands were designed in order to locate the objects to be measured inside the chamber's working space.

5 Results

Preliminary measurements of the chamber show very promising results.

At this stage the outer box has not yet been sealed, nevertheless the acoustic insulation response (Figure 6) is superior to the insulation of a single wall insulation in the frequencies of interest. The response above 6 kHz is slightly below expectations. This result can be attributed to an improper seal of the inner box.

Preliminary impulse response measurements [6] show a T_{60} reverberation time of under 50ms. The frequency response was found to be flat within 3 dB in the frequency range of interest.

6 Conclusions

A design of a small, low-cost and application specific anechoic chamber was presented. Preliminary results are very promising, but several questions remain to be answered.

The first issue to be addressed is whether the effect of the geometric cut-off frequency in the directions of width and height do not pose a limitation to the usefulness of the chamber in low frequencies.

The absorption response of the custom-designed anechoic wedges is to be measured. It also remains to be seen what the effect of limiting the wedge height to 0.15 m is. The preliminary impulse response measurements look promising, but a proper study of the absorbing material should be carried out.

More simulation experiments should be realised, like calculating the mean and variance of the SPL among the frequency band of interest. It would also be of interest to determine the optimum chamber parameters through simulations.

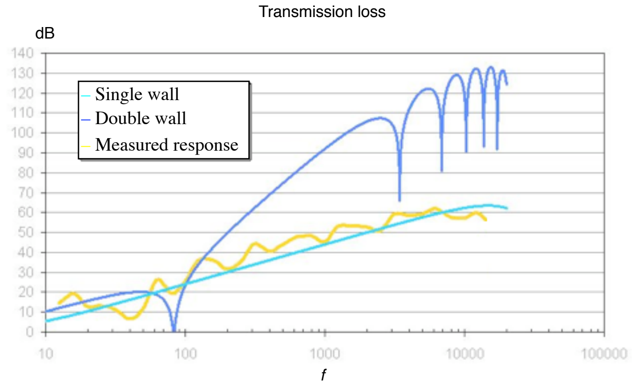

Fig. 6 – Preliminary insulation result
(outer box not sealed)

The simulations should be verified experimentally.

7 Acknowledgements

The authors gratefully acknowledge Pedro Bontempo and Marcelo García Barrese for their work in the design and construction of the anechoic chamber.

References:

[1] ISO 3745. Determinación de los niveles de potencia acústica de las fuentes de ruido a partir de la presión acústica. Métodos de laboratorio para cámaras anecoicas y semi-anecoicas.

[2] Blanco M., Herráez M (1993). Calificación de la cámara semi-anecoica del laboratorio de acústica y vibraciones de la ETS de Valladolid. SEA-TecniAcústica. p. 167-170.

[3] Blackstock D. (2000), Fundamentals of Physical Acoustics, Wiley.

[4] Beranek L., Sleeper H. (1946), The Design and Construction of Anechoic Sound Chambers, The Journal of the Acoustical Society of America

[5] Puep Ortega B., Romá Romero M. (2003), Electroacústica Altavoces y Micrófonos, Pearson Prentice Hall.

[6] Farina A. (2000), Simultaneous Measurement of Impulse Response and Distortion with a Swept-Sine Technique. AES2000.