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ACOUSTICAL SIMULATION AND ANALYSIS ON THE RESONATOR MUFFLER

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ABSTRACT

With the modernisation of transport during the period of industrial urbanization, vehicles on the road are increasing, and it brings noise disturbances caused by the internal combustion engine of vehicles. This study involves the acoustical model development and analysis of the vehicle muffler. In this study, the resonator type of muffler is considered, and the transmission loss (TL) is used as the parameter to evaluate the acoustic performance of the muffler. The muffler CAD model is created using Solid works, and the acoustical analysis is conducted using COMSOL Multiphysics. The developed muffler model is tuned several times to obtain the optimum TL. The study yielded a wide range of TL across a range of frequencies. It is found that constrictions to the intake and exhaust pipes generated a higher TL by ~20dB than the original dimensions. Using an acoustic dampener further increases the TL of the muffler with a maximum increase of 18%. The inclusion of an acoustic dampener paired with the reduced diameter of the intake and exhaust pipes resulted in the analytical model generating the highest TL in the resonator muffler.

Keywords: noise, transmission loss, resonator muffler, acoustical simulation, sound frequency.

INTRODUCTION

A muffler in a vehicle works as a silencer that performs sound attenuation to diminish the noise resulting from the internal combustion that happens in the engines. The frictions of the engine's components produce loud noise that gets routed to the exhaust system of automobiles. The muffler acts as the final noise-cancelling mechanism before the sound waves are projected to the surrounding environment. One of the most significant factors affecting the muffler's noise-cancelling capability is the absorptive material used and the shape of the muffler [1]. The primary purpose of this study is to build an acoustical simulation analytical model for the resonator muffler and analyse the sound transmission loss (TL) of the resonator muffler with respect to shape modification. A reactive or resonator muffler consists of several chambers that allow a portion of sound waves to reflect its source to cancel itself [2]. The process used by the muffler to perform noise cancellation is called frequency selection. The design of the reactive muffler and the travel of the sound waves are referenced in Figure-1.

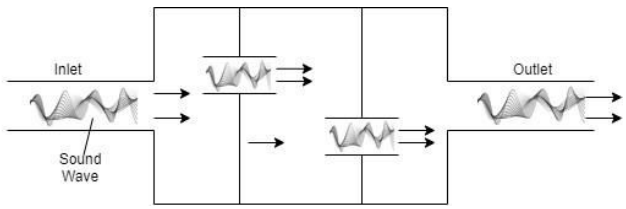

Figure-1. Mobility robot footrest.

Modifications to the geometry or preciseness chamber size will affect the TL of the muffler system. In the previous studies, most muffler analyses are often obtained using TL via the Transfer Matrix Method (TMM) [4]. When dealing with calculations, the TL becomes a significant parameter to be considered since this indicates noise cancellation.

The sound waves that travel in a muffler via compression and rarefaction are analysed and calculated. To determine how much noise loss occurs, TL needs to be computed. In this case, the TL is calculated using the Finite Element Method or Boundary Element Method. D. Neihguk, in his study, has stated that the core module used in the analysis of sound in the muffler is the acoustic module [5]. This acoustic module is presented in COMSOL Multiphysics, where the software can visualise acoustic fields and includes specialised formulations to aid in his study. The air temperature in the muffler is one aspect to be considered when performing the study. It is one of the parameters that should be defined in the finite element analysis software [6].

METHODOLOGY

Theoretical of Simple Expansion Muffler

Transmission loss (TL) is the parameter used to measure the effectiveness of the muffler in cancelling the noise produced by the internal combustion engine. The TL can be calculated by using specific equations for the type of muffler or by utilising the transfer matrix method

(TMM) to calculate the theoretical TL in a specific muffler [7].

The TL (theoretical) can be calculated using the following equation [8].

$$TL = 10log_{10}\left[1 + \frac{1}{4}\left(m - \frac{1}{m}\right)^2 sin^2 kl\right] \quad (1)$$

m = area expansion ratio
k = wavenumber
l = length of muffler chamber

Acoustical Model Development

This part provides a brief overview of the methods used in the analytical model generation and analysis of the resonator muffler. Generally, the analysis process starts with the CAD model generation. It is conducted using COMSOL Multiphysics since it is capable of CAD modelling and analysis [9]. Chamber is selected as the basis of this study, and the schematic of a simple expansion chamber is shown in Figure-2. The chamber diameter (dc) is initially set at 300mm with a length (l_c) of 1500mm, and the inlet/outlet diameter (d_{in}/d_{out}) is initially set at 70mm. The CAD model is generated based on these initial specifications, as shown in Figure-3.

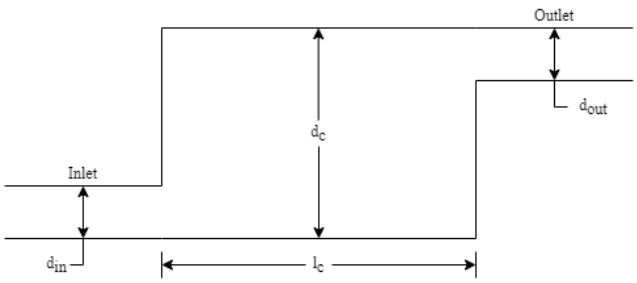

Figure-2. Schematic of simple expansion chamber [10].

Figure-3. CAD model of the simple expansion chamber.

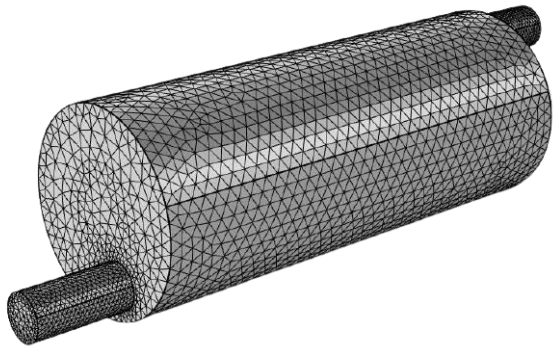

Figure-4. Extremely fine meshing of the simple expansion chamber model.

The exhaust gas temperature is set to 680 °C (953 °K) with an exhaust gas density of 0.37 kg/m^3 [11]. The mesh of the muffler is generated before the analysis is conducted, as shown in Figure-4. The element size selected for the meshing is relatively fine as higher density meshes increase the analysis's accuracy. Typically, a smaller mesh size increases computation time. However, since the component only has three domains and 18 boundaries, the computation time required is relatively low and tolerable. The completed mesh consists of 107468 domain elements, 8762 boundary elements, and 552 edge elements. The acoustic pressure frequency domain is used in this analysis [12]. The frequency range selected is from 1Hz to 1000Hz. The starting frequency is set to 1Hz with a step size of 5Hz, giving it a maximum frequency of 996Hz. A plane wave radiation is selected as the radiation boundary.

GEOMETRICAL CHANGES

Intake and Exhaust Pipe Diameters

The intake and exhaust pipes are set to an initial dimensional value of 70mm for both intake and exhaust pipes. Three variations of the simple expansion chamber resonator muffler are used to observe the effects of intake and exhaust pipes diameter constriction on the muffler's transmission loss (TL). The changes to the muffler are outlined in Table-1.

Table-1. Models dimensions.

Models 1-8 Dimensions	Dimensions (mm)							
	1A	**2A**	**3A**	**4A**	**5A**	**6A**	**7A**	**8A**
Intake Pipe Diameter,d_{in}	**70**	**20**	**70**	**20**	**70**	**20**	**70**	**20**
Intake Pipe Length, l_{in}	300							
Chamber Diameter, d_c	300							
Chamber Length, l_c	1500				1200			
Exhaust Diameter, d_{out}	70	20	20	70	70	20	20	70
Exhaust Length, l_{out}	300							

Models 1B-8B have the exact dimensions as models 1A-8A used for analysis. However, models 1B-8B have added a layer of the acoustic dampener for the TL to be studied in this analysis.

The first variation is constricting both exhaust and intake pipe diameters. In contrast, the other two variations had their diameters constricted alternatively to see if there was a substantial difference in the TL obtained. The change in intake/exhaust pipe diameters is shown in Figure-5.

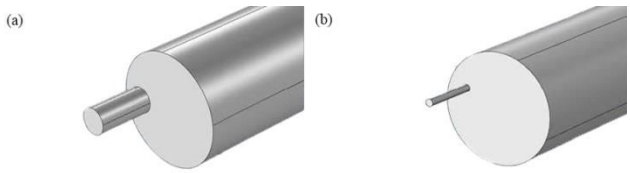

Figure-5. (a) Original intake pipe (b) Constricted intake pipe.

Chamber Length

The chamber length is the second parameter that is changed to observe the effects of chamber length on transmission loss (TL) of the muffler, as shown in Table-1. It also affects the chamber volume of the muffler. The chamber length (lc) used in the analytical model of this study is 1500mm and 1200mm. A substantial reduction of 300mm is made to examine the TL in the muffler across a range of frequencies.

Acoustic Damping

The second set of mufflers was modelled, of which a 50mm thick fiberglass dampener was added to all models. Figure-6 shows the schematic diagram of the muffler with the acoustic dampener. The acoustic dampener used in this analytical model is the E-glass fiberglass. This specific material is chosen as it has a high service temperature to allow it to be able to sustain the high-temperature environment in automotive mufflers [13].

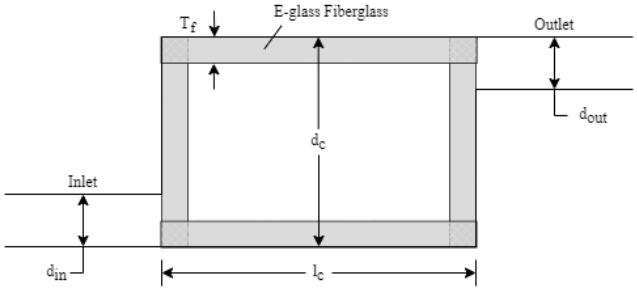

Figure-6. Schematic diagram of muffler with acoustic dampener.

RESULT AND DISCUSSIONS

Peak Transmission Loss

The peak transmission (TL) loss obtained for all Models 1B-8B is constantly higher than the peak TL obtained for Models 1A-8A. The 50mm thick fiberglass presents a substantial sound absorption in the muffler. All models experienced an increased TL of between 8-18% relative to their undampened equivalents. This is a significant increase and certainly helps in the sound attenuation of a muffler. Figure-7 shows the chart of TL versus frequency for Models 1A and 1B to visually represent the increase in TL across all frequencies until the cut-off frequency.

As observed in Figure-7, the muffler with a 50mm dampening of E-glass fiberglass obtained a higher TL, shown by the solid line. In contrast, the muffler without a dampened fiberglass layer received lower TL levels indicated by the dotted line. The increment of TL was found to be between 8 to 18% for all models, which significantly increases. The TL for all the other models exhibits the same behaviour as their fiberglass blanketed counterparts, with models 1B-8B consistently having an 8-18% increase in their respective TL.

Based on the analysis conducted, it was found that the peak TL for Models 1A and 5A are similar, with a percentage difference of 0.12%. The difference between these two models is the chamber lengths and, in turn, chamber volumes. The reduction in chamber lengths did not seem to impact the peak TL substantially. However, based on Figure-8, the muffler with the shorter chamber length can achieve a higher TL at lower frequencies. In contrast, the muffler with the original chamber length is

more capable of performing sound attenuation at higher frequencies.

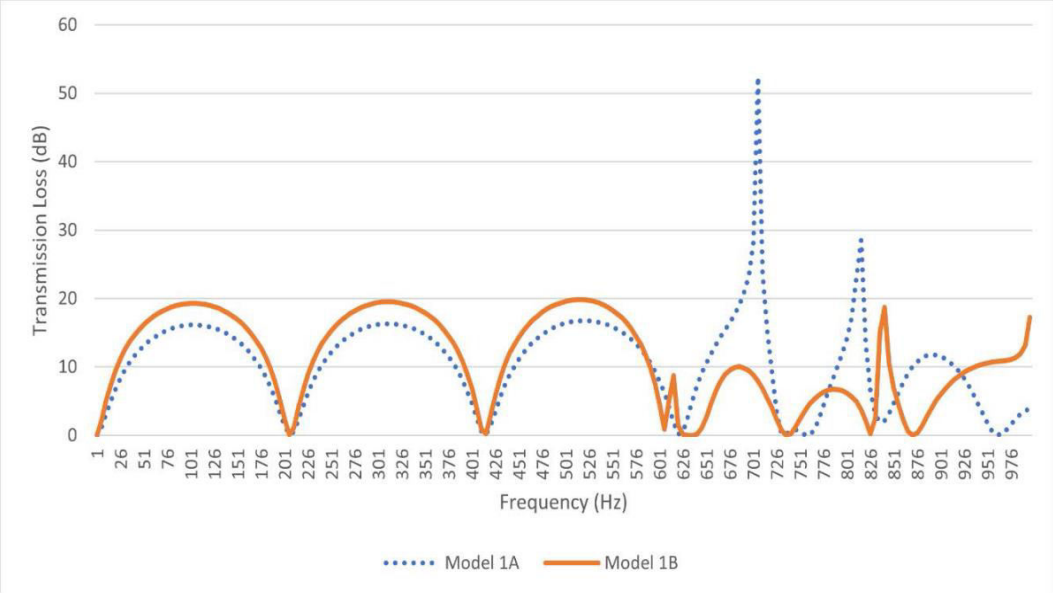

Figure-7. Models 1A and 1B transmission loss**.**

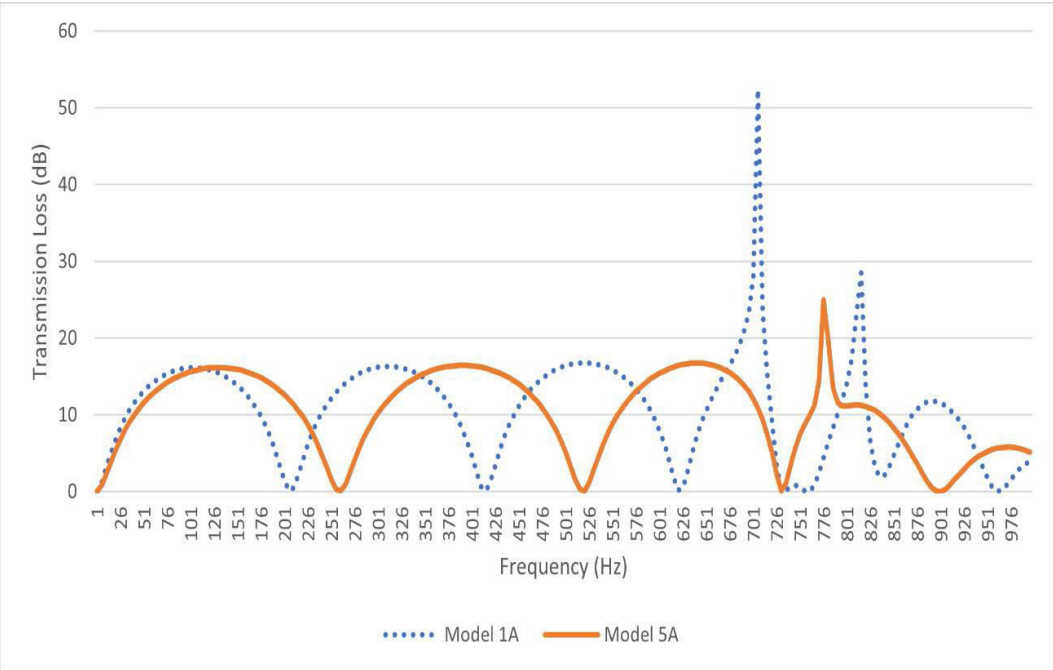

Figure-8. Models 1A and 5A transmission loss.

As observed in Figure-8, the model with the shorter chamber length depicted by the solid line achieves peak TL at lower frequencies up until ~700Hz.

Root mean square (RMS) transmission loss

Table-2 shows the transmission loss (TL) results at their peak frequency and the RMS TL for the highest and lowest RMS models obtained.

Table-2. Maximum and minimum RMS transmission loss.

Models	Peak Transmission Loss (dB) at Frequency (Hz)	Transmission Loss (dB) at 201Hz	RMS Transmission Loss
1A	16.78dB at 521Hz	1.37	12.62
6B	41.11dB at 386Hz	37.17	35.81

Table-2 shows the peak TL of Model 1A and 6B and at which particular frequency the peak TL was obtained. It is observed that the muffler model with the shorter chamber length with the addition of an acoustic dampener can achieve its peak TL at a lower frequency compared to the initial muffler model. In addition to this, at a particular frequency (201Hz), it can be seen that Model 6B achieve a higher TL compared to Model 1A. According to the RMS values, it is inferred that the best result is obtained from Model 6B. The worst outcome is from the initial model, which is Model 1A. Figure 9 shows the TL difference between the two models.

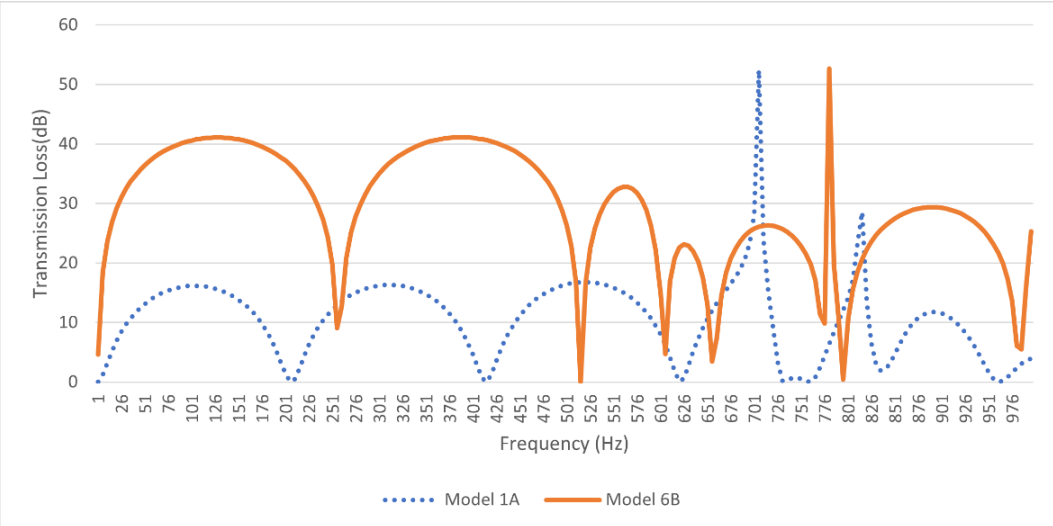

Figure-9. Models 1A and 6B transmission loss**.**

Based on the RMS TL values, the highest RMS peak TL is obtained by Model 6B, and the lowest is obtained by Model 1A, which is the initial model. Figure-9 shows the difference in peak TL for the two models. The percentage increase was found to be a sizeable 144.848% increase.

CONCLUSIONS

This study presents a simulation analysis to determine the preliminary results before manufacturing a vehicle's resonator muffler. A muffler can perform more efficiently and achieve better noise attenuation by performing geometrical modifications. The simple expansion muffler is chosen as the basis of this study, and the initial model is modelled in COMSOL Multiphysics under the Acoustic Pressure study. Geometrical changes were made to the models and the modifications performed are outlined in Table-1. The core change carried out to the muffler is the constriction of the intake and exhaust pipe diameters. Both pipes were constricted simultaneously, with subsequent models having an alternative constriction setup. However, the alternative constriction of the intake and exhaust pipes gave a similar result with little to no difference between the mufflers. Other than the intake and exhaust pipes, the muffler chamber where sound resonates and cancels out is reduced in length. Therefore, in turn, it reduces chamber volume. The peak transmission loss (TL) obtained was similar to the chamber installed with the original size and only provided a little 0.12% peak TL difference. However, the shorter chamber length muffler achieved peak TL levels at a lower frequency. To compare the performance of the resonator muffler, the second set of mufflers was analysed where there is a presence of 50mm thick fiberglass that serves as an acoustic dampener. Peak TL obtained were significantly higher with an 8-18% increase from their undampened counterparts. The constriction of both intake and exhaust pipes paired with an acoustic dampener provides the best peak TL in a muffler. A rise of 144.848% TL is obtained from the lowest to the highest peak TL across the 16 models analysed. Model 6B is the best analytical model based on RMS TL and provides the highest TL, where it offers the best noise-cancelling in the muffler.

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