Improving muffler performance using simulation-based design

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ABSTRACT

It is well-known that the reactive type muffler gives effective noise attenuation at lower frequencies but fail to attenuate higher-frequency noise. On the contrary, dissipative type can absorb high-frequency noise but cannot reduce the low-frequency noise effectively. To combine the merits of each type, a hybrid muffler design was proposed and the performance could be improved in the frequency range of interest. To this end, computational acoustic models based on Boundary Element Method (BEM) were successfully developed for predicting Transmission Loss (TL) of exhaust mufflers which have perforated tubes backed with or without bulk sound absorbing materials (fibers). With these models, TLs of the muffler(s) proposed were simulated and evaluated. In addition, simulation-based muffler analysis was carried out for parametrical studies of the muffler and efforts have been made to enhance TL in low frequency range.

Keywords: Exhaust Muffler, Finite Element Analysis, Boundary Element Method, Acoustic Characteristics, Flow Characteristics, Improved Design I-INCE Classification of Subjects Number(s): 34.1 34.2 35.6

1. INTRODUCTION

Mufflers have been extensively used to reduce the noise from various vehicles. There are two basic types of mufflers: reactive and dissipative. Reactive mufflers are generally efficient for low frequency noise attenuation and dissipative ones are very good for high frequency noise reduction (1). It is desired that to combine both types and thus have the muffler effective in broad band noise.

Traditionally mufflers are designed based on empirical formulae and the two-port network theory with use of four-pole parameters (2) and transfer matrix method (3). However, in the current project, we demonstrated the modeling technique using computational software ANSYS and SYSNOISE for a single chamber muffler with fibres (4). Then we gave designs of a hybrid muffler and showed the effectiveness in the low frequency range of interest. Some selective cases are reported here.

2. METHODS

2.1 Geometrical and FEM Modeling

The Advanced Parametric Design Language (APDL) of ANSYS is used to write macro/script files which can build muffler mesh upon having desired design parameters. This is mainly because the meshing capability limitation of SYSNOISE. The mesh is then imported to SYSNOISE for acoustics analysis with proper boundary conditions.

The basic muffler to be used for acoustic analysis is shown in Figure 1, with the geometrical parameters listed in Table 1. It is a single chamber muffler with a going-through pipe. The pipe has perforations at the portion inside the chamber. Bulk sound absorbing material (fiber) is used to fill the interior of the chamber.

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Table 1 – Geometrical parameters of the muffler

Parameters	values
Total length L_1	746 mm
Cavity length L_2	346 mm
Going-through pipe diameter D_1	24.4 mm
Pipe thickness t_w	0.5 mm
Inner cavity diameter $D_2 = D_1+2t_w$	25.4 mm
Cavity diameter D_3	73 mm
Hole diameter d_h	3 mm

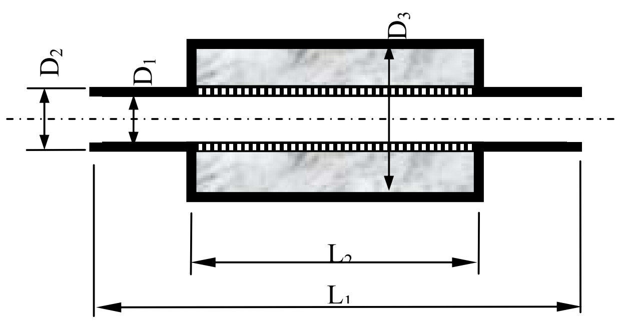

Figure 1 – Schematic drawing of a passive muffler

2.2 Boundary Conditions

After reading the acoustic FEM mesh of the muffler, the respective boundary conditions are defined onto the model. As an excitation, the velocity condition (v = -1 m/s) is specified at inlet (z = 0). It simulates the piston acoustic source at the inlet of the muffler. To represent the anechoic end for calculating transmission loss, the impedance boundary conditions, ($Z_0 = \rho_0 c_0$), has to be specified at the outlet of the muffler. ρ_0 and c_0 are the density and sound speed of the acoustic medium, air.

It is critical to model the perforation tube with or without fibre filling the expansion chamber. The relevant acoustic parameters of the thin perforated sheet is listed in Table 2.

The SYSNOISE model is shown in Figure 2.

Table 2 Geometrical parameters and physical properties of a perforated thin sheet

Parameters	Value
Density of air: ρ=	1.225 kg/m3
Sound speed in air: c=	340.0 m/s
Diameter of the hole: d_h	ϕ0.003 m
Thickness of the sheet: t_w	0.5 mm
Porosity: σ	0.2827
Flow resistivity: R	4896 Rayls/m

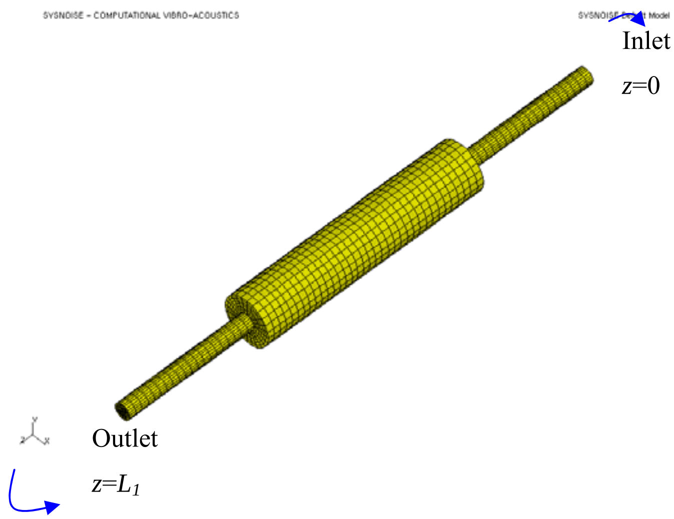

Figure 2 – SYSNOISE model of the passive muffler

3. RESULTS AND DISCUSSIONS

3.1 Single Chamber Muffler

3.1.1 Effect of Porosity

To study the effect of porosity, the porosity is changed from 5% to 85% with a step 10%. Figure 1 shows the simulation results. It can be drawn that: a) Large porosity is good for low frequency. b) Small porosity is good for high frequency

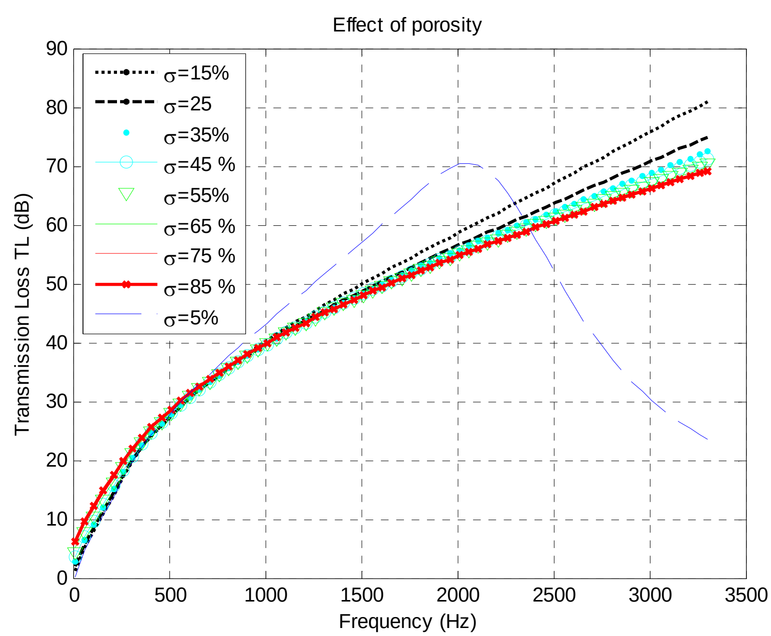

Figure 3 – TLs of SCM with different porosity design

3.1.2 Effect of Length and Diameter

The volume of the chamber is unchanged but the length is changed to 0.5 0.75 1.25 1.5 of its original length. Table 3 lists the chamber length and diameter for different cases.

Table 3 – length and diameter for different designs

Design	I	II	III	IV	V
Diameter	100	83	73	66	63
Length	173	259	346	432	484

Figure 2 shows the simulation results. From the figure, we can conclude that: a) Long chamber is good for high frequency reduction. b) At low frequency range, length effect is not monotonous. Original 28% may be a good design.

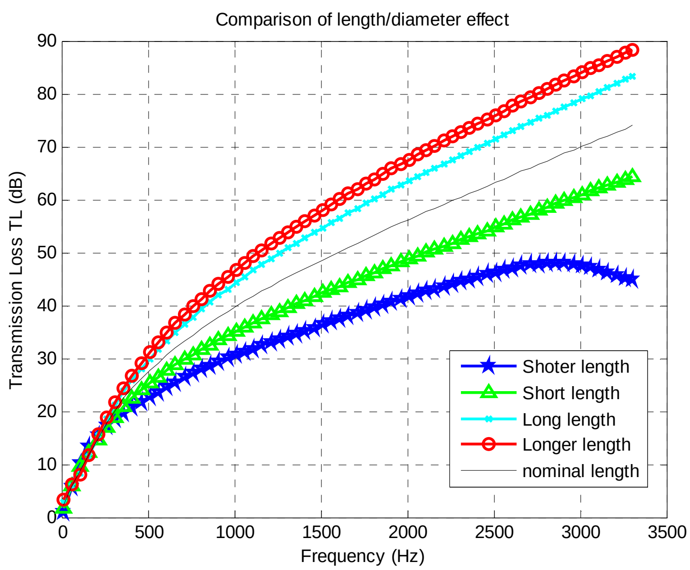

Figure 4 – Effect of length/diameter change

3.1.3 Effect of Resistivity

All above simulations are based on R=17378. Now we want to see the effect of resisitivity. From the simulation results, we found that small resistivity is good for low frequency but large resisitivity is good for high frequency, regardless of different porosity.

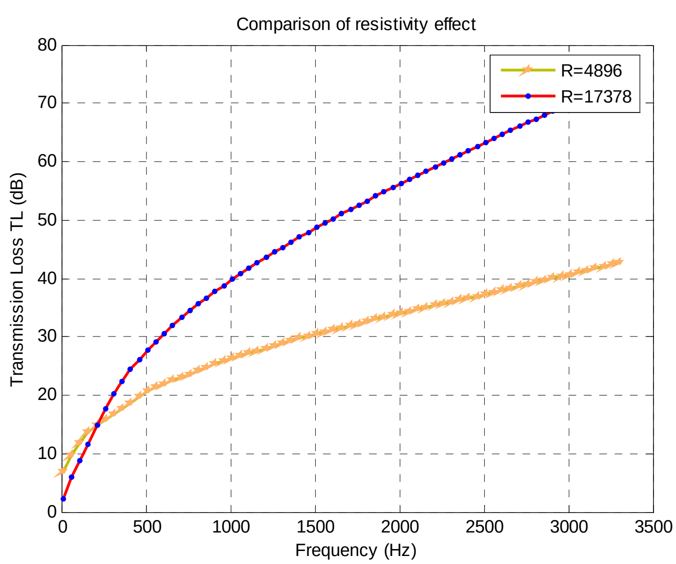

Figure 5 – TLs of SCM with different resisitivity

3.2 Hybrid Muffler

To increase the sound attenuation capability of the muffler, a hybrid muffler consisting of a straight through perforated tube resonator and a perforated tube absorptive chamber is investigated, as shown in Figure 6. Actually, it is created by dividing the previous muffler into two parts. Figure 7 shows the effect of porosity. It is noticed that the bandwidth around the working frequency is very narrow due to the small resonator volume. Among five cases, the muffler with a porosity of 8.27% behaves the best acoustic performance in the higher frequency range.

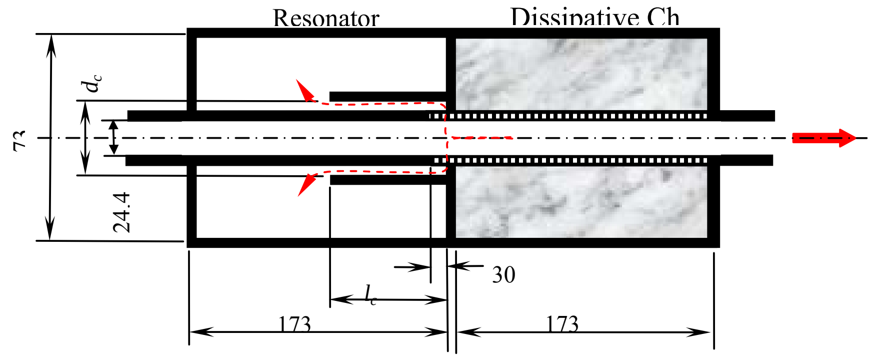

Figure 6 – Schematic of a hybrid muffler

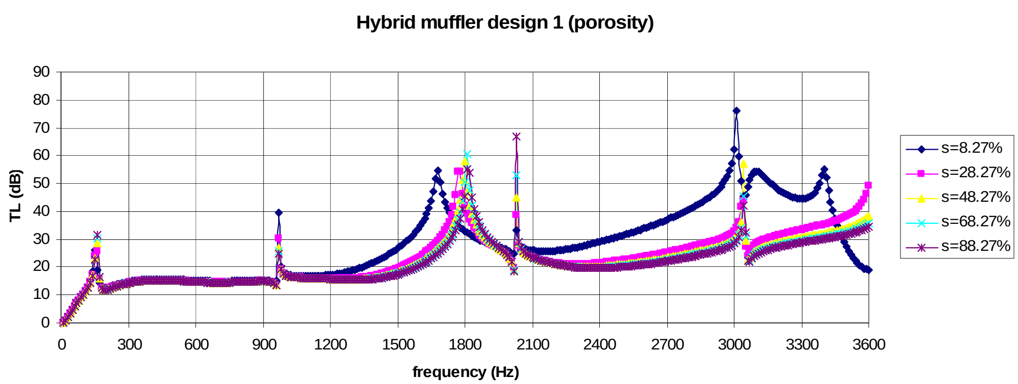

Figure 7 – TLs of hybrid muffler design 1 with different porosities

4. CONCLUSIONS

We have discussed the design of exhaust muffler of both single chamber and hybrid using computational modeling and simulation. A lot of parameters can be investigated based on the models. The simulation results show that hybrid can improve the performance at working frequency.

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