ACOUSTIC ATTENUATION PERFORMANCE OF DOUBLE EXPANSION CHAMBER SILENCERS WITH INTER-CONNECTING TUBE

Zhenlin Ji
Silex Inc., 6659 Ordan Drive, Mississauga, Ontario L5T 1K6

1. INTRODUCTION

The multi-chamber reactive silencers are widely used to reduce the engine exhaust noise, due to their broadband high noise attenuation. The one-dimensional analytical approach, which assumes plane wave propagation in the axial direction in silencers, is a classical method for the prediction of silencer's acoustic attenuation performance. However, The one-dimensional theory cannot account for the effect of multi-dimensional waves inside the silencers on the acoustic attenuation performance. The experimental and one-dimensional analytical studies on the double chamber silencers [1] demonstrated that a multi-dimensional approach is required for the accurate prediction of acoustic attenuation performance of the silencers at higher frequencies, while the simple one-dimensional theory provides reasonable predictions at lower frequencies. The objective of this study is to apply the three-dimensional boundary element method (BEM) to predict the acoustic attenuation performance of double expansion chamber silencers with inter-connecting tube and to investigate the effect of geometry with respect to the acoustic attenuation of these configurations.

2. FORMULATION

To employ the boundary element method for the prediction of the acoustic attenuation performance of double chamber silencers with inter-connecting tube, a multidomain approach is needed due to the presence of singular boundaries [2, 3]. The silencer considered here is divided into five substructures as shown in Figure 1: inlet tube, inlet expansion chamber, inter-connecting tube, outlet expansion chamber, and outlet tube. For each substructure, the BEM gives [2, 3]

$$[H^j]\{P^j\} = \rho_0 c_0 [G^j]\{V^j\}, \qquad (1)$$

where $[H^j]$ and $[G^j]$ are the coefficient matrices; $\{P^j\}$ and $\{V^j\}$ are the vectors of acoustic pressure and outward normal particle velocity at boundary nodes, respectively, for the substructure j; $\rho_0 c_0$ is the characteristic impedance of the medium. The boundaries are grouped into the inlet, outlet and rigid wall represented by the subscripts i, o and w, respectively. Equation (1) combined with the rigid wall boundary condition $V_w = 0$, yields

$$\begin{Bmatrix} P_i^j \\ P_o^j \end{Bmatrix} = \rho_0 c_0 \begin{bmatrix} T_{11}^j & T_{12}^j \\ T_{21}^j & T_{22}^j \end{bmatrix} \begin{Bmatrix} V_i^j \\ V_o^j \end{Bmatrix}, \qquad (2)$$

For two series substructures, the resultant impedance matrix can be derived by the continuity conditions of acoustic pressure and particle velocity on the interface as

$$[T^R] = \begin{bmatrix} T_{11}^1 - T_{12}^1 (T_{11}^2 + T_{22}^1)^{-1} T_{21}^1 & T_{12}^1 (T_{11}^2 + T_{22}^1)^{-1} T_{12}^2 \\ T_{21}^2 (T_{11}^2 + T_{22}^1)^{-1} T_{21}^1 & T_{22}^2 - T_{21}^2 (T_{11}^2 + T_{22}^1)^{-1} T_{12}^2 \end{bmatrix} \qquad (3)$$

Finally, combining all substructures yields

$$\begin{Bmatrix} P_i \\ P_o \end{Bmatrix} = \rho_0 c_0 \begin{bmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \end{bmatrix} \begin{Bmatrix} V_i \\ V_o \end{Bmatrix}, \qquad (4)$$

which defines the impedance matrix between the inlet and outlet of silencer. The four-pole parameters and the transmission loss calculation procedure are identical to those used earlier [3] and will not be elaborated here.

3. RESULTS AND DISCUSSION

For all configurations, the present study considers D=18" for the chamber diameter, d=6" for the inlet/outlet and inter-connecting tube diameters, and c=550 m/s for the speed of sound. For the silencers with chambers of equal lengths, Figure 2 compares the transmission loss for three different inter-connecting tube lengths. Increasing the length of inter-connecting tube shifts the resonance peaks to lower frequencies. The effect of unequal lengths of inter-connecting tube extended into two chambers is examined next by keeping the overall length of inter-connecting tube and fixing all other parameters, and the transmission loss results are shown in Figure 3. The longer extension in a chamber leads a lower resonance frequency and a lower attenuation dome after the resonance. An observation for the silencers with chambers of equal lengths is found that the troughs in the transmission loss are located at $kL_{S1} = kL_{S2} = n\pi$, and were not changed by the lengths of inter-connecting tube in the chambers. The effect of unequal lengths of chambers by fixing the lengths of silencer and inter-connecting tube and changing the location of bulkhead is shown in Figure 4. The first low attenuation dome is independent on the locations of inter-connecting tube and bulkhead, while the attenuation behavior is complex above the first pass frequency for fixed overall lengths of silencer and inter-connecting tube. Figure 5 compares the transmission loss of silencers without and with inlet/outlet extensions. The inlet and outlet extensions contribute also resonance peaks in the plane wave region. The lengths of extended inlet and outlet tubes into chambers may be chosen that the resonances are located at the troughs of the silencer with no inlet/outlet extensions leading a desirable high acoustic attenuation. An example is illustrated in Figure 5 also. This behavior demonstrates the advantage of extended inlet and outlet in the silencer design.

4. CONCLUSIONS

A three-dimensional substructure boundary element technique is employed to predict the acoustic attenuation performance of double expansion chamber silencer with inter-connecting tube. The effect of the lengths of inter-connecting tube and expansion chambers, as well as the extensions of inlet and outlet tubes is investigated. The double expansion chamber silencers exhibit a very low attenuation dome at lower frequencies, and the combination of the broadband domes and resonance peaks above the first pass frequency and below the plane wave cut-off frequency. The pass frequency of the first low attenuation dome is dependent on the lengths of silencer and inter-connecting tube for a given expansion ratio. The resonance frequencies decrease as the extended lengths of tubes into the expansion chambers are increased. By choosing the lengths of extended inlet/outlet tubes to match the resonances with troughs of the silencers without extensions an excellent acoustic attenuation may be obtained. Above the plane cut-off frequency the attenuation behavior is complex.

REFERENCES

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3. Z. L. Ji, Q. Ma and Z. H. Zhang 1994 *Journal of Sound and Vibration* 173, 57-71. Application of the boundary element method to predicting acoustic performance of expansion chamber mufflers with mean flow.

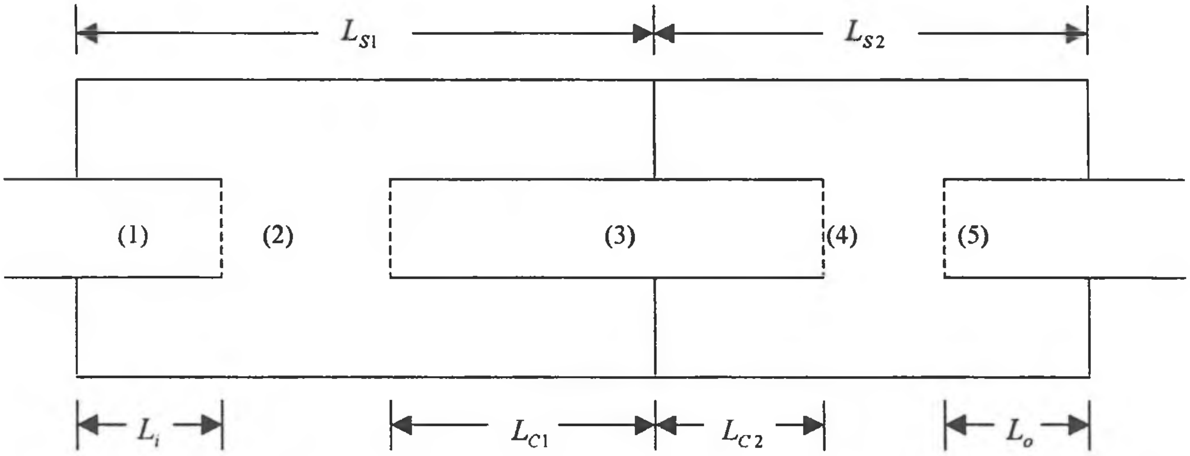

Figure 1. Double expansion chamber silencer with inter-connecting tube.

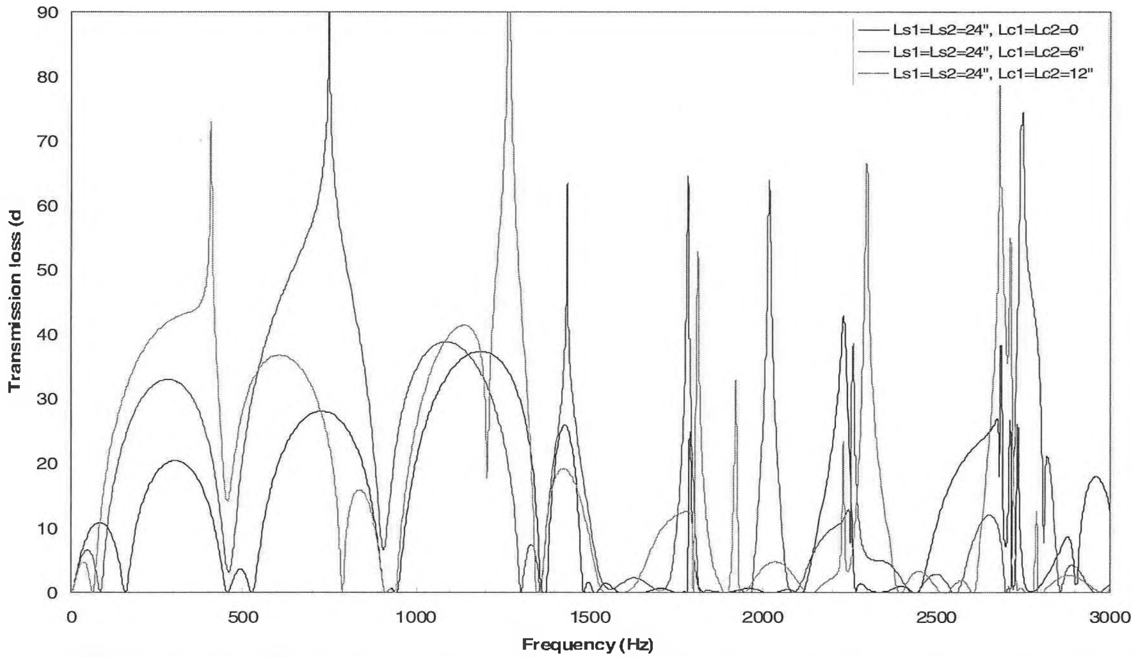

Figure 2. Effect of the length of inter-connecting tube on the acoustic attenuation performance of double expansion chamber silencers.

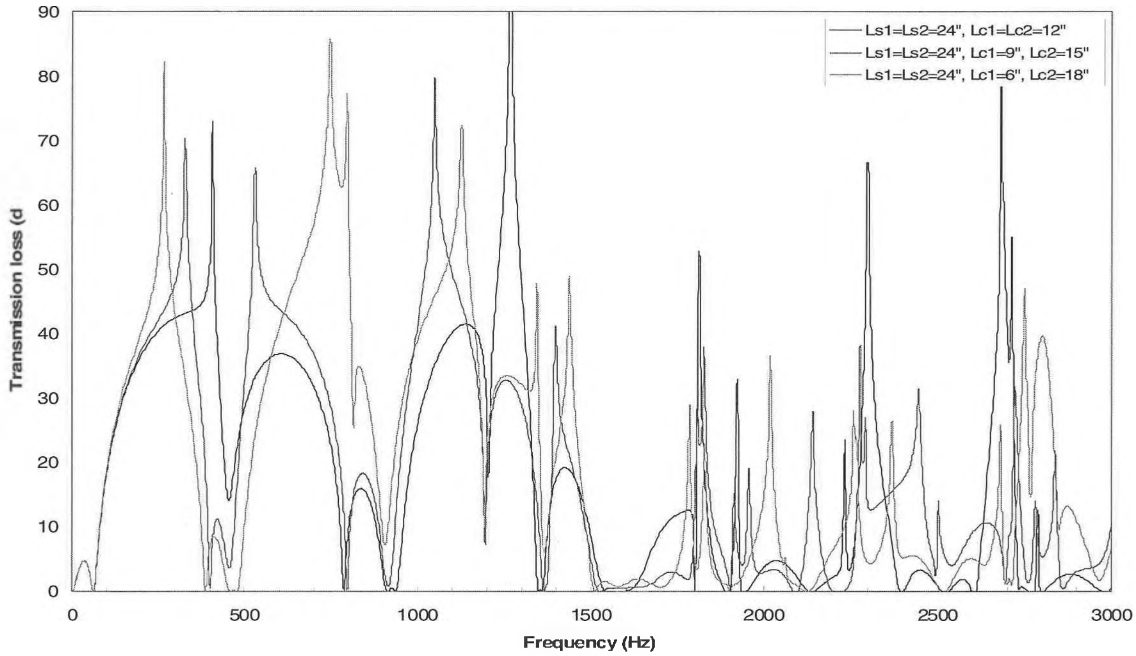

Figure 3. Effect of the extended lengths of inter-connecting tube into chambers on the acoustic attenuation performance of double expansion chamber silencers.

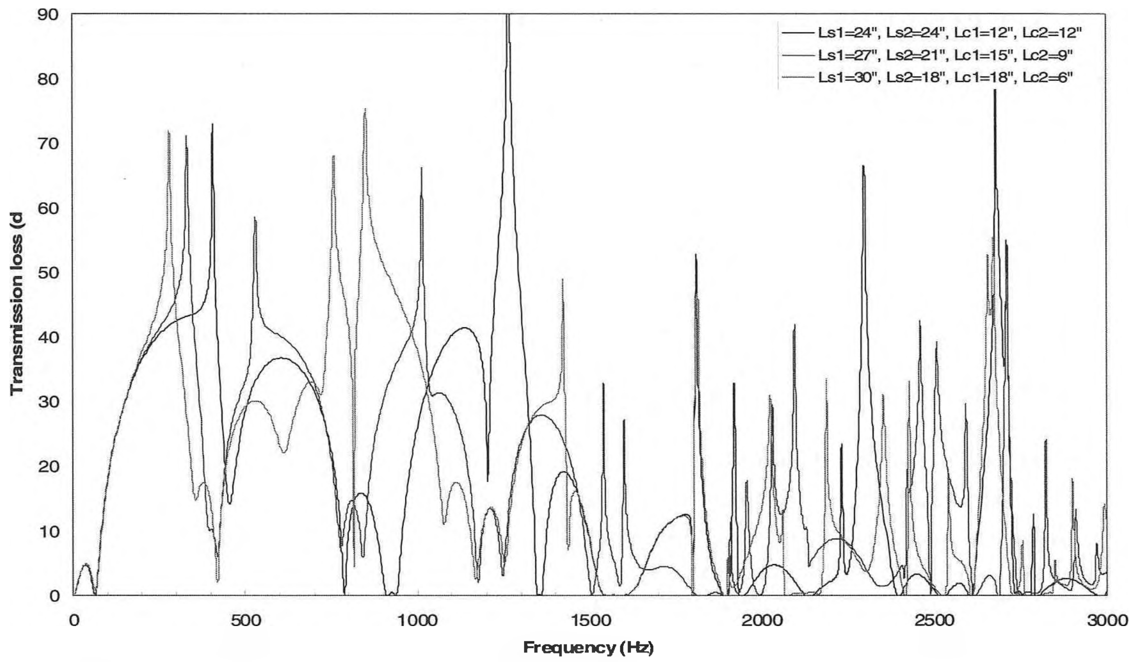

Figure 4. Effect of the lengths of expansion chambers on the acoustic attenuation performance of double expansion chamber silencers.

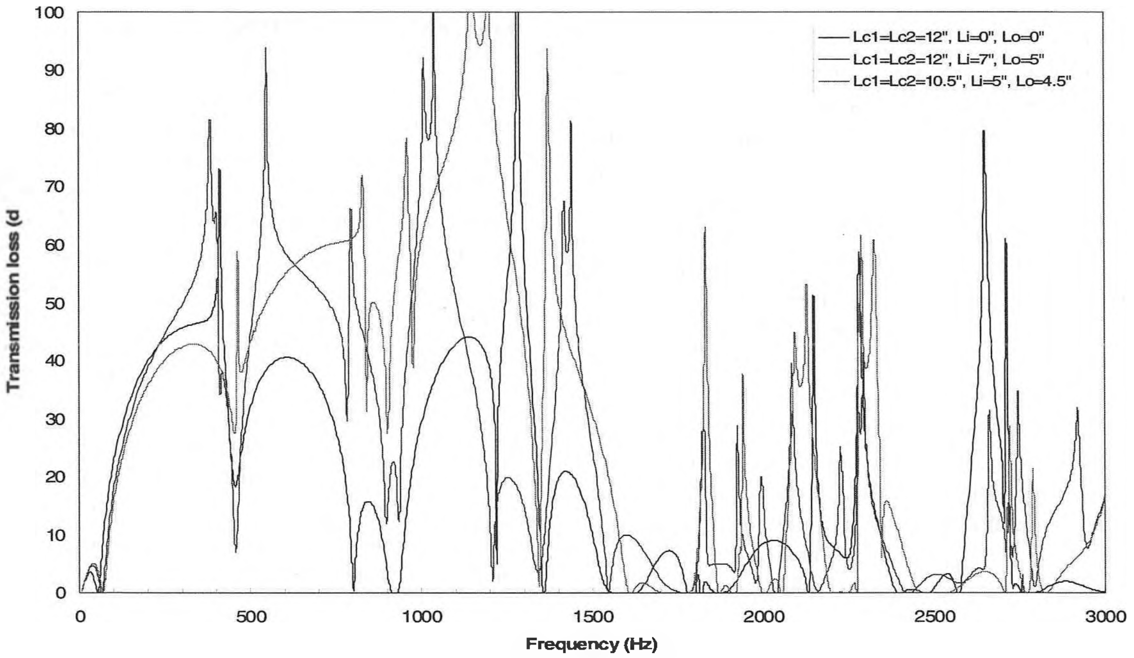

Figure 5. Effect of the inlet and outlet extensions on the acoustic attenuation performance of double expansion chamber silencers.