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RESEARCH ON DESIGNING, MANUFACTURING AND VALIDATING A SEMI-ANECHOIC CHAMBER

Ioana Luminita DRAGASANU[1], Marius DEACONU[2], Mihnea MAGHETI[3]

The paper presents the study performed to design, construct and validate a semi-anechoic chamber that will be part of a new test bench for noise reduction. The test bench will be composed of two major components: the semi-anechoic chamber and an acoustic room that will host the acoustic source. The semi-anechoic chamber was designed up on the room in room principle, the floor is made of steel and validated according recommendations.

Keywords: semi-anechoic chamber, noise reduction, validation.

1. Introduction

Noise reduction is currently assessed using big test benches that are composed of two side by side reverberation rooms, with a minimum volume of $60m^3$, separated by a wall in which the test specimen should be positioned [1]. Having in mind the dimensions of testing facility and of the sample, the present paper focuses on the component of a new testing facility, much smaller: 900x900x2000 mm. The facility concept is the same: two rooms separated by a wall that accommodates the test specimen, just that one of the rooms is semi-anechoic.

An anechoic chamber has no reflexions, meaning that any noise generated at any frequency is completely absorbed. One of the elements that helps the designer to obtain the wanted acoustic environment is to consider big dimensions for the room. A smaller room necessitates a material with higher sound absorption properties, to have the same acoustic performances as in the big room's case. This is especially true for low frequencies and that is why the big rooms present good performances up to 100Hz [2].

The semi-anechoic chambers are the ones in which the free field environment is created above a reflecting plane. These have acoustic absorbents

[1] Eng., National Research and Development Institute for Gas Turbines COMOTI, Romania, e-mail: luminita.dragasanu@comoti.ro
[2] Eng., National Research and Development Institute for Gas Turbines COMOTI, Romania, e-mail: marius.deaconu@comoti.ro
[3] Eng., Universitatea POLITEHNICA Bucuresti, Romania, e-mail: mihnea.magheti@gmail.com

attached only on the room walls and ceiling, the floor being free of acoustic treatment. In the case of the present study the floor is a steel plate.

Validating such a chamber represents a complex process, of measurements, estimations and comparisons is a series of points distributed on certain directions inside it.

2. Design of anechoic and semi-anechoic chambers

The anechoic and semi-anechoic chambers must be designed so that the difference between the noise pressure level of a sound source and background noise is higher than 10dB. In order to increase the measurement precision, the background sound pressure level inside the anechoic chamber should be very low. In order to obtain this difference, the room in room concept is used. Beside this, the concept is also used to avoid introducing unwanted noise or vibrations inside the working area from the outside environment.

Usually, the interior acoustic treatment of the anechoic and semi-anechoic chambers is made of prismatic bodies with an acoustic sound absorption coefficient $\alpha \geq 0{,}95$ for all the frequencies of interest [3].

The purpose of the prismatic bodies/anechoic wedges is to partially absorb the sound wave and partially to reflect. Because of their sharp edges, the reflected wave is blocked between the adjacent wedges through a total reflection process, so that any part that is reflected by the niche is strongly attenuated [4], [5].

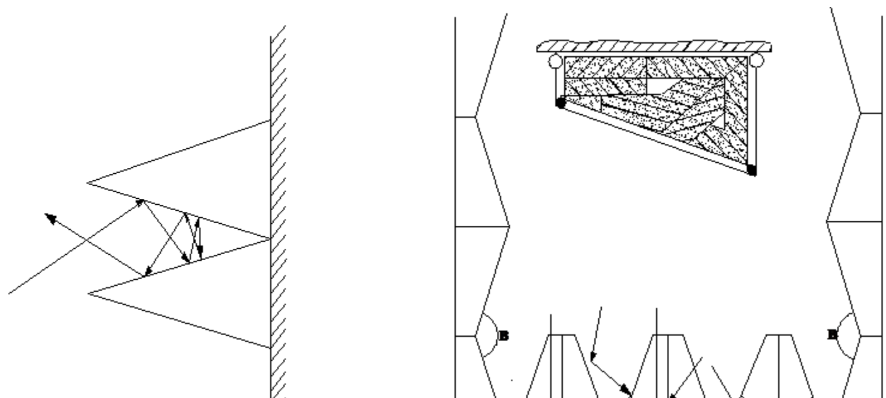


Fig. 1. Wave reflection (left - US Patent 4477505, right - US Patent 5141073)

The depth of an anechoic wedge is inversely proportional with the desired cut-off frequency. For lowering the cut-off frequency in order to obtain a sufficient sound absorption at low frequencies, the depth of the wedge must be increased proportionally with the wavelength corresponding to the desired cutting frequency.

The anechoic wedge’s length must not be smaller than ¼ from the cut-off frequency wavelength:

$$l \geq \frac{1}{4}\lambda \quad \Leftrightarrow \quad l \geq \frac{v}{4f}, \tag{1}$$

where v represents the sound speed in the considered environment, f is the desired cut-off frequency and l is anechoic wedge length.

As the cut-off frequency drops, the wave length of the cut-of frequency and the anechoic wedge length grow proportionally, and the room dimensions too.

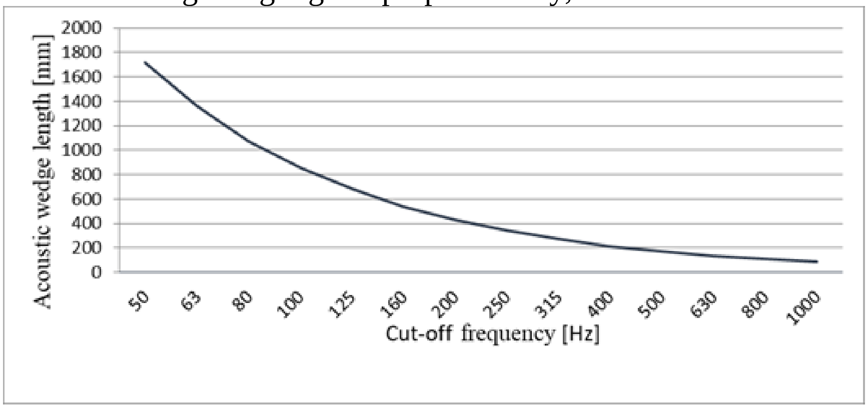


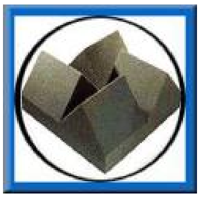
Fig. 2. Increase of the anechoic wedge length depending on the desired cutting frequency

Over time, several types of acoustic bodies were developed, different shapes and dimensions, that answer all the design requirements for the anechoic and semi-anecoic chambers, Figure 3.


Fiber glass wedges


Fonoabsorbent wedges in perforated sheet


Fonoabsorbant structures type E-Element


Acoustic foams (polyurethane foam and melamine)


Acoustic Liner type „Free field”

Fig. 3. Types of acoustic wedges and bodies

The phonoabsorbant structures type E-element, were developed by Alan Eckel and patented in 1998 under the number 5.780.785 [6]. This was designed to be an absorption body that will allow obtaining higher acoustic performances (Figure 4) so that the length of the classic wedges are reduced and so reducing the necessary space to achieve a lower cut-off frequency.

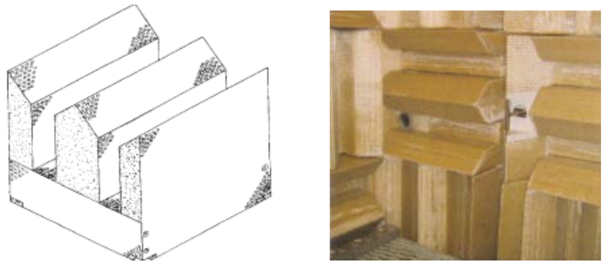


Fig.4. E-element structure - original model

To protect the absorbant structures during experiments, it has been chosen to cover them in perforated sheets. Depending on the application, the open area of the perforated sheet varies. Alan Eckel [6] proposes an open area between 23% and 52% of the total covered area of the E-element structure, while John Duda proposes an area of 7% [7]. Beside this very small open area, Duda proposes the existence of two air gaps: one between the base sticked to the wall and the exterior body and the second between the base and the exterior element. This concept is exemplified in Figure 5, where are presented also different shapes of the exterior element.

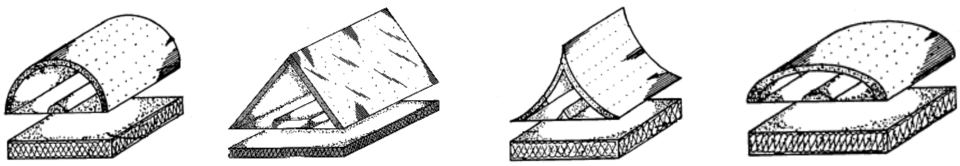


Fig.e 5. Anechoic elements proposed by John Duda

Starting from the studied anechoic and semi-anechoic chambers, and specially from the acoustic treatment applied, in the present study the pyramidal anechoic wedges and the prismatic anechoic bodies in two different dimensions were adopted, Fig. 6.

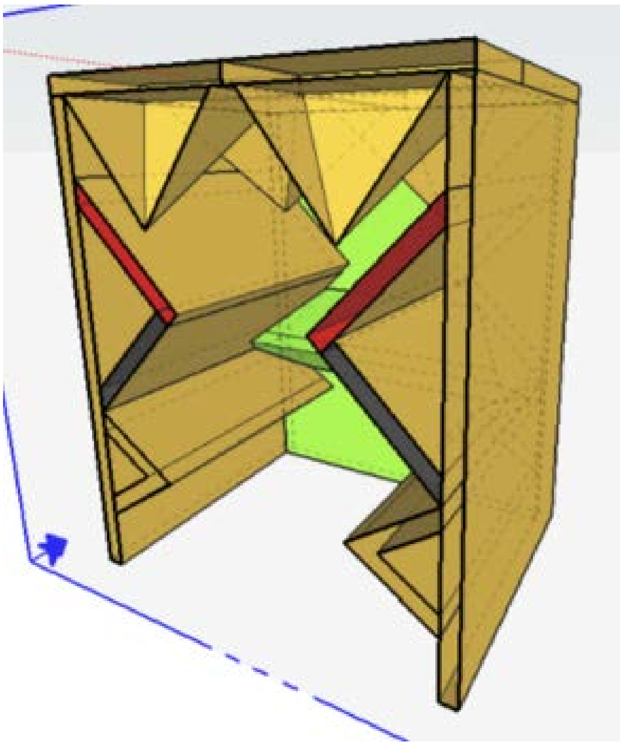


Fig. 6. The adopted acoustic treatment for the new test facility

Having in mind the purpose for which the semi-anechoic chamber was designed and realized, its final dimension is small, an unusual one for such chamber: 900x900x900mm.

The chamber's design was based on the room in room principle, the interior volume, without the acoustic treatment being of approximately 0,4m^3. The floor is represented by a steel sheet of 12mm that has an opening to accommodate the testing specimen.

3. Manufacturing the semi-anechoic chamber anechoic

Usually the walls of an anechoic and semi-anechoic chamber are made of concrete. Starting from the necessity of having a good mobility of the chamber, making it from concrete was not a feasible option, the final mass being too high to make it easy to manipulate. Thus, it has been chosen to use plywood of 12 mm for both exterior and interior walls. Between the two walls fiber glass was used together with Echophone of 15m. The interior walls were covered with Echophone of 30mm, on which the anechoic structures were mounted. The microphone that is used for measurements is introduced in the semi-anechoic chamber through a pipe.

Fig. 7. Manufacturing the semi-anechoic chamber

4. Validation of the semi-anechoic chamber

The verification of the acoustic environment of the anechoic and semi-anechoic chambers consists in determining the way the acoustic pressure of a sound source decreases, and compare it with the way the acoustic pressure decreases with the distance to source, according with inverse-square law [8].

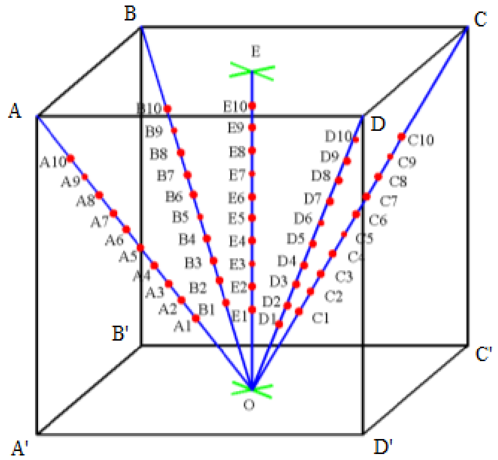


Figure 8. Measurements points for the acoustic pressure inside the chamber to be validated.

Considering the ABCDA'B'C'D' parallelepiped as being the remaining useful volume after the acoustic treatment is applied, the OA, OB, OC, OD and OE segments (Figure 8) are considered the 5 trajectories on which to measure the acoustic sound pressure, in 9 points on each segment.

Thus, for one direction, OA for example, the acoustic pressure levels estimated for each point will be determined with:

$$\begin{cases} L_p\left(OA_1\right) = 20\lg\left[\dfrac{a}{OA_1 - r_0}\right] \\ \dots \\ L_p\left(OA_{10}\right) = 20\lg\left[\dfrac{a}{OA_{10} - r_0}\right] \end{cases}, \quad (2)$$

where a is calculated with the following relation:

$$a = \frac{(OA_1 - OA_{10})^2 - 10\left(OA_1^2 + \dots + OA_{10}^2\right)}{\left(OA_1^2 + \dots + OA_{10}^2\right)\left(\left(10^{-0.05Lp_1}\right)^2 + \dots + \left(10^{-0.05Lp_1}\right)^2\right) - 10\left(OA_1 \cdot 10^{-0.05Lp_1} + \dots + OA_{10} \cdot 10^{-0.05Lp_{10}}\right)}, \quad (3)$$

and r_0 according with:

$$r_0 = \frac{\left(OA_1 + \ldots + OA_{10}\right)\left(OA_1 \cdot 10^{-0.05Lp_{A1}} + \ldots + OA_{10} \cdot 10^{-0.05Lp_{A1}}\right) - \\ -\left(OA_1^2 + \ldots + OA_{10}^2\right)\left(10^{-0.05Lp_{A1}} + \ldots + 10^{-0.05Lp_{A1}}\right)}{\left(OA_1 + \ldots + OA_{10}\right)\left(10^{-0.05Lp_{A1}} + \ldots + 10^{-0.05Lp_{A1}}\right) - \\ -10\left(OA_1 \cdot 10^{-0.05Lp_{A1}} + \ldots + OA_{10} \cdot 10^{-0.05Lp_{A1}}\right)}, \quad (4)$$

Finally, deviations from the law will be assessed in accordance with:

$$\Delta L_{pA1} = \underbrace{L_{pA1}}_{measured} - \underbrace{L_p\left(OA_1\right)}_{estimated}, \quad (5)$$

and the obtained results will be compared with the deviation limits.

It should be borne in mind that the comparison of deviations should take into account the values recorded for each frequency of interest, for each individual point.

For each direction the measurements were made and the estimated values for each sound pressure level were determined, all the values obtained for the deviations from the law, for the OA direction being presented in the following tables.

Table 1

Measured and estimated values for OA direction

Measured values [dB]									
F [Hz]	Lp A1	Lp A2	Lp A3	Lp A4	Lp A5	Lp A6	Lp A7	Lp A8	Lp A9
500	82.1	81.8	80.2	80.8	80.3	80.5	76.7	76.7	75.6
630	85.7	85.9	84.4	85.8	85.5	85.7	82.5	82.8	81.6
800	89.5	89.6	88.4	89.6	89.4	89.6	86.9	87.3	86.3
1000	88.5	87.7	85.4	86.6	85.8	86.4	83.6	83.5	82.8
1250	91.0	91.1	86.4	88.0	87.3	88.0	85.9	85.5	85.2
1600	94.5	94.9	90.0	90.0	90.6	90.6	88.3	88.6	88.1
2000	89.6	90.3	87.5	84.6	85.8	85.2	83.3	83.5	83.3
2500	94.4	94.6	90.4	88.3	90.3	88.5	87.2	86.9	87.2
3150	95.2	94.1	88.9	88.6	90.4	88.8	88.2	87.7	88.1
4000	94.2	94.5	89.7	89.5	89.6	88.5	87.9	87.4	88.2
5000	94.1	95.2	94.5	94.8	94.4	94.5	92.8	92.6	92.8
6300	92.8	94.2	94.4	94.1	94.3	94.0	92.0	91.8	92.2
8000	93.1	90.2	92.5	92.0	91.9	92.2	91.9	91.3	92.0
10000	92.6	90.4	91.3	89.9	91.0	90.2	90.7	90.4	90.4

Estimated values [dB]									
F [Hz]	Lp A1	Lp A2	Lp A3	Lp A4	Lp A5	Lp A6	Lp A7	Lp A8	Lp A9
500	83.4	82.1	81.0	80.0	78.3	79.1	77.6	76.9	76.3
630	86.7	86.0	85.4	84.8	83.8	84.3	83.3	82.8	82.4
800	90.2	89.7	89.3	88.8	88.0	88.4	87.7	87.3	87.0
1000	88.5	87.6	86.8	86.1	84.8	85.4	84.2	83.6	83.1
1250	90.4	89.5	88.7	88.0	86.8	87.4	86.2	85.6	85.1
1600	93.8	92.8	91.9	91.1	89.6	90.3	89.0	88.4	87.8
2000	89.7	88.4	87.4	86.4	84.8	85.6	84.1	83.4	82.8
2500	93.8	92.4	91.3	90.3	88.5	89.3	87.8	87.1	86.4
3150	93.0	92.0	91.2	90.4	89.0	89.7	88.4	87.8	87.2
4000	93.2	92.2	91.2	90.4	88.9	89.6	88.3	87.7	87.1
5000	95.1	94.8	94.5	94.2	93.6	93.9	93.4	93.1	92.8
6300	94.3	94.0	93.8	93.5	93.0	93.2	92.8	92.5	92.3
8000	92.0	91.9	91.9	91.9	91.8	91.9	91.8	91.8	91.8
10000	91.4	91.2	91.0	90.9	90.6	90.7	90.4	90.3	90.2

Table 2.

Verification of the anechoicity deviation from OA direction

F [Hz]	A1	A2	A3	A4	A5	A6	A7	A8	A9	Limit deviation
500	1.3	0.3	0.8	0.8	2.0	1.4	0.9	0.2	0.7	± 2.5
630	-1.0	-0.1	-1.0	1.0	1.7	1.4	-0.8	0.0	-0.8	
800	-0.7	-0.1	-0.9	0.8	1.4	1.2	-0.8	0.0	-0.7	± 2
1000	0.0	0.1	-1.4	0.5	1.0	1.0	-0.6	-0.1	-0.3	
1250	0.6	1.6	-2.3	0.0	0.5	0.6	-0.3	-0.1	0.1	
1600	0.7	2.1	-1.9	-1.1	1.0	0.3	-0.7	0.2	0.3	
2000	-0.1	1.9	0.1	-1.8	1.0	-0.4	-0.8	0.1	0.5	
2500	0.6	2.2	-0.9	-2.0	1.8	-0.8	-0.6	-0.2	0.8	
3150	2.2	2.1	-2.3	-1.8	1.4	-0.9	-0.2	-0.1	0.9	
4000	1.0	2.3	-1.5	-0.9	0.7	-1.1	-0.4	-0.3	1.1	
5000	-1.0	0.4	0.0	0.6	0.8	0.6	-0.6	-0.5	0.0	
6300	-1.5	0.2	0.6	0.6	1.3	0.8	-0.8	-0.7	-0.1	± 3
8000	1.1	-1.7	0.6	0.1	0.1	0.3	0.1	-0.5	0.2	
10000	1.2	-0.8	0.3	-1.0	0.4	-0.5	0.3	0.1	0.2	

For OB, OC, OD and OE the same procedure was used as in the case of OA direction.

5. Conclusions

One can observe that for each direction satisfactory values were obtained. For points where limit deviations are not met, an analysis of the error sources can be made, the most important being the precision with which the microphone is positioned. It was observed during tests, an increased elasticity of the stem used to fix the microphone to the measuring position. Furthermore, it must be considered the uncertainty of the measurement method. A quick evaluation of the uncertainty, only based on the B type uncertainties (introduced only by the measurement equipment), reveals that the measurement equipment may introduce 0,5 dB. This value covers the differences obtained.

Even if a number of 18 values do not respect the limit deviations, from a total of 630, it can be concluded that their number is small (under 3%) and the chamber can be considered semi-anechoic.

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