

Measurement of Sound Transmission Loss Properties in Single & Multi-layered Systems - A Comparative Study between Two-room and Standing Wave Tube Techniques

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ABSTRACT

Several methods have been established to measure the normal incidence transmission loss of noise control materials using the standing wave tube. In the automotive NVH field, multi-layered systems are common-place, for example in the interaction between the traditional mass-decoupler dash insulator and the front dash sheet metal. Most of the sound transmission loss studies utilizing the standing wave tube have so far been focused on single layer systems with only a limited number of studies on multi-layered systems. Therefore there is only some degree of information on the correlation between this said method and the more widely accepted two-room methods of determining sound transmission properties in these systems.

The paper details an empirical study using a four-microphone standing wave tube using the transfer matrix method and a couple of methods utilizing the traditional hemi-anechoic and reverberant room set up, including one using sound pressure technique and the other using sound intensity technique. The range of materials in the study includes porous and barrier materials in single and multi-layered system configurations.

It is found that the material sound transmission loss ranking is generally consistent between the two-room methods using SAE J1400 and ISO 15186 and the standing wave tube method. However when the samples are coupled with a steel plate, there are resonance conditions which makes ranking the performance difficult. Also no consistent difference between the results of the two-room methods and the standing wave method is found, which makes correlating the data between the different methods difficult.

INTRODUCTION

One of the first applications in using the standing wave tube method to determine normal incidence sound transmission loss was the measurement of muffler [1]. Since then, a variety of studies has been conducted.

The advantage of this method over the more established two-room methods is obvious. In situations where time, material and facility limitations prevent using the two-room methods, the standing wave tube method is an ideal alternative.

Today NVH test equipment manufacturers have updated their software and hardware to make normal incidence sound

transmission loss part of the standing wave tube's normal functionalities [11,15]. Recently ASTM has established the E2611-09 standard for this test method [2].

Most of the past studies utilizing the test method have examined single layer materials [3, 4, 5]; only in limited studies including that of Barnard and Rao [6] were multi-layered materials studied.

This paper compares the two different techniques of sound transmission loss testing on a variety of materials including single layer and multi-layered constructions. The first technique is the two-room method using a reverberation room and a hemi-anechoic room set up and the second technique employs the standing wave tube using the two-load method. Further the two-room technique can have two different implementations using either the sound pressure technique or the sound intensity technique; respectively SAE J1400 [7] and ISO 15186 [8] test methods are used in this study.

SOUND TRANSMISSION LOSS - THEORY

The paper will not go into details on the theory of using the two-room sound transmission loss testing methods; only a brief description will be provided here. More extensive discussion and details on this technique can be found here [7, 8, 9].

Sound transmission loss is defined by the ratio of sound energy transmitted through a material to the sound energy incident upon it. At which some of the sound is reflected back while portion of the energy is dissipated within the material itself.

$$\tau = \frac{W_t}{W_i} \quad (1)$$

And the transmission loss, in decibels, is expressed as:

$$TL = 10 \log_{10} \left(\frac{1}{\tau} \right) \quad (2)$$

TRADITIONAL TWO-ROOM TEST METHODS

The typical set up for the two-room method involves either two reverberation rooms or a reverberation room and a hemi-anechoic room setup, where the material of interest is mounted in a window between the two rooms. The well established test methods [7, 8, 9] involve measuring the sound energy generated in the source room, and the transmitted sound energy through the sample and window.

Some test methods including SAE J100 utilize sound pressure measurement on the receiving side room while others including ISO 15186 utilize sound intensity measurement.

STANDING WAVE TUBE TEST METHOD

The idea of using a standing wave tube is relatively new. Tao and Seybert [1] first studied the method using a couple of techniques: transfer matrix and decomposition. The basic method involves the use of four microphones in a standing wave tube; however some researchers have used two microphones in the study [14]. Recently ATSM E2611-09 was established using the transfer matrix technique and four microphones.

The decomposition method is detailed in [1]. Briefly, it involves two microphones being placed between the sound source and the test sample, where the measured sound wave is decomposed into the incident and reflected spectra. A third microphone is placed downstream of the sample to measure the transmitted sound wave. The method recommends an anechoic termination downstream of the sample.

The theory behind the transfer matrix method is described here [2] and here [10]; it employs four-pole parameters using four microphones and assumes a linear acoustic system. The method can use a couple of different implementations - the two-source method and the two-load method. The two-source method requires the sound source be placed consecutively at each end of the standing wave tube and the relevant equations solved. Alternatively the two-load method is used whereby testing is conducted using two different termination conditions. The study utilizes the two-load method.

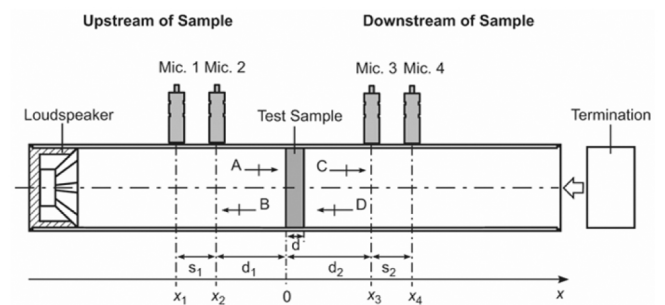


Figure 1. Bruel and Kjaer standing wave tube setup for transmission loss testing using transfer matrix implementation [11].

The basic transfer matrix is expressed as follows, where p is the acoustic pressure and u is the particle velocity on the two faces of the sample:

$$\begin{bmatrix} p \\ u \end{bmatrix}_{x=0} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} p \\ u \end{bmatrix}_{x=d} \quad (3)$$

For the two load method, one load can be designated with index a, while the second load can be indexed as b. A set of microphones upstream and downstream of the test sample are used to measure both incident and reflected waves respectively. For each load case, the forward and the backward waves, A to D can be expressed as:

$$A = j \frac{H_{1,ref} e^{-jkd_1} - H_{2,ref} e^{-jk(d_1+s_1)}}{2 \sin ks_1} \quad (4)$$

$$B = j \frac{H_{2,ref} e^{jk(d_1+s_1)} - H_{1,ref} e^{jkd_1}}{2 \sin ks_1} \quad (5)$$

$$C = j \frac{H_{3,ref} e^{jk(d_2+s_2)} - H_{4,ref} e^{jkd_2}}{2 \sin ks_2} \quad (6)$$

$$D = j \frac{H_{4,ref} e^{-jkd_2} - H_{3,ref} e^{-jk(d_2+s_2)}}{2 \sin ks_2} \quad (7)$$

The $H_{n,ref}$ is the complex acoustic transfer function between the reference and remaining microphones, where $G_{n,ref}$ is the cross power spectrum and $G_{ref,ref}$ is the reference auto spectrum.

$$H_{n,ref} = \frac{G_{n,ref}}{G_{ref,ref}} \quad (8)$$

Assuming the sound wave is normal incidence within the tube. The pressure and the velocity in the tube for each load case can be expressed by:

$$p_0 = A + B \quad (9)$$

$$p_d = Ce^{-jkd} + De^{jkd} \quad (10)$$

$$u_0 = \frac{(A-B)}{\rho c} \quad (11)$$

$$u_d = \frac{(Ce^{-jkd} - De^{jkd})}{\rho c} \quad (12)$$

The transfer matrix can then be expressed as:

$$T = \begin{bmatrix} \frac{p_{0a}u_{db} - p_{0b}u_{da}}{p_{da}u_{db} - p_{db}u_{da}} & \frac{p_{0b}p_{da} - p_{0a}p_{db}}{p_{da}u_{db} - p_{db}u_{da}} \\ \frac{u_{0a}u_{db} - u_{0b}u_{da}}{p_{da}u_{db} - p_{db}u_{da}} & \frac{p_{da}u_{0b} - p_{db}u_{0a}}{p_{da}u_{db} - p_{db}u_{da}} \end{bmatrix} \quad (13)$$

From the transfer matrix, the coefficients can be rearranged to solve for expressions A and C. The sound transmission coefficient, referencing Equation 1, is expressed in the presence of an anechoic termination as:

$$\tau = \left| \frac{C}{A} \right|^2 \quad (14)$$

The normal incidence sound transmission loss is then expressed as:

$$TL_n = 10 \log_{10} \left(\left| \frac{T_{11} + (T_{12} / \rho c) + \rho c T_{21} + T_{22}}{2e^{jkd}} \right|^2 \right) \quad (15)$$

SAMPLING OF CURRENT EMPIRICAL STUDIES

In the origin work by Tao and Seybert [1], a muffler was tested. Separate studies by Jung, et al and Kino and Ueno [3,5] focused on single layer porous materials such as glass wool, fiber and foam. Yousefzadeh, et al [4] studied single layer impermeable materials including lead, plywood and steel. In the paper by Barnard and Rao [6] four different multi-layered material combinations of fiber, foam and rubber were tested. Purposefully they tested symmetrical samples with an understanding that the transfer matrix function should result in theoretical numerical errors. Both Yousefzadeh, et al and Barnard and Rao made comparison testing with the traditional two-room method. In particular Yousefzadeh, et al employed the sound pressure technique while Barnard and Rao employed sound pressure, sound intensity and field transmission loss techniques.

Yousefzadeh, et al concluded that the two methods have good correlation for the plywood sample tested. Although not explicit in his discussion, but by examining the data from the