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An experimental study of Sound Transmission Loss (STL) measurement techniques using an impedance tube

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A comparison between the two sound transmission loss (STL) measurement techniques using a four-microphone impedance tube (i.e. two-load method and anechoic termination method) is presented. A modified B&K type 4206 impedance tube has been designed and built. STL tests have been carried out for three homogeneous and isotropic materials with disk-type test samples of identical diameters and different thicknesses. In addition, the results have been compared with those of the classical and more reliable method of two-room. For both methods, the effect of downstream (tube termination) boundary conditions have been studied. The two-load method yields results which matches with two-room measurements, especially when the two boundary conditions are considerably different. The anechoic termination method, on the other hand, is significantly dependant on the termination boundary conditions.

1 Introduction

The classical method for STL measurement of noise control materials is the 'two-room' method. The test specimen is located in the opening between an anechoic and a reverberant room. Sound is then generated in the reverberant room, is recorded by two microphones in each of the rooms and STL is measured using one of the various procedures available. This technique is well-defined, time-tested and reliable [1]; however, it is very expensive and requires large test chambers.

In recent years, an alternate method has been developed for STL measurements using an impedance tube: a rigid tube where sound is internally guided and forced to propagate along the tube axis. Originally used by Kundt to prove the wave properties of sound [4], impedance tubes are now considered as an economical alternative for the two-room method. More favorably, the whole testing apparatus can be set up on a laboratory desk (see Fig. 2).

There are a number of different procedures to measure the STL using an impedance tube [7, 9]. In this article, evaluation of STL in a four-microphone impedance tube has been studied (see Fig. 1). For this purpose, a modified Brüel and Kjær (B&K) type 4206 impedance tube has been designed [5, 6] and built. Both of the two existing procedures (i.e. two-load method and anechoic termination method) have been used to analyze the sound pressures and calculate the STL based on the transfer matrix approach elaborated by Song and Bolton [2].

This paper focuses on applying the two-load and anechoic termination methods to homogeneous isotropic materials. A complete comparison of the two methods has been presented and the effect of the tube termination conditions has been studied. In addition, the results have been compared with those of the classical two-room method [8]. The two-source method [9], on the other hand, is neglected in this study because it is not applicable to symmetrical systems like the one in this paper.

2 Theory

Impedance tubes are used below their lowest cut-off frequency to produce plane waves. In this case, the resulting sound field in the tube consists of one component traveling towards the sample and one reflected component [4]. Thus, complex sound pressures at the four microphone locations in the tube can be expressed as

$$\begin{cases} P_1 = Ae^{j(\omega t - kx_1)} + Be^{j(\omega t + kx_1)} \\ P_2 = Ae^{j(\omega t + kx_2)} + Be^{j(\omega t - kx_2)} \\ P_3 = Ce^{j(\omega t - kx_3)} + De^{j(\omega t + kx_3)} \\ P_4 = Ce^{j(\omega t + kx_4)} + De^{j(\omega t - kx_4)} \end{cases} \tag{1}$$

with complex coefficients A to D being the amplitudes of the waves and k being the wave number.

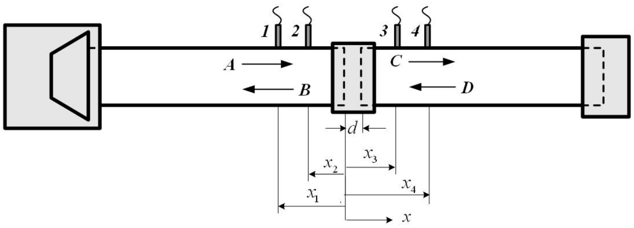

Fig. 1 Schematic view of a four-microphone impedance tube

The amplitudes can thereby be expressed in terms of the four pressures:

$$\begin{cases} A = \dfrac{j(P_1 e^{jkx_2} - P_2 e^{jkx_1})}{2\sin k(x_1 - x_2)} \\ B = \dfrac{j(P_2 e^{-jkx_1} - P_1 e^{-jkx_2})}{2\sin k(x_1 - x_2)} \\ C = \dfrac{j(P_3 e^{jkx_4} - P_4 e^{jkx_3})}{2\sin k(x_3 - x_4)} \\ D = \dfrac{j(P_4 e^{-jkx_3} - P_3 e^{-jkx_4})}{2\sin k(x_3 - x_4)} \end{cases} \tag{2}$$

The transmission loss matrix is introduced as relating the forward and backward traveling acoustic waves as

$$\begin{Bmatrix} A \\ B \end{Bmatrix} = \begin{bmatrix} \alpha & \beta \\ \gamma & \delta \end{bmatrix} \begin{Bmatrix} C \\ D \end{Bmatrix} \tag{3}$$

where the frequency-dependant matrix coefficients are related to the acoustical properties of the sample [2]. α, the transmission loss coefficient, is of special interest here. Once the transmission loss coefficient has been determined, the sound transmission loss (STL) is calculated in dB as follows,

$$STL = -20\,log\left(\left\|\alpha\right\|\right) \tag{4}$$

3 Test Procedure

To solve the set of two equations in terms of the four unknowns in the transmission loss matrix (Eq. 3), two techniques are available: two-load method and anechoic termination method. A sample is located between the two tubes and sound pressure is recorded by all the four microphones for different conditions, as in Figure 1.

3.1 Two-Load Method

To obtain four independent equations, the test is performed for two different conditions at the end of the tube: terminating it with a rigid cap and leaving it open (no cap). The four equations are then solved together and the transmission loss coefficient is found to be

$$\alpha = \frac{A_1 D_2 - A_2 D_1}{C_1 D_2 - C_2 D_1} \qquad (5)$$

3.2 Anechoic Termination Method

In this method, an anechoic termination is applied to the end of the tube so as to cancel the backward traveling wave there; $D \rightarrow 0$. In this case, the transmission loss coefficient is easily found to be equal to the ratio of *A* to *C*.

Although this method halves the number of measurements in comparison with the two-load method, it is not reliable because of the difficulties in implementing a desirably anechoic termination. In fact, the reflection coefficient of tube termination has a significant effect on the measurements and accounts for the fluctuations in STL curves. Pispola et al. have studied this effect and improved the accuracy of the anechoic termination method [3].

4 Experimentation

The testing apparatus constructed for the STL measurements at Noise, Vibration and Acoustics (NVA) Research Center of University of Tehran consists of two identical 1100-mm-long stainless steel tubes with thickness of 5mm. The internal diameter of each tube is 35 mm, while the internal diameter of the sample holder and all the samples is approximately 40 mm; i.e. equal to the external diameter of the tubes. Four ½" B&K free-field microphones are used to measure the pressure, the ones on the same tube placed 25 mm apart (see Fig. 1). The distance between microphones 2 and 3 to the tube end facing the sample is 125 mm. A 7W Samsung loudspeaker is used as the sound source and is placed inside a wooden sound box lined with absorptive material. A removable cap is placed at the tube end to apply the two termination conditions (see Fig. 2).

For data acquisition and signal processing, a B&K type 2719 power amplifier, a four-channel B&K type 3560-C signal analyzer platform, and a personal computer equipped with PULSE 8.0 software is used. The lower and upper working frequency ranges are determined as 650 and 5600 Hz based on the microphone spacing and tube diameter, respectively. In addition, any microphone phase calibration error is neglected since the microphones are manufacturer phase calibrated [1].

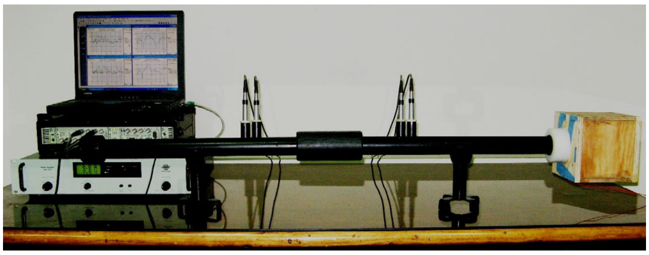

Fig. 2 The experimental setup for STL measurements at NVA

STL tests were carried out for three disk-type samples of plywood, lead and steel with identical diameters and thicknesses of 18, 3 and 6 mm, respectively. To study the effect of tube termination conditions, two rolled 10-cm-long pieces of glass wool were used as absorbents in three conditions: 20 cm, 10 cm and no absorbent. These three conditions contribute to three different test configurations for the anechoic termination method. For the two-load method the following seven configurations were considered:

termination condition	length of glass wool used at the termination (cm)						
open	20	20	0	0	10	10	0
closed	20	0	20	0	10	0	10

Table 1 Termination Conditions of the Two-Load Method

5 Results

All tests have been reported in octave bands from 500 to 4000 Hertz and the results of STL measurements of lead, plywood and steel are presented in figures 2 to 4, respectively. For the anechoic termination method, all samples gave the best results in case of 10 cm of glass wool at the tube end. From the seven termination configurations mentioned above for the two-load method, the results of the best configuration (closest to the measurements of the two-room method) have been presented for each material. This happened in the second, sixth and second configuration for lead, plywood and steel respectively. The worst results, on the other hand, correspond to the first and fifth configurations whose two termination conditions are less different.

After all, the best results were obtained with the two-load method, specifically for the plywood sample with maximum of 6 dB deviation from the two-room results. The results of the anechoic termination method are generally less accurate than the two-load method. The method consistently results in smaller values of STL. The two methods best agree in the case of plywood with a maximum difference of 5 dB.

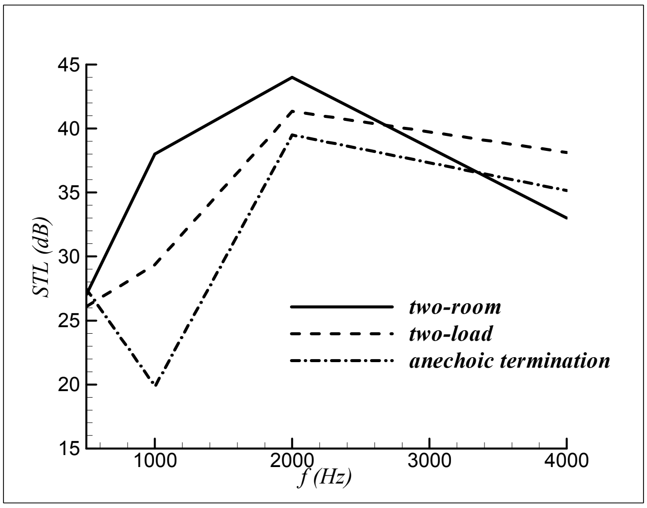

Fig. 3 Transmission Loss Curves for Lead

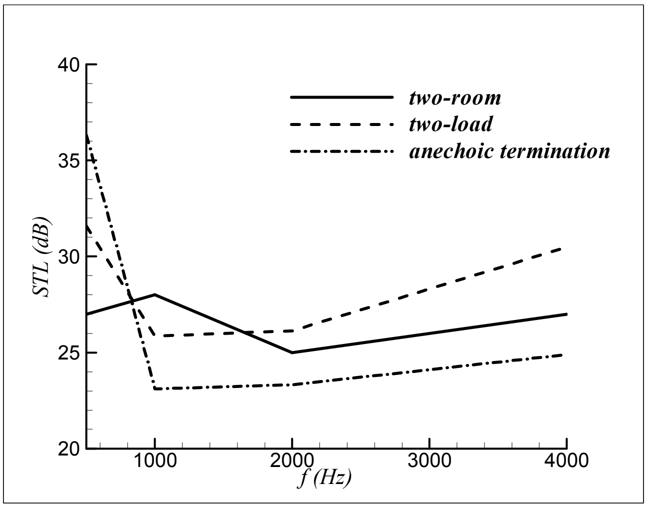

Fig. 4 Transmission Loss Curves for Lead

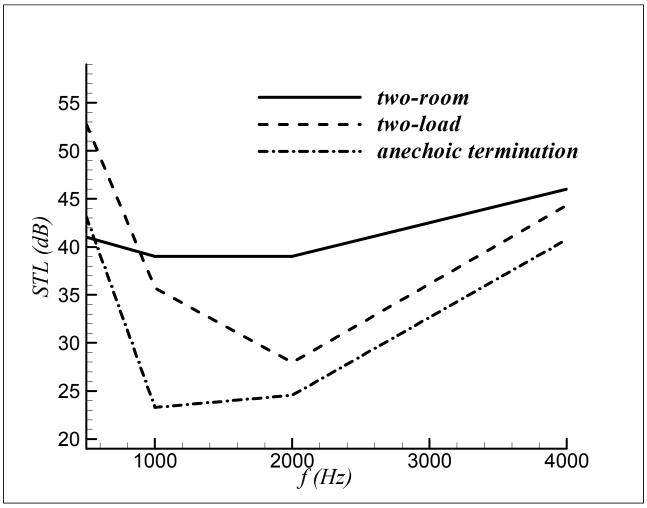

Fig. 5 Transmission Loss Curves for Lead

6 Conclusions

Sound power transmission through a sample depends on the sample's acoustical properties and on the boundary conditions of the tube. Although the use of an absorber at the tube end is strongly recommended especially for the case of an open termination, a 10 cm glass wool absorber gives better results than a 20 cm one. For the two-load method, as long as the two boundary conditions are not very much alike, the results are close the results of two-room method.

For both methods, the best results were given for the plywood sample. Moreover, STL was measured least accurately at the frequency of 500 Hz. This discrepancy is due to the fact that, according to the microphone spacing, the lower frequency range of the apparatus is determined as 650 Hz.

For the anechoic termination method there is more deviation between the results, imperfections in the anechoic termination being a major cause of it. As a consequence of this investigation, the two-load method is suggested as a reliable alternative for the anechoic termination method since it is more accurate and stable over a broad frequency range, and has a better repeatability.

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