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SOUND TRANSMISSION LOSS MEASUREMENTS - AN AUTOMOTIVE OVERVIEW

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Automotive market is becoming very much cost sensitive day by day, but at the same time customer expectations from the OEMs are ever increasing in difference aspects. In terms of Automotive NVH, one of the important expectation is low in-cab noise in the passenger compartment. This criteria is mostly achieved by traditionally applying sound package treatment inside the vehicle at different locations. These sound package treatment used inside the vehicle are mostly categorized into absorbers, insulators and damping treatments. Out of these major sound package treatments, sound insulators play a vital role in blocking the noise coming from powertrain or tire-road interaction. Most of the time, OEMs give target levels to acoustic material manufactures for designing sound insulation treatments. Sometimes these target levels are just results from four microphone impedance tube or from two reverberation chamber testing. This paper presents a detailed discussion on pros and cons of both methods with more emphasis on sound transmission loss measurements inside a four microphone impedance tube as most of the time target levels tested using four microphone tube are overestimated due to lack of expertise required for correct testing and analysing the test data. The paper also talks about different mounting conditions of test sample inside the four microphone impedance tube with validation of experimental results with simulation. The paper also gives an overview of other novel ideas for reducing in-cab noise using simple techniques.

1. Introduction

Today's OEMs are investing huge money and man power for making vehicle quieter and comfortable. The prime goal of this man power is to work on different NVH aspects of the vehicle and reduce the interior as well as exterior noise. One of a goal is, sound package treatment of a complete vehicle. This sound package design of a complete vehicle is divided into three main categories, sound absorptive, sound insulation and damping treatments. These absorptive and insulation treatments are mostly designed based upon their acoustic performance which is evaluated in terms of sound absorption and sound transmission loss measurements carried out in an impedance tube suite or reverberation chamber suite. As reverberation chamber suite is not an economical option for most of the OEMs, they prefer to have impedance tube suite to measure sound absorption and sound transmission loss of sound package treatments. NVH engineers extensively use two and four microphone impedance tubes to define sound package targets for different vehicles. These targets are then forwarded to acoustic material manufacturers or suppliers to develop the sound package treatments. But here lies the main problem, as the usage of impedance tubes requires a typical expertise to carry out complete cycle of acoustic measurements starting from sample selection – sample preparation – sample mounting – tube calibration- testing – and correct analysis. The paper presents the theory behind the four microphone impedance tube along with comparison of theoretical results with experimental results.

2. Theory

The transfer matrix method based on the decomposition of incident and reflected waves measured in upstream and downstream of a sample in a standing wave tube 1. By considering the measurement set-up shown in Fig 1, it is possible to relate the acoustical pressures *P* and the particle velocities *V* at both surfaces of the test sample by using a transfer matrix formulation. [1]

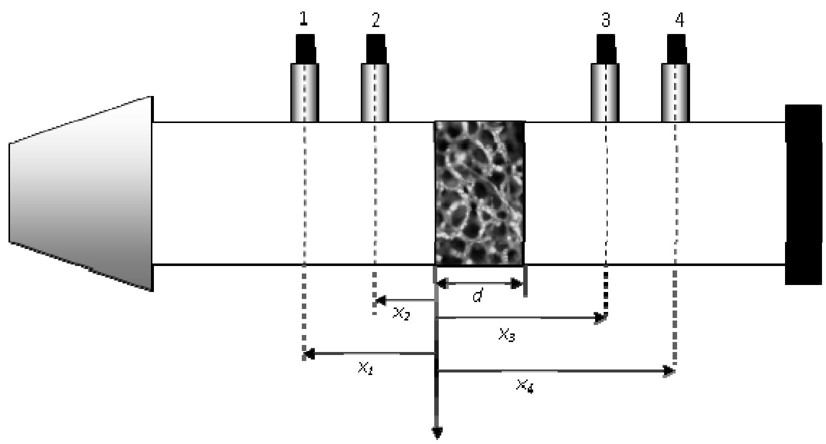

Figure 1. : Schematic of the four microphone tube

Using the decomposition technique, the contributions of the incident and reflected acoustical waves (*A*, *B*, *C* and *D*) at both sides of the material can be calculated by using measured complex pressures at the different four microphone positions as follows

$$A = \frac{j\left(P_1 e^{jkx_2} - P_2 e^{jkx_1}\right)}{2\sin k\left(x_1 - x_2\right)} \quad (1)$$

$$B = \frac{j\left(P_2 e^{-jkx_2} - P_1 e^{jkx_2}\right)}{2\sin k\left(x_1 - x_2\right)} \quad (2)$$

$$C = \frac{j\left(P_3 e^{jkx_4} - P_4 e^{jkx_3}\right)}{2\sin k\left(x_3 - x_4\right)} \quad (3)$$

$$D = \frac{j\left(P_4 e^{-jkx_3} - P_3 e^{-jkx_4}\right)}{2\sin k\left(x_3 - x_4\right)} \quad (4)$$

These coefficients can be used, in turn, to evaluate the sound pressures and particle velocities at the front and rear surfaces of the sample. The latter quantities, at $x = 0$ and $x = d$, are related by the transfer matrix. Using these coefficient, it is easily possible to calculate normal incidence sound absorption coefficient and sound transmission loss of the porous material using reflection coefficient and transmission coefficient

$$R = \frac{T_{11} + \frac{T_{12}}{\rho_0 c} - \rho_0 c T_{21} - T_{22}}{T_{11} + \frac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} + T_{22}} \quad (5)$$

$$T = \frac{2e^{ikd}}{T_{11} + \frac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} + T_{22}} \quad (6)$$

3. Four Microphone Impedance

The four microphone impedance Tube used in this study is shown in fig. 2. The tube is based upon ASTM E2611 standards and consists of two tubes-upstream and downstream tube. These tubes are connected together using a special sample holder. At one end of impedance tube, a loudspeaker is fitted to excite the sample in the frequency range 100 Hz to 4500 Hz. [2]

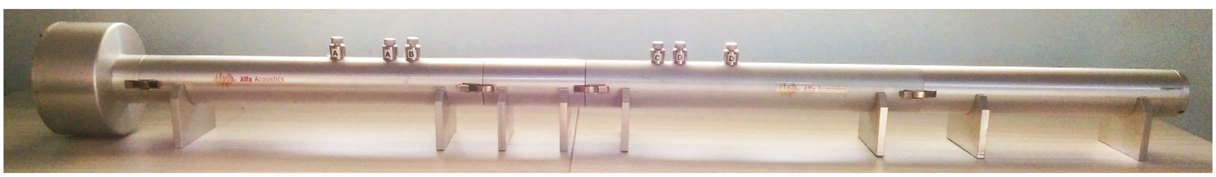

Figure 2: Four microphone tube

The test samples were considered melamine and polyurethane foam. The diameter of the test samples 44.8, 45 and 45.1mm to check the frame stiffness on sound transmission loss measurements. The samples were cut using rotating blade (die-cut) on vertical drilling machine at very slow speed to fit snugly inside the impedance tube and to avoid creation of air gaps around the circumference of the sample. The setup is shown in fig 3.

Figure 3: Rotating blade set up for cutting samples

4. Results and Discussion

The test samples considered in study were melamine foam and PU foam. The sound absorption coefficient and sound transmission loss was measured using impedance tube as per ASTM E1050 and ASTM E2611 respectively [3]. The normal incidence sound absorption coefficient was used as an input to inverse algorithm to get physical properties of the materials like porosity, airflow resistivity, tortuosity and characteristics lengths. These physical properties were then used with mathematical model to predict sound transmission loss of the materials. These properties are given in table 1.

Table 1. Physical Intrinsic Properties

Material Properties	Melamine Foam-29 mm	PU Foam – 25 mm	Units
Porosity [ϕ]	0.995	0.986	-
Airflow Resistivity [σ]	10872	23367	Ns/m^4
Tortuosity [α_∞]	1.003	1.7	-
VCL [Λ]	99	43	um
TCL [Λ']	142	258	um

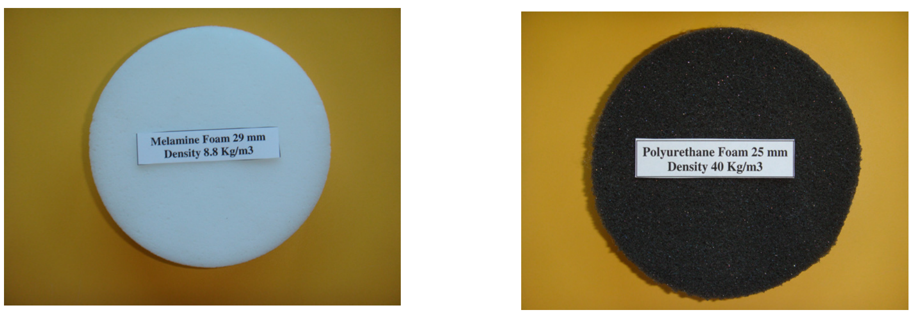

Figure 4: (a) Melamine Foam -29 mm (b) PU Foam -25 mm

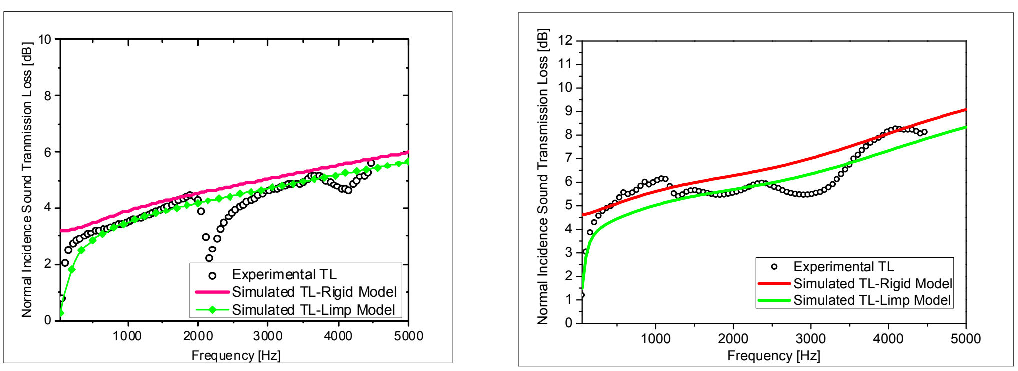

Figure 5: Comparison of Sound Transmission Loss (a) Melamine Foam (b) PU Foam

The normal incidence sound transmission loss of acoustic materials depends upon type of the frame materials as well as on sample mounting. In Automobile applications, the most used material is felt. Sometimes, the felt material is used in combination with barrier layers. During testing as the sample size is very small, the sample becomes too stiff which results into high sound transmission loss of the test sample as shown in fig 5. So it is very important that sample has to be precisely cut using water-jet or die cutter. From above figures, it is clear that, frame of the acoustic test sample plays an important role during measurement of sound transmission loss. More results of this study will be presented during the conference.

5. Conclusions

From this study, it is clear that, sample preparation and sample mounting during the measurement of normal incidence sound transmission loss is very critical. So it is important to take special precautions during cutting of the samples for testing. It is also important to understand the type of the material based upon its frame structure.

6. References

[1] Song B.H. and Bolton S.J., "*Effect of circumferential edge constraint on the acoustical properties of glass fiber materials*", Journal of Acoustical Society of America, 110, pp. 2902-2916, 2001

[2] ASTM E1050, "*Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube*, Two Microphones and a Digital Frequency Analysis System", 2012

[3] ASTM E2611, "*Standard Test Method for Measurement of Normal Incidence Sound Transmission of Acoustical Materials Based on the Transfer Matrix Method*", 2009