MEASURING ACOUSTIC TRANSMISSION LOSS USING THE 3-POINT METHOD

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1. Introduction

The use of dual simultaneous microphone measurements has been known to produce very good results that are just as accurate as single traveling microphone techniques, and much faster. The best use of this is the measurement of the normal incidence absorption coefficient of sound absorbing materials with the standing wave impedance tube (1). It is this methodology of dual simultaneous microphone measurements that can be applied to the measurement of transmission loss in silencer systems to eliminate the requirement of a replacement, un-silenced section (as the current methods require).

This paper covers the derivation and use of the 3-point method for measuring transmission loss where dual simultaneous measurements are taken to obtain the incident sound pressure levels.

2. Theory

The definition of transmission loss is the ratio of the incident intensity of sound to the transmitted intensity. Since intensity is difficult to measure, we typically make use of the proportionality of intensity to the mean square pressure. As long as the inlet and outlet regions of the silencer are of the same cross section, and the properties of the fluid (density, temperature) do not significantly change, then the *TL* can be expressed as:

$$TL = SPL_i - SPL_t \qquad (1)$$

where it is understood that SPL_i is measured without the silencer in place, and SPL_t is measured with the silencer in place, on the exhaust side of the silencer. This method (hereafter referred to as the *traditional* method) is how most standards call for the *TL* to be measured (2,3). The standards usually require the use of an anechoic or reverberation chamber for testing.

The derivation of the 3-point method incorporates the auto and cross power spectrum which can be obtained by most dual channel simultaneous measurement systems. We begin with the general solution to the 1-D wave equation for points 1 and 2 (4):

$$P_1 = \left(P_i e^{-ikx_1} + P_r e^{ikx_1}\right) \quad P_2 = \left(P_i e^{-ikx_2} + P_r e^{ikx_2}\right) \qquad (2a,b)$$

where: $k = 2pf/c$ (wave number) (1/m)
w = frequency (rad/s)

Figure 1 illustrates the location of the 3 points used as well as the incident, P_i, reflected, P_r, and transmitted, P_t, pressure waves.

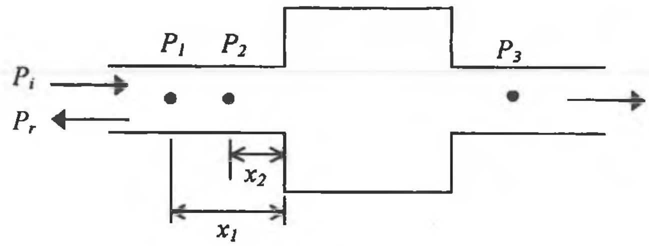

Figure 1. 3-point *TL* measurement locations

For transmission loss, only P_i is required. This quantity cannot, however, be measured at a single point, since P_r will also be present. To overcome this problem and the difficulty in measuring the complex values for P_1 and P_2, one can obtain the following auto and cross power spectrum from points 1 and 2 with a dual channel, simultaneous data acquisition system:

$$P_{11} = P_1 P_1^* \qquad P_{22} = P_2 P_2^* \qquad P_{12} = P_1 P_2^* \qquad (3a,b,c)$$

where $P_1{}^*$ and $P_2{}^*$ denote the complex conjugates of P_1 and P_2 respectively. These quantities of P_{11}, P_{22}, and P_{12} (represented by capitals because they are vectors in the frequency domain) can be readily measured. By substituting Eqs. (2a,b) into Eqs. (3a,b,c) a system of three equations and three unknowns can be formed for the auto power spectra of the incident and reflected waves (P_{ii}, P_{rr}) along with the cross power spectra between the two (P_{ir}). By knowing x_1, x_2, and k, the system of equations can be solved for P_{ii} (since only the incident portion of the wave is of interest):

$$P_{ii} = \frac{P_{11}(E - DB) + P_{22}(DA - E) + P_{12}(B - A)}{(B - A)(C - D)} \qquad (4)$$

where:

$$A = e^{2kx_1}\left(e^{-i} + e^{i}\right) \quad B = e^{2kx_2}\left(e^{-i} + e^{i}\right) \quad C = e^{-ik(x_1 - x_2)}$$

$$D = e^{ik(x_1 - x_2)} \quad E = e^{k(x_1 + x_2)}\left(e^{-i} + e^{i}\right)$$

Once P_{ii} is known, the third point can be used to measure P_{tt}. Finally, the transmission loss can be calculated by:

$$TL = 10\log_{10}\left|\frac{P_{ii}}{P_{tt}}\right| \quad (dB) \qquad (5)$$

The important thing to note is that the measurements at points 1 and 2 **must** be taken simultaneously. This is necessary in order to obtain the proper phase in the cross product between the two.

3. Discussion of Results

All testing for this work was conducted using a custom built model of a duct silencer system. The system, shown in Fig. 2, consisted of a source end with a straightening section (for plane wave propagation), a test section with variable parallel baffle configurations, and a termination section with an anechoic termination (to prevent reflected waves from returning after the sound has left the test section).

The *traditional* method was used as the standard by which the 3-point method would be compared. To accomplish this, the incident sound pressure (P_i) was measured with the test section completely empty, and then baffles of sound absorbing material were installed for the transmitted sound pressure measurement (P_t). This same baffle configuration was used for the three sound pressure level measurements used for the 3-point method (P_1, P_2, P_3).

Figure 3 displays the results (presented using 1/3 octave analysis) of the *traditional* and 3-point methods for a section with one 10cm thick baffle of yellow fiberglass insulation, along with the difference between the two. Two dashed lines have been placed on the graph to illustrate a ± 3dB region. This region has been chosen as the range in which no perceptible difference between methods would be noticed by the end user, and as a region in which repeatable test results can be expected. It can be seen that for all of the useful frequency range, the differences between the two methods are very small, and follow the center (0dB difference) line very well.

Various Microphone locations were tested to determine which locations would give the best results. The two upstream mics were found to give the best results when they were kept quite close to each other (less than 5cm center-to-center gap) and as close to the test section as reasonably possible. Similarly, it was found that the location of the downstream mic did not have an appreciable impact on the results, as long as it was located as close to the test section as was reasonably possible.

4. Summary and Conclusions

Traditional measurement of transmission loss (*TL*) involved measuring sound pressure levels with and without the silencing element in place. Proposed in this paper was a method for measuring *TL* that can be performed entirely while the silencing element is in place. In order to accomplish this, two measurement points are used upstream of the silencing element to obtain the pre-silencing conditions (two points needed to resolve the incident and reflected portions of the sound waves) and a third is used downstream to obtain the post-silencing conditions. This 3-point method has been shown to match the results of the *traditional* method very well. With this method, silencers can be tested for *TL* in field (*"in-situ"*) conditions for easier post-installation evaluation.

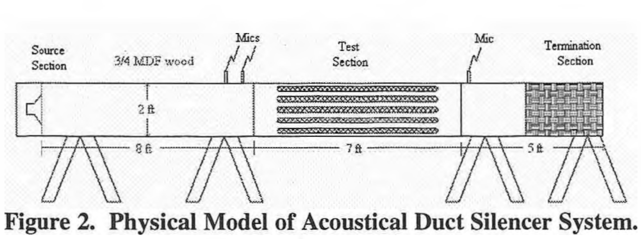

Figure 2. Physical Model of Acoustical Duct Silencer System.

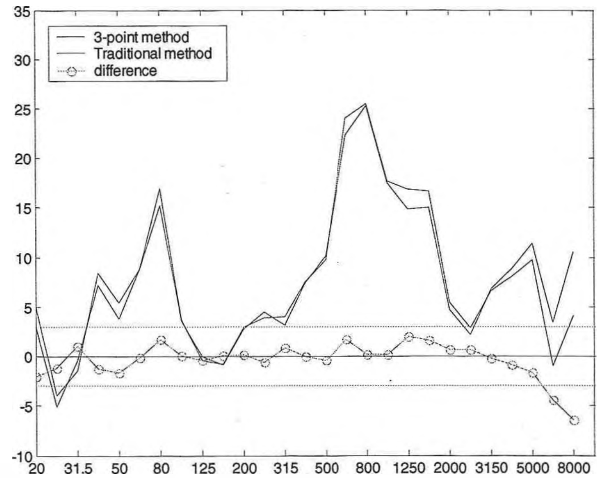

Figure 3. TL of traditional and 3-point methods for single baffle of 10cm thick yellow fiberglass insulation.

5. Acknowledgements

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