Determination of Absorption Coefficient of Acoustic Materials by Prototype Impedance Tube

[1]Vishalagoud. S. Patil, [2]Dr. S. N. Kurbet
[1]Assistant Professor, [2]Professor
[1]Government Engineering College, Haveri, Karnatakastate, India,
[2]Basaveshwar Engineering College, Bagalkot, Karnataka state, India

Abstract - **The paper presents a completely new measurement technique of the sound absorption properties of materials, based on the measurements of active intensity and sound energy density. A noise itself is a signal which conveys information about the source of the noise. Noise is present in many degrees in almost all environments. The reduction of noise because of vibration of parts of the body of a vehicle is a challenging task. Acoustic materials are the most common means of reducing the sound or noise generated. Impedance tube is an instrument by which the property like absorption capacity or coefficient of the materials can be determined by using microphone sensors. The prototype of impedance tube instrument is made and then different acoustic materials are tested similar to actual impedance tube working procedure. The results obtained are more realistic to impedance tube results.**

keywords - **Absorbers, impedance, acoustic, SPL, noise, intensity etc.**

I. INTRODUCTION

Sound is generated due to many reasons. If it is within the audible range, then it can be neglected. If the sound increases beyond the audible range of human ears for example above 90 dB, then it requires a special treatment to reduce it according to the operating conditions. Dampers, barriers and absorbers are the materials used to attenuate the noise generated. Hence, acoustic materials are used all over the world for reducing the noise inside the automobiles. Sound-absorbing materials absorb most of the sound energy striking them and reflect very little [1]. Sound absorbing materials are used in most of the areas of noise control engineering to reduce sound pressure levels. The function of absorptive, silencers and barrier materials is to absorb airborne sound waves [2]. To use them effectively, it is necessary to:

- Identify the important physical attributes and parameters that cause a material to absorb sound.
- Provide a description of the acoustical performance of sound absorbers used to perform specific noise control functions.
- Develop experimental techniques to measure the acoustical parameters necessary to measure the acoustical parameters of sound absorbing materials and the acoustical performance of sound absorbers.
- Introduction of sound absorbing materials in noise control enclosures, covers and wrappings to reduce reverberant build up and hence increase insertion loss
- Introduction of sound absorbing materials onto surfaces of rooms to control reflected sound.

The term "acoustic" properties of a porous absorbers refers to;

- Macro properties of absorbers assemblies
  -Absorption coefficient and normal surface impedance
- Bulk properties of the porous material itself
  -Characteristic impedance and wavenumber
- Micro scale properties that create bulk properties
  - Flow resistivity, Porosity, Tortuosity, Characteristic Lengths
  - It is at the microscale that the porous material actually interacts with the fluid

Absorbers and barriers are used for airborne noise problems, and dampers and isolators are used for structure borne noise problems [3]. Absorption coefficient measurements are not easy, where materials are placed and having no regard of their shape or extension. Material properties may be adjusted to produce more absorption in one frequency range than another [5]. Usually the measurement of absorption coefficient is made in a reverberant room, according to the ISO 354 standard. Sound absorption coefficient depends not only on material or the medium through which it propagates, but also on many factors as shown in the Fig. 1 below [12].

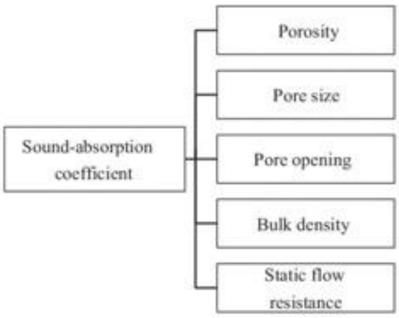


Figure 1 Factors affecting sound absorption coefficient

II. ABSORPTION COEFFICIENT

Sound incident on a material is reflected, absorbed, and transmitted, as indicated in Fig. 2. When such a material is installed on the hard surfaces, its absorbing effect includes the transmitted sound as well as the pure absorption in the material. In this sense an open window is considered a "perfect" absorber, but is really a perfect transmitter. The coefficients deter-mined are based on this conception; that is, that what is not reflected is "absorbed." The open window is taken as the standard absorber with a coefficient of 1.00, or 100 per cent absorption. A material in the room with a coefficient of absorption of 0.50, means that it absorbs 50 percent as much sound as an open window of equal area.

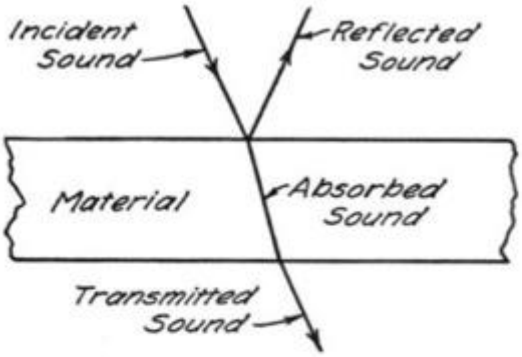


Figure 2 Reflection, Absorption and Transmission of sound

The absorption coefficient is defined as the ratio of absorbed energy to incident energy.

If E_i = incident Energy /Sound
E_r = Reflected Energy /Sound
E_a = Absorbed Energy / Sound &
E_t = Transmitted Energy / Sound

By conservation of energy,

Ei = Er + Ea+ Et ……………………… (1)

And Absorption coefficient, α = Ea / Ei …………….. (2)

Sound pressure level (SPL) or acoustic pressure level is a logarithmic measure of the effective pressure of a sound relative to a reference value. Sound pressure level, denoted L_p and measured in dB, is defined by,

$$L_p = 20\log_{10}\left(\frac{\tilde{p}}{p_0}\right) \quad \text{dB}$$

Where

L_p	=	Sound Pressure Level in decibels (dB)
$\tilde{P}$	=	Sound Pressure in Pascals
p_0	=	Reference sound pressure
	=	20µPa = 20 x 10^{-6} Pa

Sound pressure and Sound Intensity are given by

$$L_i = 10\log_{10}\left(\frac{I}{I_0}\right) \text{Pa}$$

$$I = I_0\, 10^{\frac{Li}{10}} \quad \text{W/m}^2$$

Where

L_i	=	Sound Pressure (Pa)
I	=	Sound Intensity Level (W/m^2)
I_0	=	Reference sound Intensity Level
	=	1 p W/m^2 = 10^{-12} W/m^2

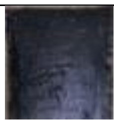
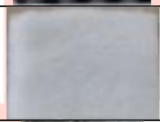
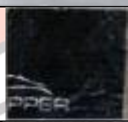
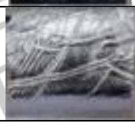
III. Acoustic Materials

In this experimental testing, total seven different acoustic materials are used to apply on to structural steel material of the truck cabin. Namely;

1. Structural steel (M1)
2. Water based Sound Deadening Coating (M2)
3. Vinyl Noise Barrier (M3)
4. Polyester Wadding (M4)
5. Polyethylene Foam (M5)
6. Wool Foam (M6)
7. Copper Noise Barrier (M7)
8. Cell Foam Cotton (M8)

The systematic pictures and basic mechanical properties of these materials are as shown in Table 1 below.

Table 1 Acoustic materials and properties

Sl. No	Material		Thickness [mm]	Density [Kg/m^3]
2.	Water based Coating		1	1300
3.	Vinyl Noise Barrier		2	1220
4.	Polyester Wadding		10	1760
5.	Polyethylene Foam		10	330
6.	Wool Foam		20	1314
7.	Copper Noise Barrier		2	8960
8.	Cell Foam Cotton		10	1540

The combination of materials is also made as;

9. M1+M2+M3 = M9
10. M9+M4 =M10
11. M9+M5 = M11
12. M9+M6 = M12
13. M9+M8 = M13
14. M1+M2+M7 = M14
15. M15+M4 = M15
16. M15+M5 = M16
17. M15+M6 = M17
18. M15+M8 = M18

Sound waves provide a very attractive method for noninvasive measurements of the morphological characteristics of porous materials [9]. The acoustic properties evaluate the material sound absorbing efficiency, whereas the non-acoustic properties allow one to predict the material acoustic response in various industrial applications by the use of an appropriate mode [11].

IV. Experimental Setup

Absorption coefficient measurements are not easy, especially if one needs to do them in situ, i.e. where materials are placed and having no regard of their shape or extension. Usually the measurement of absorption coefficient is made in a reverberant room, or using the traditional standing wave tube technique [8]. A prototype of impedance tube method is adopted in finding out the absorption coefficient of these materials. The Fig. 4 shows the prototype model of the impedance tub and Fig. 5 shows experimental setup. It is made using plywood of thickness 18mm. Experimental set consists of a computer for measurement of sound intensity which is connected to DAQ. A microphone sensor attached to DAQ is inserted in impedance tube prototype model. A sound speaker is attached to the tube and is played by connecting to music player. A two-microphone impedance tube is used to measure the normal sound absorption coefficient of the materials coupled to an air cavity and a rigid termination [10].

Figure 4 Prototype model of impedance tube

Figure 5 Experimental setup of impedance tube model

The specifications of the prototype model are as listed in Table 2 below.

Table 2. Specifications of the prototype impedance tube model

Sl. No	Particulars	Specifications	Remarks
1	Model Material	Ply wood of thickness 18 mm.	
2	Dimensions of the box	48 x 12 x 12 inches	(L x B x H)
3	Loudspeaker	20 Watt	
4	Microphone Used	GRAS 40 PH array microphone	
5	Microphone sensor positions	• 3 inches in front of the sound source • 3 inches on either side (front and back) of the acoustic material	
6	Distance of materials from Sound source	40 inches	

The prototype model is prepared so that there is no air flow inside the model during testing of the material. Incident intensity (Ei), transmitted intensity (Et) and absorbed intensity (Ea) of the sound can be measured using microphone sensor in terms of dB. Here, the reflected intensity (Er) is assumed to be zero.

V. Experimental Procedure:

Determination of coefficient of absorption (α) of acoustic material used in the present work is necessary as the behavior and absorption of sound pressure developed inside the cabin depends on this property with respect to operating conditions. Since, the acoustic materials behave differently in different conditions. The test procedure to determine the absorption coefficient is done similar to impedance tube testing. Here, the prototype of impedance tube is developed with suitable dimensions as mentioned in Table 1 and is made up of plywood. The test procedure is as follows:

- A sound source of 20 watts is attached at one end of the tube/box and the materials to be tested are being placed at a distance of 3 feet from the source in the slot made.
- Three holes of 12 mm diameter are made to insert the microphone sensor inside the tube/box. First hole at a distance of 3 inches from the source (A), second hole at the 3 inches before the material to be tested and third hole at a distance of 3 inches after the material.
- The tube is completely made vacuum by closing all the sides at the time of testing.
- Sound source is made ON using music player/computer connected to speaker for the full volume. Microphone is placed at the point 'A' and the sound intensity developed is measured.
- Now the microphone sensor is placed at the point 'B' and the test is repeated to measure sound intensity at point 'B'. These two intensities will remain same all the material testing.
- Now a material is to be tested is placed at the slot inside the tube. The microphone is placed at the point 'C' and the test procedure is repeated to measure sound intensity at point 'C'.
- Similarly, materials are replaced and the test procedure is repeated to measure sound intensity at point 'C'.
- Then the incident sound intensity (Ei), transmission sound intensity (Et), absorption sound intensity (Ea) and absorption coefficient (α) are calculated for all the materials.

1 Sound intensity at the source and before the acoustic materials.

The sound intensity at the sound source at a distance of 3 inches front of the source is measured Fig. 6a in terms of SPL. It is noted that 113.53 dB sound pressure level is measured at the point of source (A). After conversion the sound pressure is 9.49

N/m2 and sound intensity is 0.225 W/m2. The sound intensity at the distance of 2 feet 9 inches from the sound source and 3 inches before the acoustic material is known as incident sound intensity (Ei) and is as shown in the Fig. 6b measured in terms of SPL. It is noted that 109.43 dB sound pressure is measured before the material (B). After conversion the sound pressure is 5.92 N/m2 and sound intensity is 0.0877 W/m2.

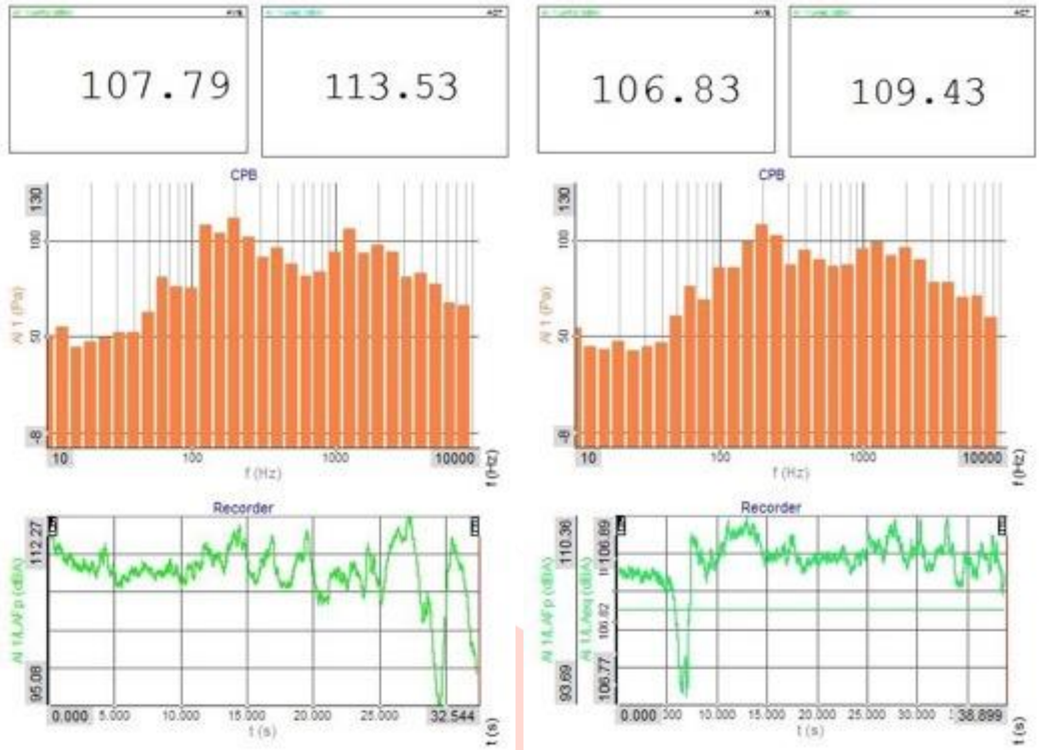


Figure 6 a SPL at the source b Incident SPL before the material

2 Sound intensity after the acoustic material

The sound intensity at the distance of 3 inches after the acoustic material is known as transmitted sound intensity (Et) is measured in terms of SPL for all 18 materials as shown in the Fig. 7 to 24 below.

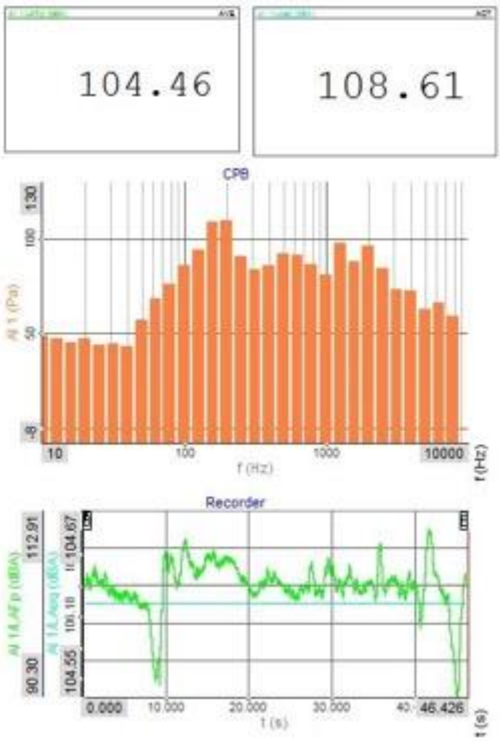


Figure 7 Transmitted sound intensity after the source for M1 (Et)

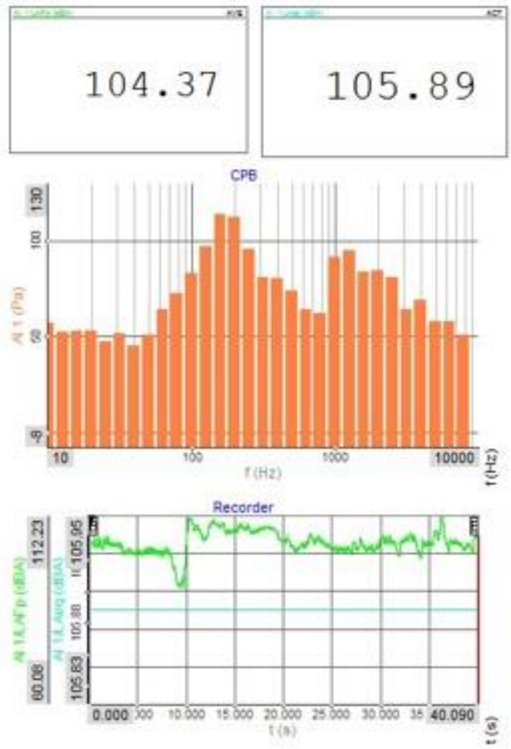


Figure 8 Transmitted sound intensity after the source for M2 (Et)

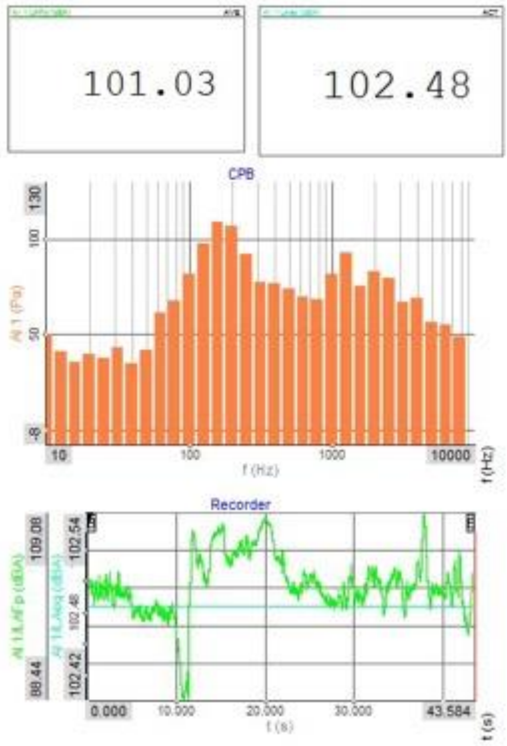


Figure 9 Transmitted sound intensity after the source for M3 (Et)

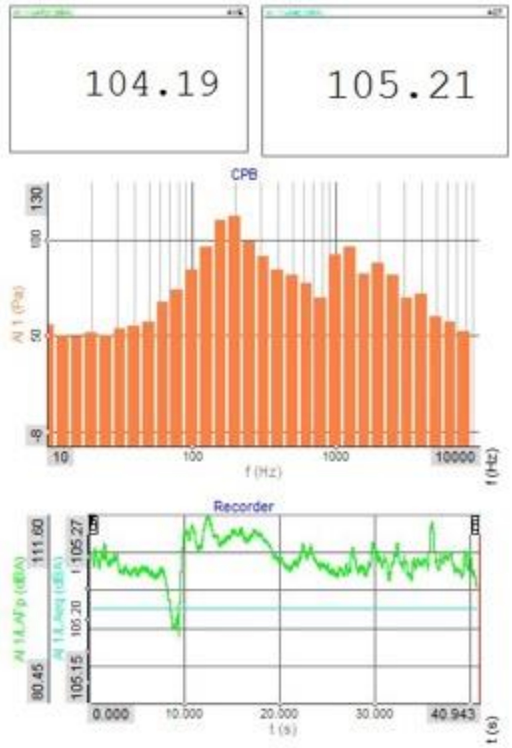


Figure 10 Transmitted sound intensity after the source for M4 (Et)

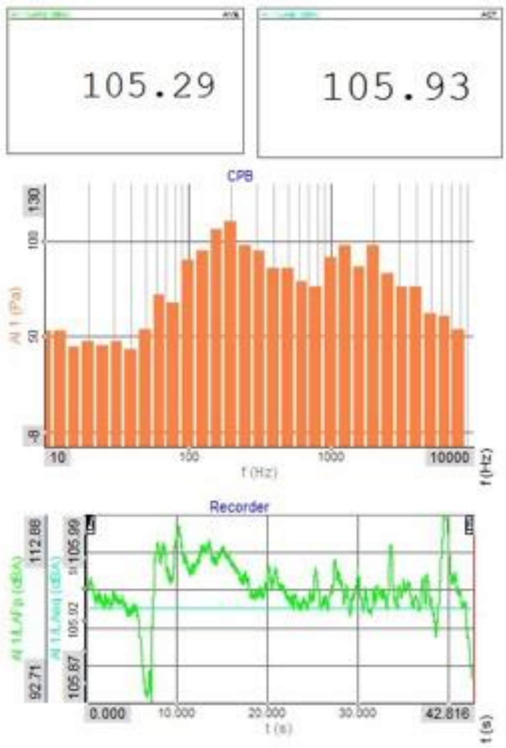


Figure 11 Transmitted sound intensity after the source for M5 (Et)

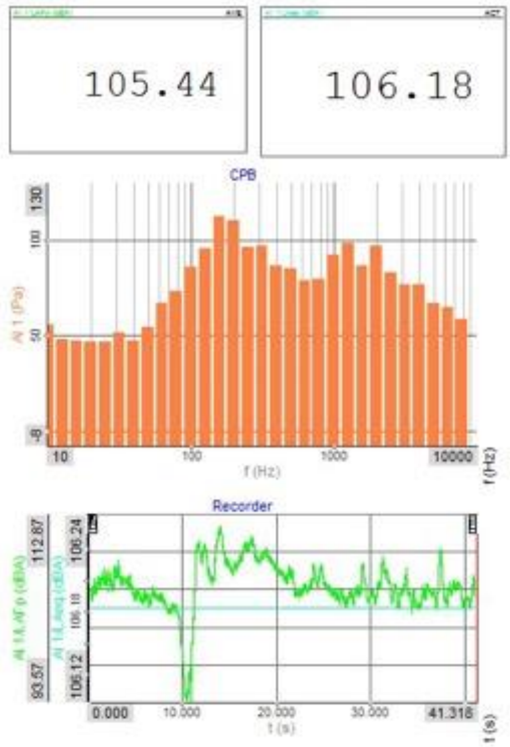


Figure 12 Transmitted sound intensity after the source for M6 (Et)

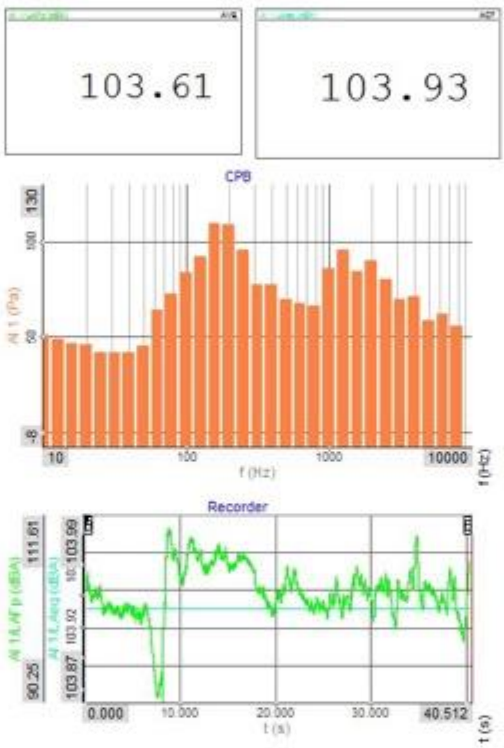


Figure 13 Transmitted sound intensity after the source for M7 (Et)

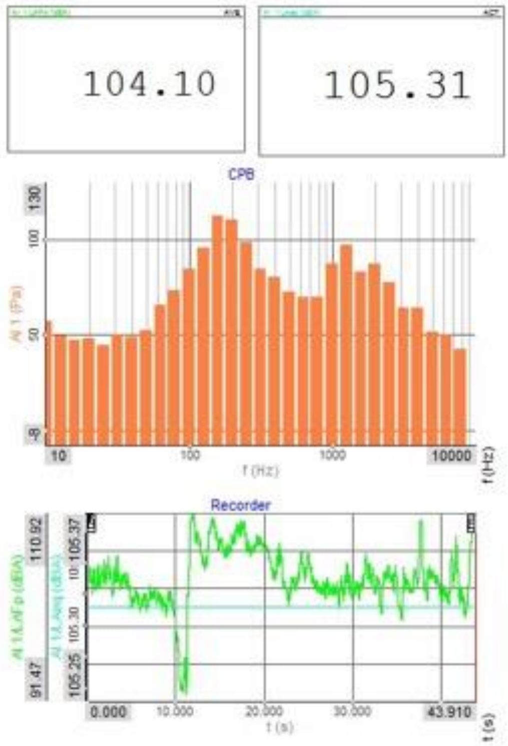


Figure 14 Transmitted sound intensity after the source for M8 (Et)

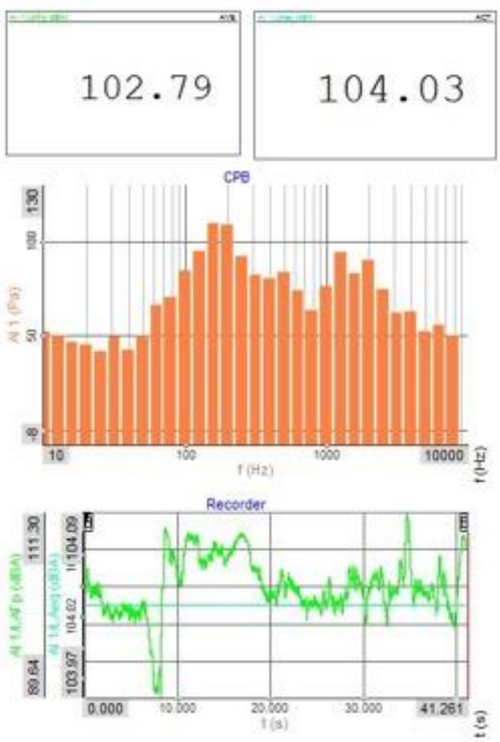


Figure 15 Transmitted sound intensity after the source for M9(Et)

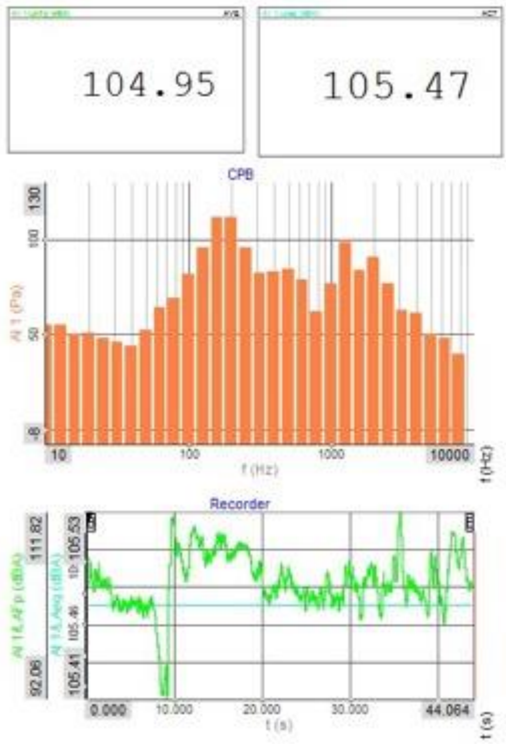


Figure 16 Transmitted sound intensity after the source for M10 (Et)

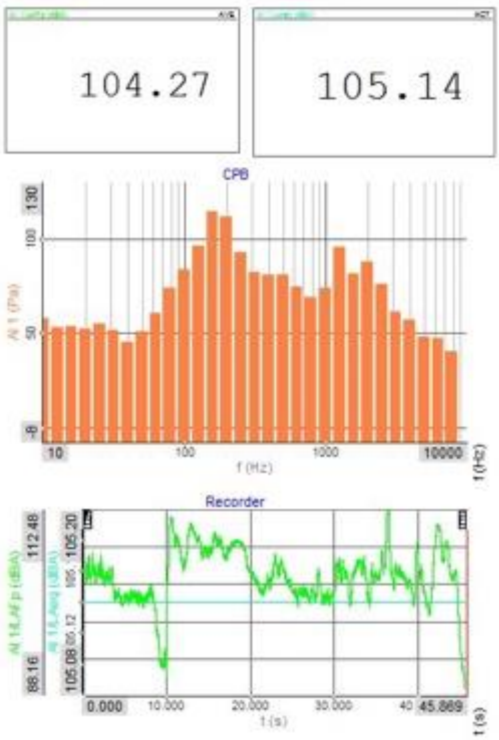


Figure 17 Transmitted sound intensity after the source for M11 (Et)

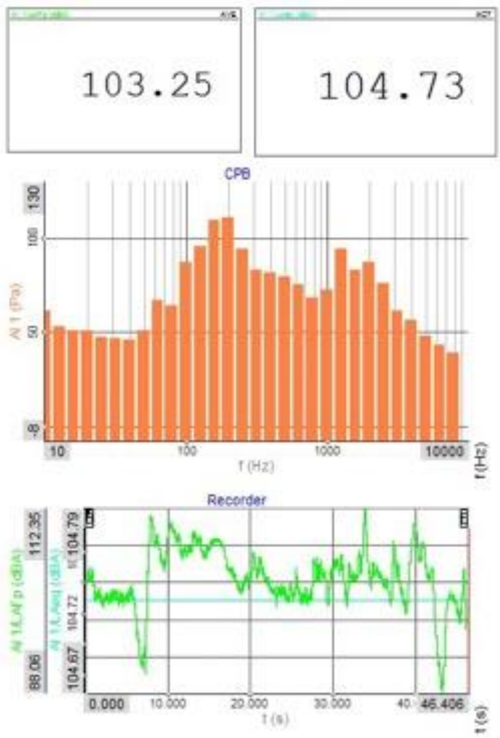


Figure 18 Transmitted sound intensity after the source for M12 (Et)

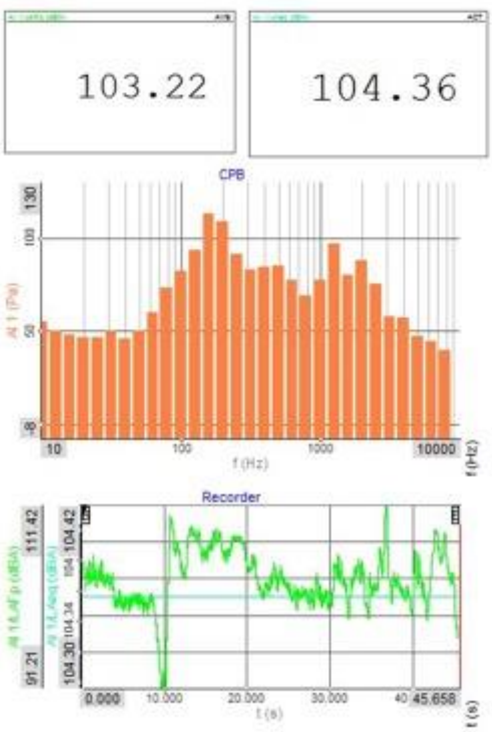


Figure 19 Transmitted sound intensity after the source for M13(Et)

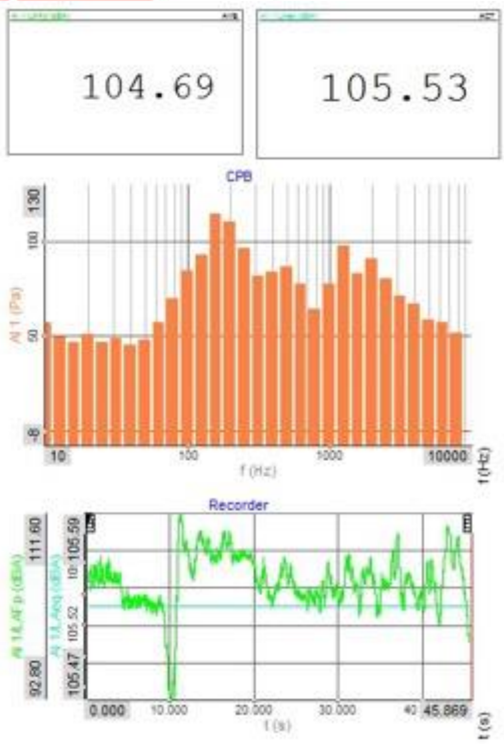


Figure 20 Transmitted sound intensity after the source for M14 (Et)

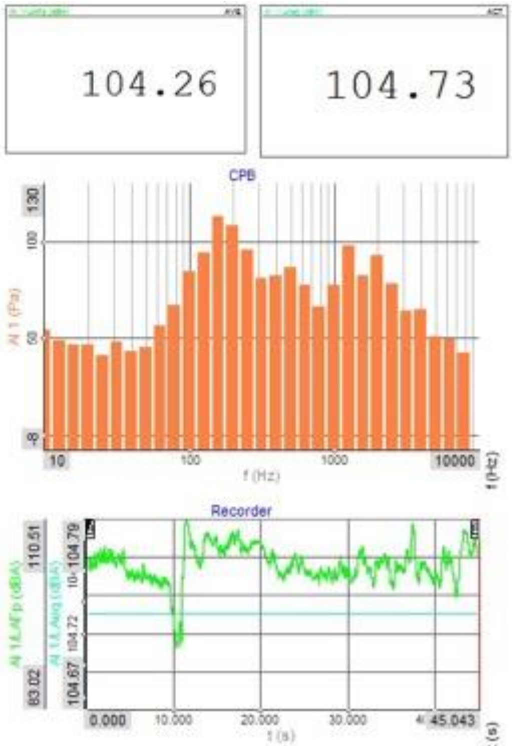


Figure 21 Transmitted sound intensity after the source for M15 (Et)

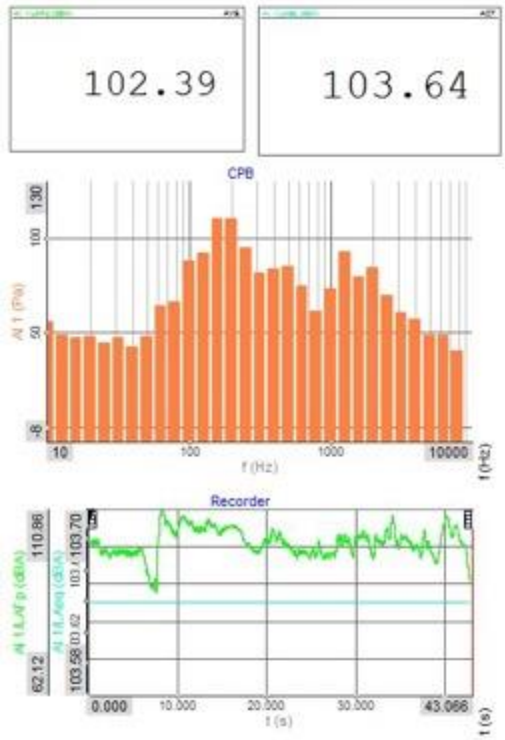


Figure 22 Transmitted sound intensity after the source for M16 (Et)

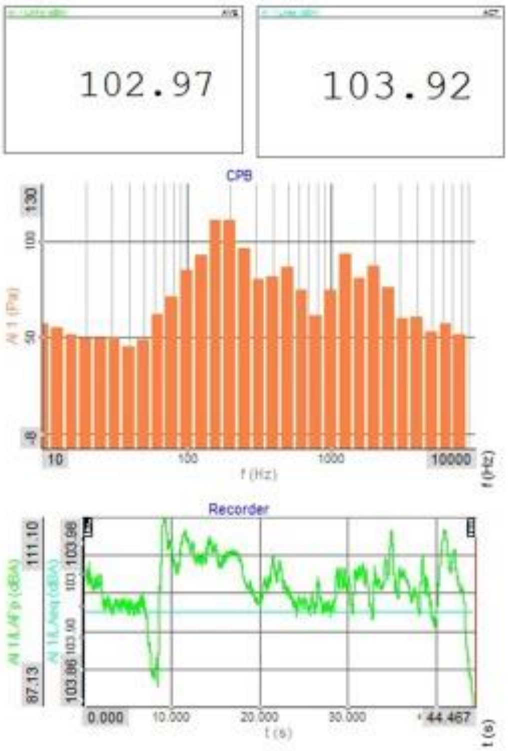


Figure 23 Transmitted sound intensity after the source for M17(Et)

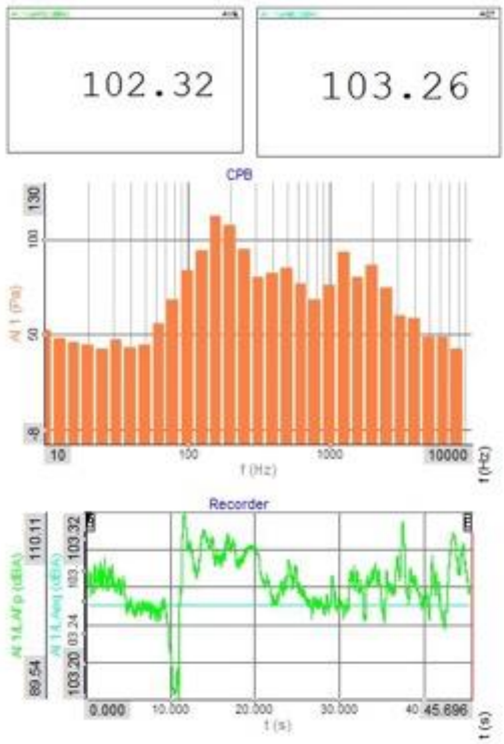


Figure 24 Transmitted sound intensity after the source for M18 (Et)

After conversion dB to N/m2 the transmitted sound intensities for M1 to M18 materials are listed Table 3 as follows.

Table 3 Sound Intensities measured for acoustic materials

Material	**Et (N/m2)**	**Material**	**Et (N/m2)**
M1	5.38	M10	3.75
M2	3.94	M11	3.61
M3	2.66	M12	3.44
M4	3.64	M13	3.3
M5	3.95	M14	3.78

M6	4.074	M15	3.44
M7	3.14	M16	3.04
M8	3.68	M17	3.14
M9	3.18	M18	2.91

From the results it is observed that the absorption coefficient of the acoustic materials can be evaluated experimentally by making the prototype of impedance tube. Further the prototype can be made more sophisticated and more compact than this porotype model by using other type of materials so that the absorption coefficient values obtained gets improved to more real values.
The absorption coefficient from these incident, transmitted and absorbed intensities is calculated using equations (i) & (ii). The values are tabulated in the Table 4 below.

Table 4 Readings of Incident intensity (Ei), transmitted intensity (Et) and absorbed intensity (Ea) and absorption coefficient (α)

	Before Acoustic Material			**After Acoustic Material**			**Absorbed Intensity**	**Absorption Coeff.**	
Material	**Ei (dB)**	**Ei (N/m2)**	**Ei (W/m2)**	**Et (dB)**	**Et (N/m2)**	**Et (W/m2)**	**Ea = (Ei – Et)**	**α = (Ea / Ei)**	**Final α**
M1	109.43	5.92	0.0877	108.61	5.38	0.0726	0.0151	**0.172178**	**0.17**
M2	109.43	5.92	0.0877	105.89	3.94	0.0388	0.0489	**0.557583**	**0.55**
M3	109.43	5.92	0.0877	102.48	2.66	0.0176	0.0701	**0.799316**	**0.79**
M4	109.43	5.92	0.0877	105.21	3.64	0.033	0.0547	**0.623717**	**0.62**
M5	109.43	5.92	0.0877	105.93	3.95	0.039	0.0487	**0.555302**	**0.55**
M6	109.43	5.92	0.0877	106.18	4.074	0.041	0.0467	**0.532497**	**0.53**
M7	109.43	5.92	0.0877	103.93	3.14	0.0246	0.0631	**0.719498**	**0.71**
M8	109.43	5.92	0.08777	105.31	3.68	0.0338	0.0539	**0.614595**	**0.61**
	Combination of materials								
M9	109.43	5.92	0.0877	104.03	3.18	0.0252	0.0625	**0.712657**	**0.71**
M10	109.43	5.92	0.0877	105.47	3.75	0.0351	0.0526	**0.599772**	**0.59**
M11	109.43	5.92	0.0877	105.14	3.61	0.0325	0.0552	**0.629418**	**0.62**
M12	109.43	5.92	0.0877	104.73	3.44	0.0295	0.0582	**0.663626**	**0.66**
M13	109.43	5.92	0.0877	104.36	3.3	0.0272	0.0605	**0.689852**	**0.68**
M14	109.43	5.92	0.0877	105.53	3.78	0.0357	0.052	**0.59293**	**0.59**
M15	109.43	5.92	0.0877	104.73	3.44	0.0295	0.0582	**0.663626**	**0.66**
M16	109.43	5.92	0.0877	103.64	3.04	0.0231	0.0646	**0.736602**	**0.73**
M17	109.43	5.92	0.0877	103.92	3.14	0.0246	0.0631	**0.719498**	**0.71**
M18	109.43	5.92	0.0877	103.26	2.91	0.0211	0.0666	**0.759407**	**0.75**

VI. CONCLUSIONS

From the experimental results reported above, it can be concluded that the new Intensity Method for absorption coefficient measurements is simple and reliable. The measurement results are more realistic, and no artifact was produced even with samples with very low absorption or very large variation of the absorption coefficient over the frequency range.

VII. ACKNOWLEDGEMENT

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