EVALUATION OF EXTENDED INLET & OUTLET TUBE PARAMETERS IN SINGLE EXPANSION CHAMBER REACTIVE MUFFLER FOR MAXIMUM TRANSMISSION LOSS

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Abstract

The primary cause of noise pollution is the internal combustion engine. An item used to quiet down the exhaust system is a silencer. In order to reduce noise, it is placed along the exhaust pipe. Engine exhaust noise is one of the noise pollutants that affects the environment. Exhaust systems are created to reduce noise to acceptable decibel levels and sound quality, while emissions are calculated based on environmental standards. The two-load method is developed as a set up for experimental analysis to forecast the reactive muffler's acoustic performance. The design and operation of the silencer regulates the reduction in exhaust noise level. As a result, the silencer configuration is crucial. In this study, an effort has been made to examine various methodologies for calculating gearbox loss for extended inlet and outlet tube parameters of a reactive silencer with a single expansion chamber. The following methods are used to study the muffler's acoustic performance in detail: (1) Theoretical analysis; (2) The Finite Element Method using COMSOL Multi-Physics; and (3) Experimental validation using the method of two loads.

Keywords - Transmission Loss, Single Expansion Chamber reactive muffler, Numerical Method, Experimental Method, Inlet & Outlet tubes.

1. Introduction

Accurately predicting the reactive muffler's sound radiation properties is crucial for the design of automotive exhaust systems. When engines are used in homes or other places where noise poses a risk, noise pollution is a serious issue. Noise levels above 80 dB are harmful to human health. Additionally, diesel generator sets are frequently seen in public and business settings as a backup or additional source of electricity. Therefore, it is necessary to lessen the noise that generator diesel engines produce. Mufflers can be used to lessen the noise produced by diesel engines. Sound waves propagating along a duct can be attenuated using either an absorptive or a reactive muffler. There are several parameters that describe the acoustic performance of a muffler and/or its associated piping. These include the noise reduction (NR), the insertion loss (IL), and the transmission loss (TL). Exhaust noise from engines is one of the components of noise pollution to the environment. Numerical methods are often useful for optimization of model with complicated shapes and where the cost is involved. So, it is essential to optimize the model by Numerical Analysis and validate it by Experimental method. The internal changes in the geometry of the muffler are made to develop the impedance mismatch for maximizing the transmission loss [1]. Moreover, for a given internal configuration mufflers must work for a broad range of engine speed. The TL measured with experimental setup is compared with numerical method to demonstrate that the TL can be predicted reliably with the setup which is prepared. [2]

2. Theoretical Analysis

The empirical relation for theoretical analysis of single expansion chamber reactive muffler is given by the transmission Loss (TL) of muffler and is calculated by the following empirical formula [3].

$$TL=10\log10\ [1-1/4(m-1/m)^2 Sin^2 kl]$$

Where,
m: Expansion ratio; cross-sectional area of expansion chamber to cross-sectional area of inlet & outlet pipe.
k: Wave number; 2πf/c
c: velocity of sound, m/s
l: Length of expansion chamber; m
TL: Transmission Loss; Db

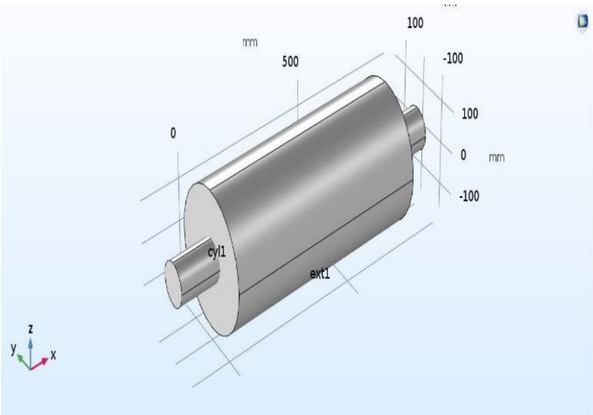
The muffler Transmission Loss for the Single Expansion Chamber reactive muffler is evaluated using theoretical analysis [4]. The design conditions used for evaluating Transmission Loss of Single Expansion Chamber reactive muffler are listed as follows

a. The length of expansion chamber is kept constant i.e., L=740mm.
b. The diameter of expansion chamber is kept constant i.e., D=160mm.
c. The diameter of inlet and outlet pipe connected to expansion chamber is kept constant i.e., d = 50mm.
d. The length of inlet pipe connected to expansion chamber is kept constant i.e., l_1=90 mm.
e. The length of outlet pipe connected to expansion chamber is kept constant i.e., l_2= 70 mm.

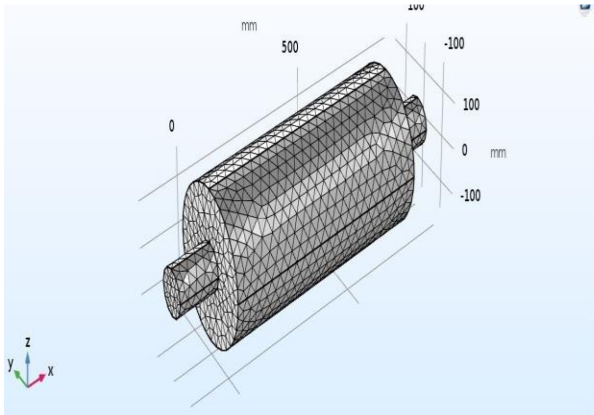
The MATLAB program is prepared and the analysis is carried out for the frequency range of 1-1600 Hz.

3. Numerical Analysis

The figure 1 shows the modelling of Single Expansion Chamber reactive muffler using COMSOL Multiphysics.



Model



Meshed model

Figure1: Model and meshed model

The Numerical Analysis is carried out using COMSOL Multiphysics [5]. The Numerical Simulations of the Transmission Loss of the muffler were performed using COMSOL. In this analysis; mean flow of the muffler is ignored. The geometry of the muffler is drawn using same program. The muffler is meshed automatically using Tetrahedral Elements.

The Sound Pressure P is Calculated using Helmholtz Equation,

$$\nabla.\left(\frac{1}{\rho 0}\nabla_p - q\right) + \frac{k^2}{\rho_0}p = 0 \qquad (1)$$

WHERE, $k = \frac{2\pi f}{c_0}$ is the wavelength, ρ_0 The Density of the Fluid and c_0 is The Velocity of Sound, q is The Two Pole Source term which Means Acceleration per Unit Volume and equals to 0 in this study. With this equation, a Solution on Frequency Domain Can be Found Using Parametric Solver. The Transmission Loss of the Muffler is Calculated Using Following Equation,[6].

$$TL = 10\ log\left(\frac{P_{in}}{P_{out}}\right) \qquad (2)$$

Where, P_{in} and P_{out} denotes acoustic effects at Inlet and outlet respectively, which are Calculated as,

$$p_{in} = \int_{\varphi}^{1} \frac{P_0{}^2}{2pc_0} dA \qquad (3)$$

$$p_{out} = \int_{\varphi}^{1} \frac{|P_c|^2}{2pc_0} dA \qquad (4)$$

the inlet pressure value Po is set to 1 bar.

The Model Uses Sound Hard Wall Boundary Conditions at the Solid Boundaries as by Following Equation,

$$\left(-\frac{V_p}{P}\right).n = 0 \qquad (5)$$

The Numerical analysis is carried out for the Frequency Range of 1-1600 Hz. The results are shown in the form of graph in figure 2.

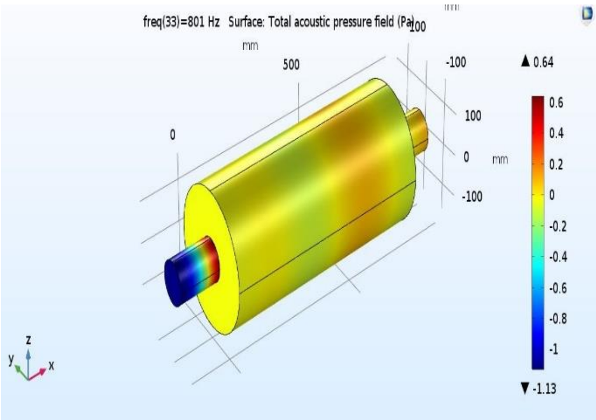
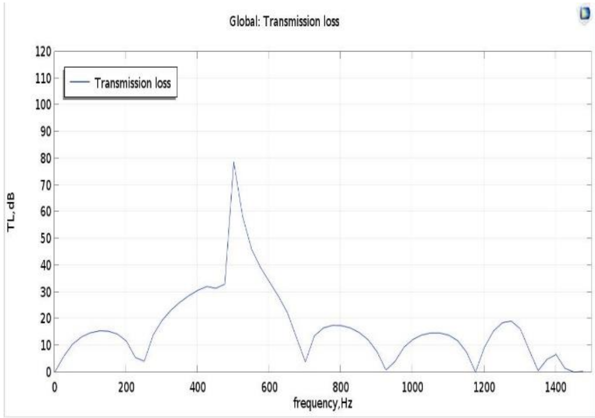
	
Acoustic Pressure distribution	Transmission Loss curve

Figure2: Results of Numerical analysis

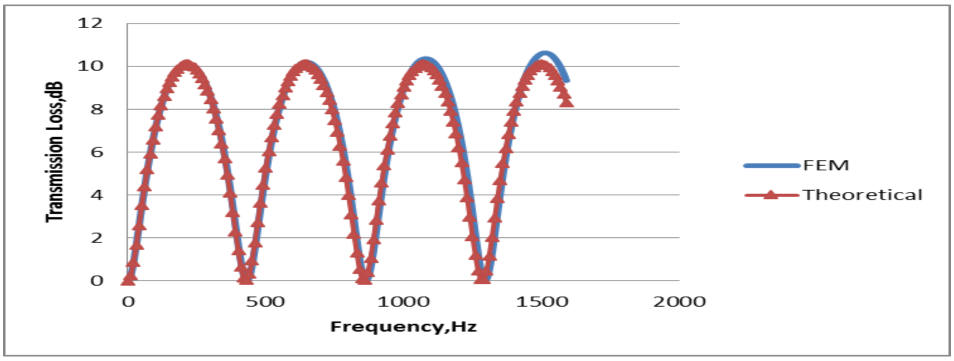


Figure 3: Comparison of Theoretical and Numerical Transmission loss

The figure 3 shows the comparison of transmission loss obtained using Theoretical and Numerical analysis. The results obtained using these two analysis methods shows good agreement with each other.

4. Experimental Analysis

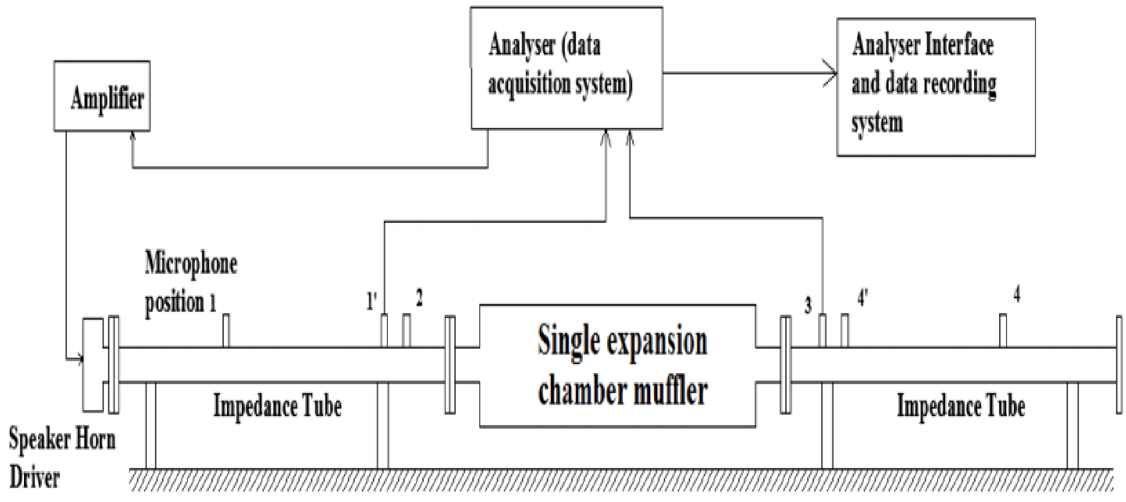


Figure 4: Test Setup

In the experiment analysis, the single expansion chamber muffler model acoustics performance is validated using method of two loads. The test setup is as displayed in figure 4.

The test set up comprises 1) Noise generation system, 2) Noise propagation system and 3) Measurement system. The key elements of the setup are as shown in figure 5. There are measurement positions at a fixed distance within the impedance tube. For sound propagation, this tube is used. At one end, the sound source is connected, and the test muffler is linked to the other end of the impedance tube. Both impedance tubes on both sides of the muffler are used. The Data Acquisition is carried out using FFT Analyzer. A sound source capable of generating 120 dB noise is used. The Transfer Function technique is employed by using two microphones.

4.1 Method of two loads

Mr. A.F. Seybert (2003) applied this technique for the muffler[7]. Transfer matrix is used in this method. To calculate Transmission Loss, this method utilizes four pole equations created from four microphone positions. The two different loads, in order to keep results stable, are employed in this method. In the present research, two loads used are as displayed in figure 5.

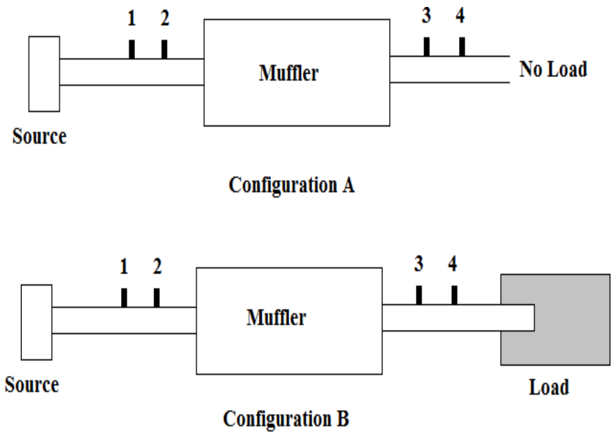


Figure 5: Configurations for TWO Load method

The acoustic output of any muffler can be analysed with equations created from four microphone positions to calculate transmission loss [8]. The four poles for elements 1-2 can be stated as

$$\begin{bmatrix} A_{12} & B_{12} \\ C_{12} & D_{12} \end{bmatrix} = \begin{bmatrix} cos kl_{12} & j\rho c \, sin kl_{12} \\ \frac{j \, sin kl_{12}}{\rho c} & cos kl_{12} \end{bmatrix} \quad (6)$$

The equation (7) states four poles for elements 2-3 as

$$\begin{bmatrix} A_{23} & B_{23} \\ C_{23} & D_{23} \end{bmatrix} \quad (7)$$

Where,

$$A_{23} = \frac{\Delta_{34}(H_{32a}H_{32b} - H_{32b}H_{34a}) + D_{34}(H_{32b} - H_{32a})}{\Delta_{34}(H_{34b} - H_{34a})}$$

$$B_{23} = \frac{B_{34}(H_{32a} - H_{32b})}{\Delta_{34}(H_{34b} - H_{34a})}$$

$$C_{23} = \frac{(H_{31a} - A_{12}H_{32a})(\Delta_{34}H_{34b} - D_{34}) - (H_{31b} - A_{12}H_{32b})(\Delta_{34}H_{34a} - D_{34})}{B_{12}\Delta_{34}(H_{34b} - H_{34a})}$$

The equation (8) states four poles for elements 3-4 as

$$\begin{bmatrix} A_{34} & B_{34} \\ C_{34} & D_{34} \end{bmatrix} = \begin{bmatrix} coskl_{34} & j\rho c\ sinkl_{34} \\ \frac{j\ sinkl_{34}}{\rho c} & coskl_{34} \end{bmatrix} \qquad (8)$$

The transfer function between P_i and P_j is stated by the term H_{ij},as

$$H_{ij} = \frac{P_j}{P_i}$$

The final Transfer matrix is stated as follows

$$\begin{pmatrix} A_{14} & B_{14} \\ C_{14} & D_{14} \end{pmatrix} = \begin{pmatrix} A_{12} & B_{12} \\ C_{12} & D_{12} \end{pmatrix} \begin{pmatrix} A_{23} & B_{23} \\ C_{23} & D_{23} \end{pmatrix} \begin{pmatrix} A_{34} & B_{34} \\ C_{34} & D_{34} \end{pmatrix} \qquad (9)$$

The Transmission Loss is given by

$$TL=20\log_{10}\left[\frac{1}{2}\left(\left|A_{14} + \frac{B_{14}}{\rho c} + \rho c C_{14} + D_{14}\right|\right)\right] \qquad (10)$$

The equation (10) is used for calculating experimental Transmission Loss.

4.2 Procedure for Experimental Analysis

The range of frequency considered for the experiment is 1-2000 Hz. Place 1-2-3-4 is used for measuring sound pressure in the 1-400 Hz frequency range and places 1'-2-3-4' are used for 400 Hz to 2000Hz.

Figure 6: Actual experimental set up

In order to obtain the H31, H32 and H34 transfer function with corresponding positions, test microphone is placed at place 3 and the other is positioned in turn at place 1, 2 and 4. Actual experimental set up is displayed in figure 6. The readings have been taken for No load and with load conditions [8][9][10].

5. Results and discussion

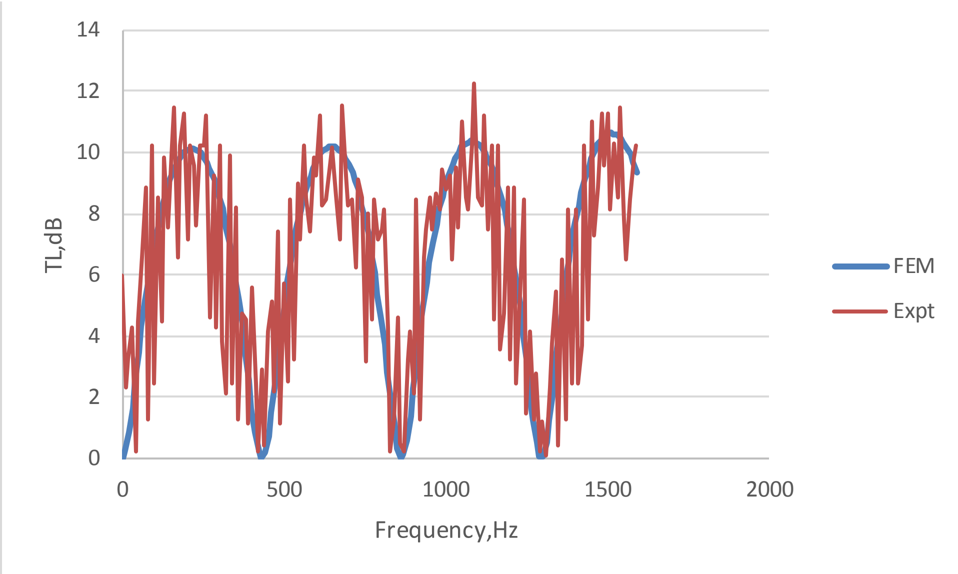


Figure7: comparison of Numerical and Experimental Transmission loss

Figure 7 displays the comparison of Transmission Loss obtained using Finite Element Analysis and Experimental Analysis for the model. The troughs are obtained at 421 Hz, 871 Hz, and 1311 Hz. The trough displays the points where minimum Transmission Loss is attained. The muffler model showing uplifted troughs is considered as good model. The crests are observed at 241 Hz,651 Hz and 1091 Hz. The crest displays the points where maximum Transmission Loss is attained. The maximum Transmission Loss indicates that, minimum noise is radiated at the specified frequency. The experimental results and FEM results shows good agreement. The small difference in the experimental outcome from that of the FEM result is attributable to sound leakage from the impedance tube, FFT white noise production issues, Impedance tube imprecise surface finish consistency.

6. Conclusion

Theoretical analysis, numerical analysis, and experimental analysis are used in this research paper to analyse the acoustic analysis of extended inlet & outlet tube parameters in the single expansion chamber reactive silencer. Based on the empirical relationship for Transmission Loss, a MATLAB programme is created for the theoretical analysis. Modelling, meshing, and analysis are all done using COMSOL Multiphysics for numerical analysis. The analysis is conducted in the frequency domain. The experimental analysis employs two load methods. Here, loads are changed without modifying the source's position. It is believed that the results of numerical and experimental analysis are in good agreement with one another after they have been validated by one another.

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