REDUCTION OF NOISE USING MULTIPLE EXPANSION CHAMBERS

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ABSTRACT

Expansion chambers are often used to reduce the noise in different systems like air conditioning systems, exhaust systems, and car muffler systems. This study focuses on the effectiveness of multiple expansion chambers in reducing noise in such systems. Optimized designs are realized by utilizing changes in cross sectional areas, changes in the lengths of the expansion chambers, or combined changes of both. It is found beneficial to apply taper functions to the expansion chambers' geometry, resulting in similar effects of the window functions utilized in the field of digital signal processing.

1. INTRODUTION

Expansion chambers are effective tools for reducing noise in several applications. The most familiar example is probably the automotive muffler, where a single tuned expansion chamber is utilized.

Double expansion chambers were considered by Lamancusa,[5] who calculated the transmission loss coefficients for various cases with different geometric parameters. Kim and Ih[6] studied the sound attenuation due to an expansion chamber with curved duct bends. Gerges et al.[12] studied the transmission loss caused by expansion chambers with and without inlet/outlet extend tubes. Suwandi et al.[13] considered the acoustic performance of simple expansion chamber mufflers using a plane wave transmission line theory. Wu et al.[3] presented transmission loss predictions for a single-inlet-double-outlet cylindrical expansion-chamber muffler by using the modal meshing approach. Chiu and Chang[7] performed a shape optimization analysis on multi-chamber cross-flow mufflers using SA optimization. Venkatesham et al.[11] analyzed transmission loss of rectangular expansion chamber with arbitrary location of inlet-outlet by means of Green's functions. Chiu[2] optimized the shape of multi-chamber mufflers with plug-inlet tube on a venting process using genetic algorithms (GA). Chiu and Chang[9] made a numerical assessment of a space constrained venting system with multi chamber plug mufflers by GA method. Chaitanya and Munjal[10] studied the effect of wall thickness on the end corrections of the extended inlet and outlet of a double-tuned expansion chamber.

In this study, a duct with multiple expansion chambers is analyzed. The chambers are considered with different sectional areas. The choice of the areas is determined by analytical formulae inspired by the theory of windowing often used in the field of digital signal processing. Comparison of acoustic performance is made using the calculated transmission loss spectra.

2. ANALYSIS

Although the analysis presented in this paper is made general to account for an arbitrary number of expansion chambers, focus is placed on three expansion chambers illustrated in Figure 1.

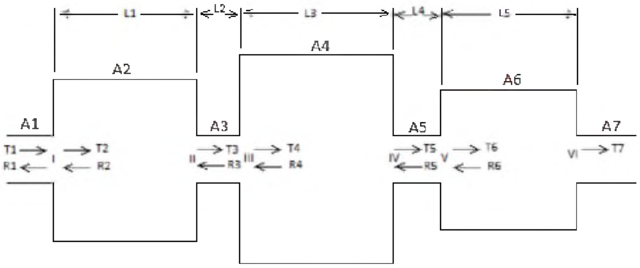

Figure 1. Geometry of three expansion chambers with unequally area chamber [Aj: Area, Lj: Length].

The theoretical transmission loss is defined as the logarithmic ratio of incident to transmitted acoustic powers as

$$TL = 20Log_{10}(T_1 / T_7)\text{..}(1)$$

where T_1 Is the pressure amplitude of the acoustic wave incident into the first expansion chamber, and T_7 is the pressure amplitude of the transmitted acoustic wave exiting the third expansion chamber.

Transmission phenomenon in a duct with expansion chambers can be considered by several methods, one of them is the transfer matrix method which is easy to program on computer to obtain theoretical values for transmission loss. Adopting acoustic pressure P and mass velocity V as the two state variables,[1] every junction in the duct system can be related to the previous junction by a matrix. Then, a global transfer matrix can relate variables at the seventh junction to those at the first junction by applying continuity conditions of pressure and volume velocity as

$$\begin{bmatrix} P(r) \\ U(r) \end{bmatrix} = \begin{bmatrix} T \quad 2X2 \quad transfer \quad matrix \\ for \quad the \quad rth \quad junction \end{bmatrix} \begin{bmatrix} P(r-1) \\ U(r-1) \end{bmatrix}\text{............}(2)$$

illustrated below

where

$\begin{bmatrix} P(r) & U(r) \end{bmatrix}$ is called the state vector at the upstream point r, $\begin{bmatrix} P(r-1) & U(r-1) \end{bmatrix}$ and is called the state vector at the downstream point $r-1$.The transfer matrix for the rth element can be denoted by [T_r].[1],[4]

Choice of the cross sectional areas of expansion chambers are based on tapering function (window function), illustrated in Table 1.

Table 1. Taper Functions[8]

Taper Functions	DSP Window
$w(n) = 0.54 - 0.46\cos(\frac{2\pi n}{N-1})$	Hamming Window
$w(n) = \cos(\frac{\pi n}{N-1} - \frac{\pi}{2})$	Cosine Window
$w(n) = n$	Linear Window
$w(n) = 1$	Rectangular Window

In figure (1) let $A_1=A_3=A_5=A_7$, so in Hamming and linear window $A_2 < A_4 < A_6$ depend on table (1) and for Cosine window $A_2 < A_4 > A_6$, also in Decrease then Increase window $A_2 > A_4 < A_6$ Increase then Decrease window $A_2 < A_4 > A_6$, and in Rectangular window $A_2 = A_4 = A_6$.

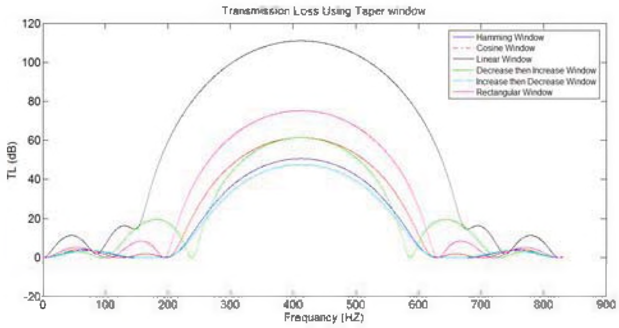

Figure 2. Transmission Loss due to three expansion chambers with various geometry.

3. RESULTS

The transmission loss due to multiple duct expansion chambers is calculated using the transfer matrix method and. The basic geometry of the expansion chambers is selected to have the following properties: $L_1 = L_2 = L_3 = L_4 = L_5 = 0.2$m, the radius of the tube = 0.1m. The areas of the expansion chambers are decided upon imposing taper functions listed in Table (1) with a mean radius of the expansion chamber = 0.21m. Thus, the areas of the chambers (A_2 , A_4 , A_6) depend on the taper function and $A_1=A_3=A_5=A_7$.

As seen in Figure 2, the transmission loss is affected by the taper function. The best result is the linear taper function according to which the areas of chamber increase or decrease linearly, it attenuate high value of transmission loss and wide range.

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