Insertion Loss of Multi-Chamber Mufflers

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1.0 Introduction

Expansion chamber mufflers are commonly used as noise control devices in piping systems, when the application of passive silencers is not possible. Single expansion chamber mufflers has been studied extensively [1, 2, 3]. Lamancusa [4] conducted a parametric study on the transmission loss of double expansion mufflers. However, insertion loss is more meaningful than transmission loss for the effect of the inlet and tail pipe lengths are properly taken into account. A parametric study on the insertion loss of two chamber and three chamber mufflers was conducted and preliminary results of our study are presented in this paper. The results of this paper assume anechoic termination at the tail pipe exit and hence the tail pipe effects are neglected. Further, the damping due to the flow medium and the pipe walls is negligible.

2.0 Solution Procedure

The details of two chamber and three chamber mufflers are shown in Figure 1. Standard solution methods usually evaluate the transmission loss of the muffler, which is the amount of sound transmitted through the muffler installed in an infinitely long pipe. Insertion loss on the other hand reflects the actual attenuation provided by the muffler. The insertion loss is defined by,

$$I.L. = 20 \log \left| \frac{P_{o,w}}{P_{o,n}} \right|, \quad dB \qquad (1)$$

where, $p_{o,w}$ is the sound pressure downstream of the muffler with the muffler in place and $p_{o,n}$ is the sound pressure at the same location without the muffler.

Three conventional methods can be used to evaluate the insertion loss of the mufflers: plane wave analysis (one dimensional wave propagation model); transfer matrix methods; and numerical schemes such as finite element methods. Plane wave analysis [1, 4] is easy to apply, but the valid frequency is limited to the size of the muffler components. Munjal [2] has used transfer matrix methods extensively and in this paper, we have applied finite element discretization to evaluate the insertion loss.

Craggs [3] developed a finite element code to solve for the insertion loss of reactive mufflers. Misra and Ramakrishnan [5] used an existing standard structural finite element package with acoustic elements, ABAQUS, [6] to solve for the acoustics of complex heat transport piping systems. Details of the finite element formulation and its acoustical application are given in references 5 and 6. In the present paper, the outlet of the muffler system is assumed to be anechoically terminated and hence the effect of the tail pipe is neglected. The preliminary results focus on the effects of: the inlet pipe length; and the lengths and cross sectional sizes of the two chamber and three chamber muffler elements. Both one dimensional and two dimensional elements (the chosen examples are axi-symmetric) are used to evaluate the applicable frequency range of the one dimensional models. Comparison with transmission loss results of Lamancusa [4] for a two chamber muffler is also presented to highlight the limitations of transmission loss calculations.

3.0 Results and Discussion

The insertion loss results were calculated for four (4) two chamber and for four (4) three chamber mufflers. The details of the mufflers are outlined in Table 1. The results for Case 1. are shown in Figure 2. The insertion loss evaluated using a plane wave model, One-D acoustic elements as well as the transmission loss are presented in Figure 2a. The plane wave predictions agree very well with the finite element results. Even though the spectral trend is similar, the transmission loss fails to account for the resonances of the inlet pipe (3 m for Case 1.), where as the insertion loss properly accounts for the reduced noise loss at the various inlet pipe frequencies. If source frequencies happen to match with the inlet resonances, the muffler would have negligible effect. The transmission loss calculations would not have recognized the shortcoming of the muffler. The insertion loss values are seen to be higher than the transmission values. The effective bandwidth between the two predictions seems to be comparable if one neglected the inlet pipe effects. The insertion loss evaluated using One-D and Two-D acoustic elements in ABAQUS is shown in Figure 2b. The two results agree well with each other up to about 110 Hz and start to diverge even though the loss spectra are similar. The wave length at 110 Hz is 3 m. The expansion chamber dimension becomes comparable to the wavelength and the Two-D effects (higher order axial and radial modes) become important.

The insertion loss results for double expansion chamber mufflers are presented in Figure 3. The effect of the inlet pipe is reflected in the dip around 55 Hz. The width of the passband and the magnitude of the maximum insertion loss are used to evaluate the muffler performance. The maximum insertion loss was 49 dB with a passband of 40 Hz was calculated for Case 1. The effect of changing the length is seen in Cases 2 and 4. The maximum insertion loss reduced to around 41 dB with a passband of 20 Hz (one half of the value of Case 1). Reducing the area ratio of even one chamber reduced the maximum insertion loss by about 5 dB. This behaviour is similar to single chamber mufflers, except that the insertion loss of double chambers can be as high as 50 dB for an expansion ratio of 16. The maximum insertion loss of a single expansion chamber of comparable dimensions is about 25 dB [5].

The insertion loss results for triple chamber mufflers are presented in Figure 4. The results are very similar to the double chamber mufflers. The maximum insertion loss is much higher for triple chamber than for double chamber mufflers. The maximum insertion loss is 74 dB with a passband of 40 Hz for Case 1. If the dominant lengths are modified (Case 2 and Case 4), the maximum insertion loss reduces by 9 dB to 64 dB with halving of the passband to 20 Hz.

4.0 Conclusions

Preliminary results of the insertion loss of double and triple expansion chamber mufflers were presented. The behaviour of the mufflers was seen to be similar to that of a single chamber muffler. The main salient result was that the amount of insertion loss can be substantially increased by the use of the more chambers if possible. The passband width can be better controlled with two and three chamber mufflers as compared to the single chamber muffler. The triple chamber muffler therefore offers the maximum performance as compared to a single chamber muffler of comparable overall dimensions.

References

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5. A. Misra and R. Ramakrishnan, "Application of ABAQUS to Acoustical Modelling," Proceedings, ASME PVP Conference, Vol. 235: Design and Analysis of Pressure Vessels, Piping and Component, 1992.

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Table 1. Details of Muffler Parameters

	Double Chambers			Triple Chambers		
	L_4	L_3	d_3/d_1	L_4	L_6	d_4/d_1
Case 1	1	1	4	1	1	4
Case 2	2	1	4	2	1	4
Case 3	1	1	3	1	1	3
Case 4	1	2	4	1	2	4
L_1 = 3 m, d_1 = .305 m	L_2 = 1, d_2/d_1 = 1			L_2=1, L_3=1, L_5=1, d_2/d_1=4, d_3/d_1=4		

Figure 1. Details of Expansion Chamber Mufflers

a) Double Chamber Muffler b) Triple Chamber Muffler

Figure 2. Compariosn of Insertion Loss Results

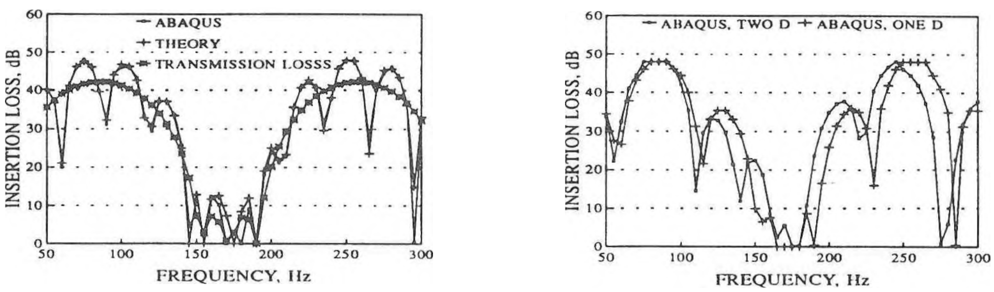

Figure 3. Insertion Loss Results for Double Chamber Muffler

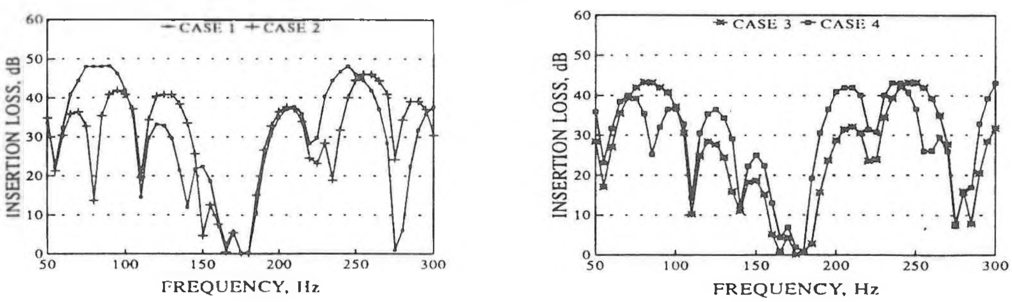

Figure 4. Insertion Loss Results for Triple Chamber Muffler