DEVELOPMENT OF A PORTABLE ANECHOIC CHAMBER AND CHARACTERIZATION USING REVERBERATION TIME

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Reverberation time measurement technique is in general used to understand building acoustics and response of acoustic liners. However, the background noise level is used to characterize an anechoic chamber. For that a free field microphone is required having high bandwidth and response to very low noise level, which is expensive. Quoting the statement “necessity is mother of invention”, present research aims to characterize a portable anechoic chamber by using reverberation time measurement using a microphone. The paper has two sections. First section describes the fabrication of a portable anechoic chamber and the second section describes the characterization of the chamber using reverberation time. In this section, a customized measurement technique has been proposed using a novel signal processing technique, based on pseudo sampling, which enhances the performance in measuring very low reverberation time such as $T60 \approx 0.02$ seconds in total spectrum and in octave bands. The octave band analysis also helped to understand the frequency bandwidth of the chamber for measurement. Subsequently, acoustic insertion loss across a finite sonic crystal has been measured in this chamber. The measurement has been evaluated numerically in a non-reflecting acoustic domain by applying characteristic acoustic impedance on the acoustic domain wall. The numerically estimated results agree to experimentally measured data up to large extent. From this exercise, it has been inferred that the portable anechoic chamber wall is equivalent to a nonreflecting boundary. Summarizing, the proposed reverberation time measurement technique can be used to characterize any anechoic chamber.

1. Introduction

The acoustics of any chamber in general estimated from the measured reverberation time following ASTM or ISO standards. In general, the reverberation time is more for a reverberant chamber or chamber having acoustically reflective wall and less for a chamber having acoustic absorbing liner. In general, the reverberant room and anechoic chamber are used for different kind of acoustic measurement following various standards. However, it is difficult to characterize such chambers in deterministic nature [1-4].

The anechoic chamber is extremely essential in measuring acoustic properties of any reflecting and scattering surfaces of large object. The Accurate measurement is only possible in the presence of least acoustic reflection from walls. In general researchers use open field environment to do such measurements. However, in such situation the acoustic reflection from ground cannot be eliminated. The most complex part of an anechoic chamber is its size and cost. In present industrial growth sce-

narios, the requirement of portable anechoic chamber is essential to measure the acoustic properties radiation from any product. The present research initiated with a requirement of measuring accurate acoustic insertion loss of a finite sonic crystal. In order to achieve the desired result a portable anechoic chamber has been felt indispensable. The fundamental characteristics of an anechoic chamber is non-reflecting acoustic surfaces and very low back ground noise. Researchers already tried to characterize such chambers as full anechoic or hemi-anechoic chambers in various method [3-8].
From literature, it can be noticed that many acoustic measurements are more reliable in an anechoic environment over impedance and transmission loss tube method [7,8] particularly for building acoustics. Moreover, the design and fabrication of standard anechoic chamber is enormously expensive and the instrumentation needs very high band width of acoustic sensor as the back ground sound pressure level is quite low. The present work explains the design and fabrication of a portable anechoic chamber, laboratory level and its characterization using measurement of reverberation time.

2. Reverberation time and measurement

In present work the reverberation time has been measured following ASTM C423 standard. In brief, a noise source and a microphone is used to generate and capture acoustic signature. In each measurement, the average decay curve can be defined as [1]:

$$\left(L_i\right)=\frac{1}{N}\sum_{j=0}^{N}L_{i,j},\ i,j\in\mathbb{N} \tag{1}$$

Where, $\left(L_i\right)$ is the average of the sound pressure levels measured at the i^{th} data point in each of N decays, and N is the number of decay points, at least 50. The $L_{i,j}$ is the sound pressure level measured at the i^{th} data point during the j^{th} decay. In every measurement band, the first data point to be used to calculate the decay rate shall be the first data point for which integration begins at least 100 to 300 ms after the test signal was turned off. In each measurement band the number of data points in the average decay, M, shall be the maximum value of the index, i, for which: $\left(L_1\right)-\left(L_i\right)\le 25dB.$
The operational definition for the decay rate is the negative of the slope of the linear, first-order regression on the average decay curve of Eqn.1. The expression for the decay rate is:

$$d'=\frac{6}{M\left(M^2-1\right)\Delta t}\left[\left(M+1\right)\sum_{i=1}^{M}\left(L_i\right)-2\sum_{i=1}^{M}i\left(L_i\right)\right] \tag{2}$$

where, d' is the decay rate, dB/s. The general reverberation time has been calculated based of the decay rate such as time taken for 60dB is called T_{60}. However, two significant complexities can be observed to calculate particularly T_{60}. One is band width of acoustic sensor and second is noise source level which should be above ~80 dB over ambient noise, so that the T_{60} can be measured. In order to avoid such situation, normally, the T_{60} used to be calculated by $2\times T_{30}$ or $3\times T_{20}$. Moreover, for characterizing and anechoic chamber $6\times T_{10}$ has been used in present experiment.
The another major issue that has been observed particularly for an anechoic chamber is the decay rate. Though the acoustic sampling is high still the intuitive T_{60} for a dead room is in general less than 0.1 seconds. The acoustic sub sampling has been used to generate pseudo samples to estimate sound pressure level as accurate as possible.

3. Fabrication of portable anechoic chamber

On necessity, the design and fabrication of a portable anechoic chamber has been carried out. Due to constraint of fund, and the necessity of the desired experiments, the internal volume has been set $\geq 8\ m^3$. The outer dimension of the chamber has been kept ~14.7 m^3. The chamber has been made in three layers. First the outer layer has been made with wooden beams and 19mm plywood. The beams have been given to increase the strength of the chamber. The second layer is perforated sheet backed with 50mm rock wool panel. The perforated sheets are having ~30-35% perforation and 0.5mm thickness. The rock wool slabs are kept in a fabric blanket and backed with perforated sheet. Next, the internal cavity has been lined with acoustic wedges made with charcoal foam having 200mm height of wedges. The panel size was 4 square feet. The panels have been mounted in all six sides of the cavity using glue. In base a netted bed has been mounted to walk on top of the wedges. The fabricated anechoic chamber can be seen in below figure.

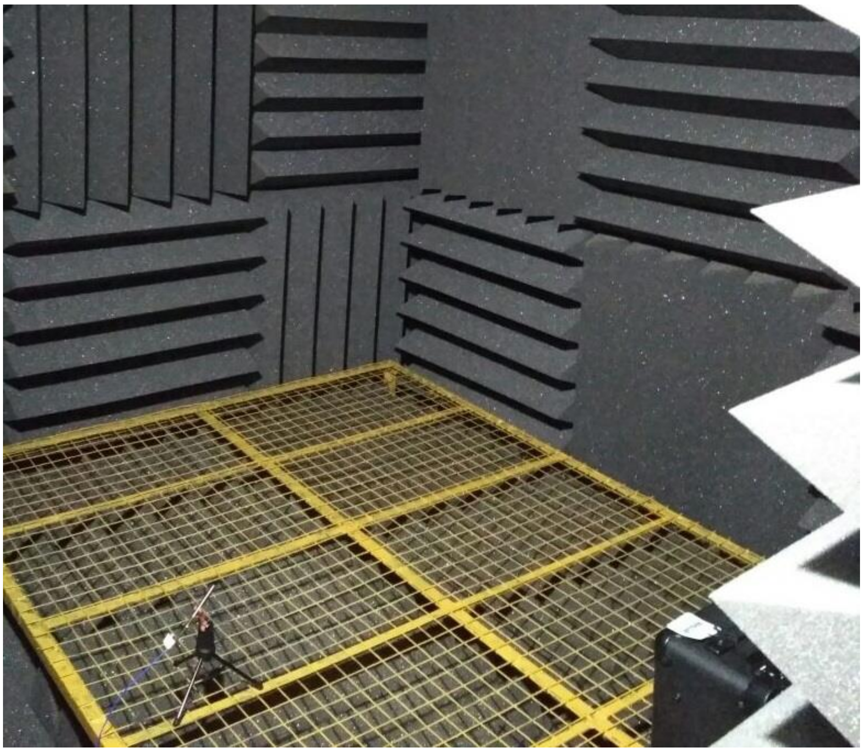


Figure 1. Fabricated portable anechoic chamber.

4. Experimental investigation

Next, the challenge of characterizing the anechoic chamber has become indispensable. A novel attempt has been made to characterize the anechoic chamber using a noise source (Ahuja© PA system) and PCB© make array microphone. The noise has been generated using National Instruments© (NI) cDAQ 9234© and the acoustic signature has been captured using NI-9234© module. A customized LabVIEW application software has been developed to measure the reverberation time. The developed graphical user interface (GUI) has been shown in Fig.2. The sampling of acoustic signal acquisition has been kept the maximum capability of the data acquisition (DAQ) board such as 51200 samples/second and the microphone has been calibrated using a class one calibrator CLA-200 PCB© make.

As discussed earlier section, the source has been kept in centre of the chamber and a white noise has been generated for 30 seconds to reach a steady state sound pressure level (SPL). Once the steady state SPL has been achieved the source has been stopped and the acoustic signal for next 5 seconds have been captured. From first observation, it has been observed that the time taken for decaying

30dB sound is almost less than 0.1 second, which is general time resolution used to measure the reverberation time. Next, an algorithm has been developed to measure the SPL level at 0.001 second resolution by introducing proposed pseudo sampling technique discussed in earlier section.

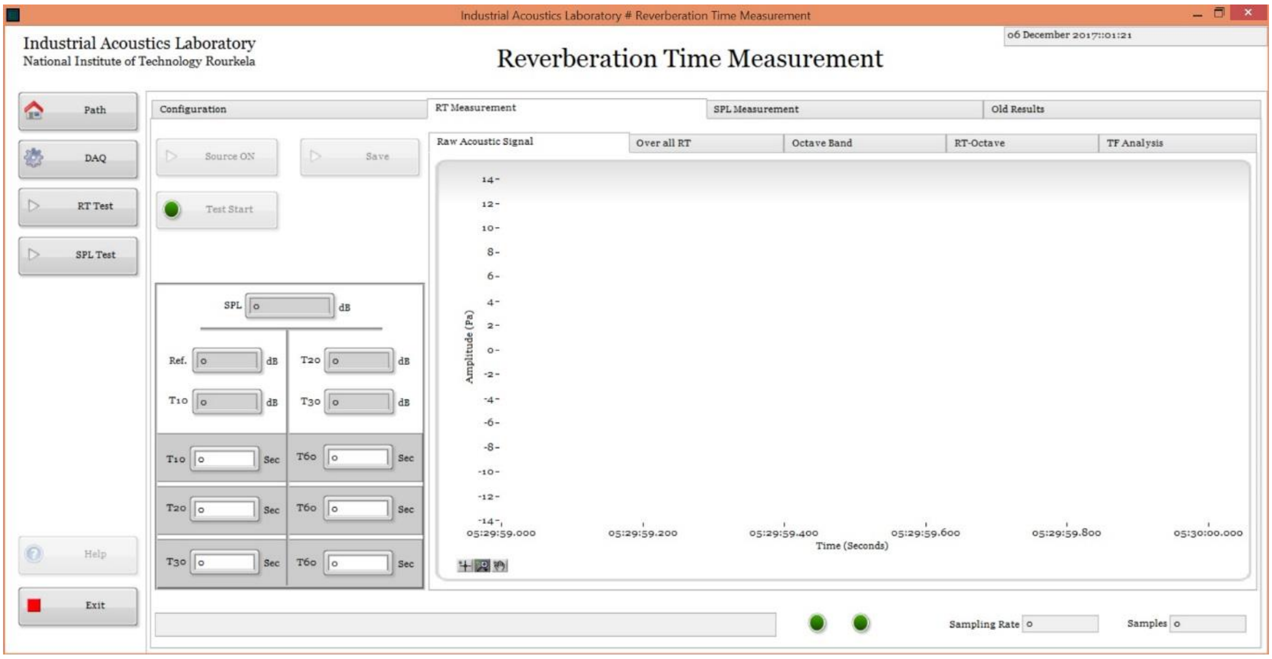


Figure 2. Application software GUI to measure the reverberation time.

Next, the measurement has been carried out with proposed methodology. The observed overall reverberation time (RT) is less than observed ~0.025 seconds. Moreover, the T_{60} have been calculated for 1/3rd octave band, shown in Fig.3. From table it can be perceived that the T_{60} for different octave band is ~ 0.02 seconds in cutoff frequency zone. The observed RT vale is quite low than in general perceived the RT of a dead room such as 0.1 seconds [2].

5. Case study

Next, the performance of the anechoic chamber has been evaluated by a case study. For investigation a sonic crystal has been fabricated. The sonic crystal is made with four rows and six columns, comprised with 24 circular cylindrical scatterers of height 310mm, having diameter 42mm and having lattice constant 21mm. The crystal has been made with PVC pipes which have been fixed with a wooden base plate using glue. The top of the crystal has been covered with acoustic absorber such as glass wool panel. Next, the sonic crystals have been placed inside a portable anechoic chamber. Two different boundary conditions have been tested such as rigid top and absorber top. Two calibrated PCB© make microphones have been used to measure the sound pressure before and after the sonic crystal. The noise source has been kept 0.65m away from the crystal. A Dayton© audio make speaker amplified with Ahuja© amplifier has been used as noise source. The white noise has been generated from the noise source. The acoustic signals have been captured at 51200 samples/second to measure sound pressure level (SPL). The acoustic insertion loss has been measured by subtracting the SPL level in Octave band and power spectral density.

Next, a simulation has been carried out to estimate the acoustic insertion loss of a sonic crystal [5,6]. The 2D geometry has been meshed with customized triangular elements having element length one tenth of the wavelength of the maximum desired frequency. Assuming there is no acoustic reflection from the wall, the acoustic domain boundary has been applied with acoustic characteristic impedance. The walls of the scatterers have been considered as rigid wall or perfectly reflecting surface. The noise source has been simulated by applying a line of oscillating pressure of 1 Pa. The frequency domain analysis has been carried out with a frequency resolution of 2 Hz.

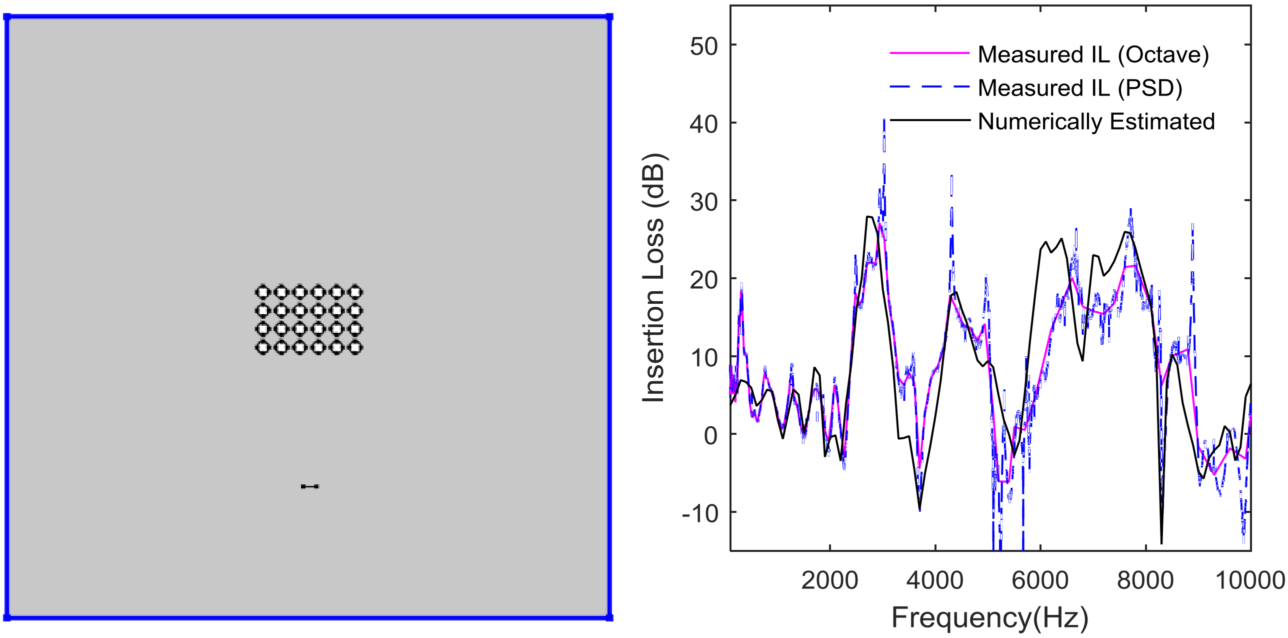
Freq. (Hz)	T_{10}	T_{20}	T_{30}	$T_{60}[T_{10}]$	$T_{60}[T_{20}]$	$T_{60}[T_{30}]$
20	0.008	0.0149	0.0518	0.0478	0.0448	0.1036
25	0.008	0.0129	1.279	0.0478	0.0388	2.558
32	0.008	0.0129	0.0568	0.0478	0.0388	0.1136
40	0.008	0.0129	[illegible]	[illegible]	0.0388	0.1116
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
63	0.008	0.0129	0.0548	[illegible]	0.0388	0.1096
80	0.007	[illegible]	[illegible]	[illegible]	0.0359	0.1076
100	0.007	0.012	0.0518	0.0418	0.0359	0.1036
125	0.007	0.012	0.0518	0.0418	0.0359	0.1036
160	0.007	0.012	0.0498	0.0418	0.0359	0.0996
200	0.006	0.011	0.0498	0.0359	0.0329	0.0996
250	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0996
315	0.006	0.011	[illegible]	0.0359	0.0329	0.0956
400	[illegible]	0.01	[illegible]	[illegible]	[illegible]	[illegible]
500	0.006	0.01	0.0458	0.0359	0.0299	0.0916
630	0.005	0.009	0.0299	0.0299	0.0269	0.0598
800	0.004	0.007	0.0209	0.0239	0.0209	0.0418
1000	0.004	0.008	0.0159	0.0239	0.0239	0.0319
1250	0.005	0.008	0.0189	0.0299	0.0239	0.0379
1600	0.005	0.008	0.0129	0.0299	0.0239	0.0259
2000	0.005	0.008	0.011	0.0299	0.0239	0.0219
2500	0.004	0.007	0.011	0.0239	0.0209	0.0219
3150	0.004	0.007	0.01	0.0239	0.0209	0.0199
4000	0.003	0.006	0.009	0.0179	0.0179	0.0179
5000	0.004	0.007	0.011	0.0239	0.0209	0.0219
6300	0.004	0.006	0.009	0.0239	0.0179	0.0179
8000	0.004	0.006	0.009	0.0239	0.0179	0.0179
10000	0.004	0.006	0.009	0.0239	0.0179	0.0179

1/3rd Octave Center Frequencies

Source Cutoff Frequency 175-8000 Hz

Cutoff Frequency of Chamber Size ≤ 400 Hz

Figure 3. Reverberation time T_{60} in octave band using T_{10}, T_{20} and T_{30} time.



(a) (b)

Figure 4. Acoustic analysis of a sonic crystal; (a) simulation environment, and (b) estimated and measured acoustic insertion loss (IL).

Two boundary probes, mimicking the microphone positions, have been placed on both sides of the crystal to estimate the acoustic insertion loss (IL) across the sonic crystal, which is equal to acoustic transmission loss (TL) in present case. The estimated acoustic IL has been shown in Fig.4(b). From figure, it can be noticed that the numerically estimated results agree to experimental results adequately. From this it can be inferred that the boundary load that is a nonreflecting acoustic surface is equivalent with present portable anechoic chamber.

6. Conclusion

Summarizing, a portable anechoic chamber cane be fabricated using multi-layer acoustic material such as wood panel, rook wool slab, perforated sheet followed by acoustic wedges. The cut-off frequency of the anechoic chamber largely depends upon the size of the chamber and acoustic liners used in the chamber. The standard method of measuring reverberation time has been tweaked to measure the T_{60} for a highly acoustic absorbing room. The demonstrated reverberation time of the chamber is ~0.02 second for different one third octave bands which is quite acceptable. The performance of the chamber has been estimated by evaluating the acoustic insertion loss of a finite sonic crystal. The measured and estimated results agree up to large extent. So, concluding the acoustic characterization of an anechoic chamber can be done by measuring the reverberation time and the desired T_{60} for such chamber should be less than 0.02seconds to achieve adequate acoustic measurement performance.

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