ACOUSTIC ANALYSIS OF EXTENDED INLET & OUTLET TUBE PARAMETERS IN SINGLE EXPANSION CHAMBER REACTIVE MUFFLER FOR INCREMENT IN TRANSMISSION LOSS

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Abstract : *The internal combustion engine is the major source responsible for noise pollution. A muffler is a device used to reduce noise within the exhaust system. It is arranged along the exhaust pipe for the purpose of noise attenuation. Exhaust noise from engines is one of component noise pollution to the environment. Exhaust systems are developed to attenuate noise meeting required dB levels and sound quality; emissions based on environment norms. Set up for experimental analysis is developed to predict the acoustic performance of reactive muffler using the two-load method. The decrease in the exhaust noise level is controlled by muffler construction and operating techniques. Therefore, the muffler configuration plays an important role. In this research work, an effort has been made to study the different methodologies for evaluation of transmission loss for extended inlet & outlet tube parameters of single expansion chamber reactive muffler. The detail study of acoustic performance of the muffler is carried out by: (1) Theoretical analysis (2) The finite element method by using COMSOL Multi-Physics, (3) Experimental validation by method of two loads.*

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

1. Introduction

In automotive exhaust system design, accurate prediction of sound radiation characteristics of reactive muffler carries significant importance. Noise pollution produced by engines becomes a major concern when used in residential areas or areas where noise creates hazard. Noise level greater than 80dB is injurious for human being. As well as the diesel generator sets are observed as common norm in public and corporate places as electric source or backup. Hence it is necessary to reduce the noise produced by diesel engines of generator. Noise of diesel engine can be reduced by using muffler. 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. 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. 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.

$TL = 10\log10\,[1 - 1/4(m - 1/m)^2 Sin^2 kl]$
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. The design conditions used for evaluating transmission loss of single expansion chamber reactive muffler are listed as follows

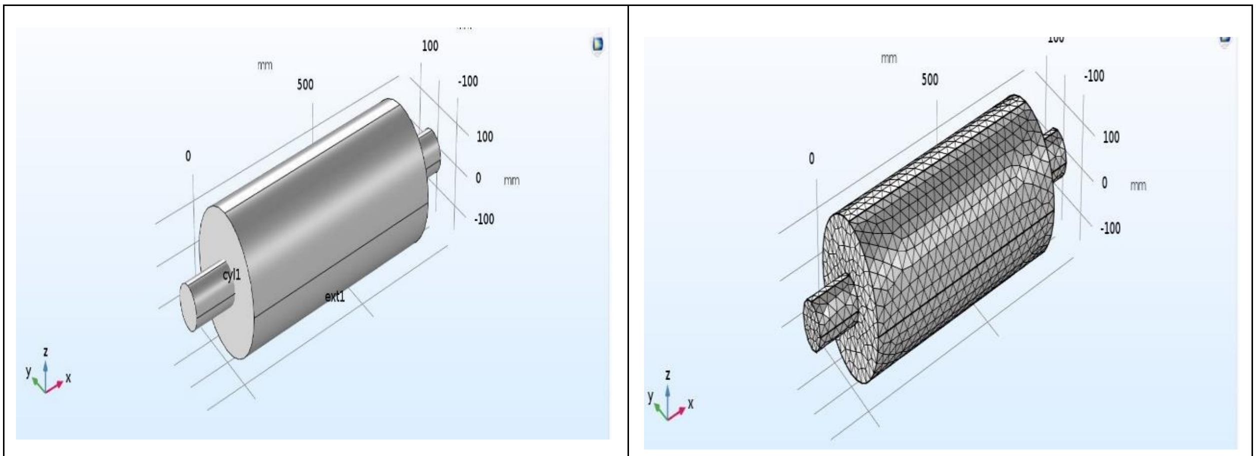
a. The length of expansion chamber is kept constant i.e., L=740mm.
b. The diameter of expansion chamber is kept constant i.e., D=160mm.

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. 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.

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

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

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

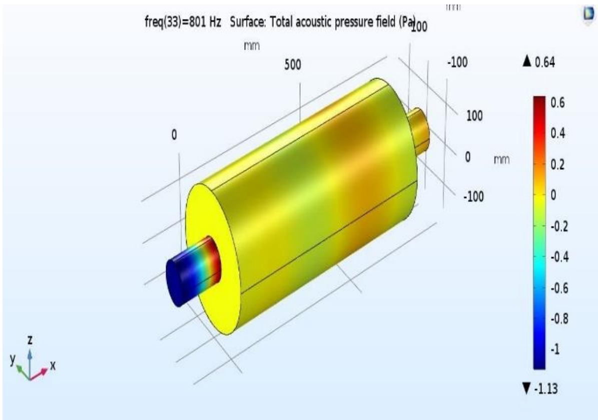
$$p_{out} = \int_{\varphi}^{1} \frac{|P_c|^2}{2pc_0} dA \qquad (4)$$

the inlet pressure value Po is set to 1 bar.

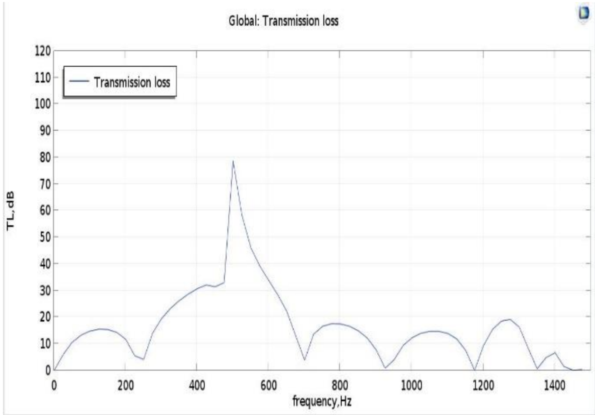
the model uses sound hard wall boundary conditions at the solid boundaries as by following equation,

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

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

Figure 2: Results of numerical analysis

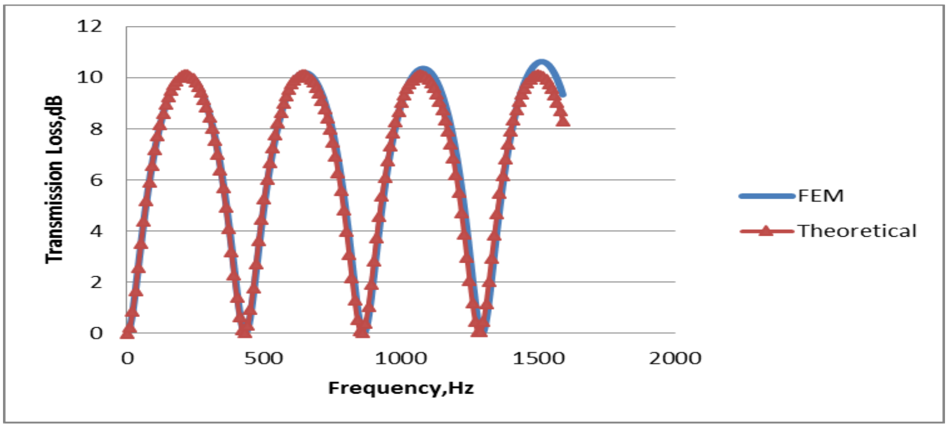


Figure 3: Comparison of theoretical and numerical transmission loss

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

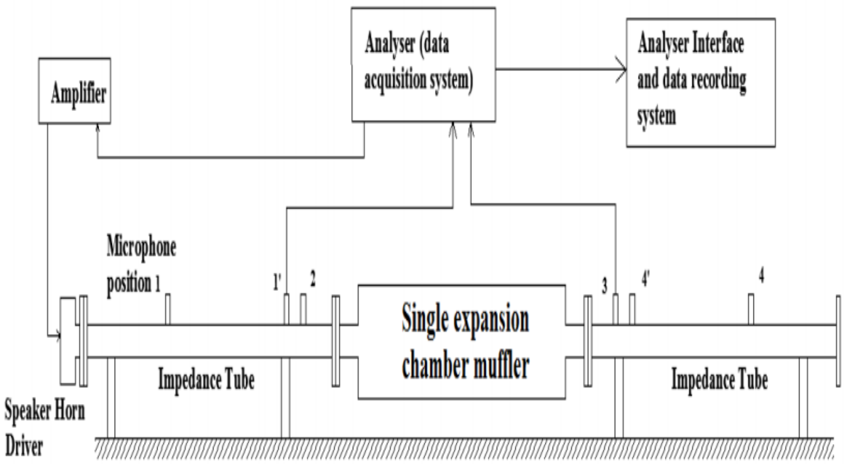


Figure 4: Test Setup

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 analyser. 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. 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.

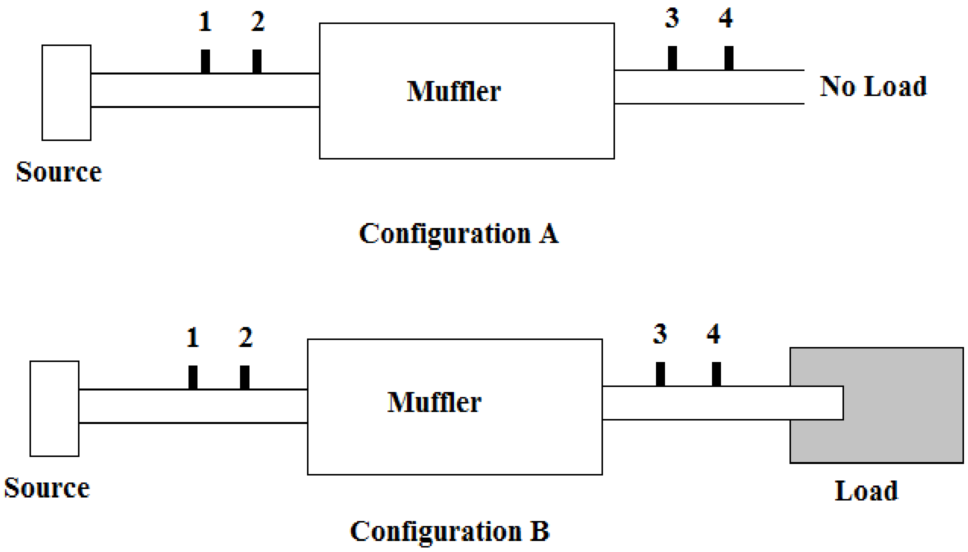


Figure 5: Configurations for Two Load method

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

$$\begin{bmatrix} A_{12} & B_{12} \\ C_{12} & D_{12} \end{bmatrix} = \begin{bmatrix} coskl_{12} & j\rho c\ sinkl_{12} \\ \frac{j\ sinkl_{12}}{\rho c} & coskl_{12} \end{bmatrix} \quad (6)$$

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

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

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

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

The transmission loss is given by

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

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.

5. Results and discussion

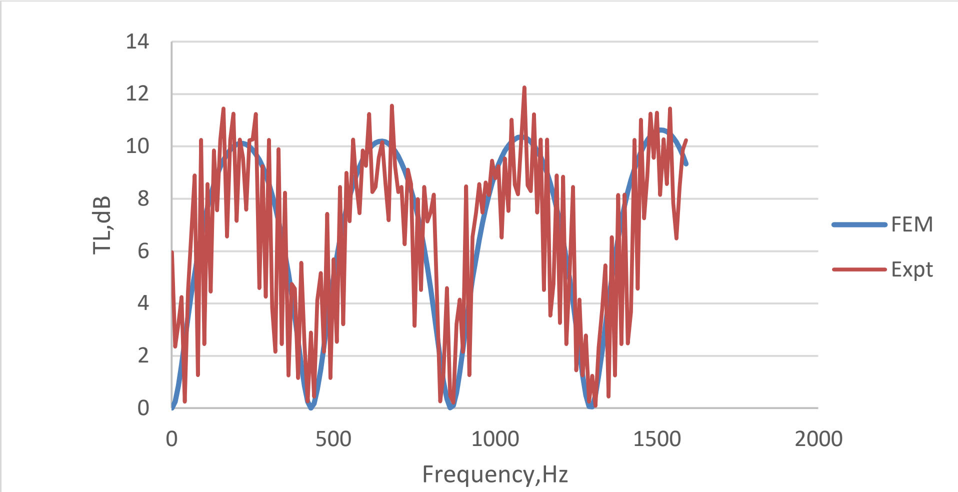


Figure7: Comparison of numerical and experimental transmission loss

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.

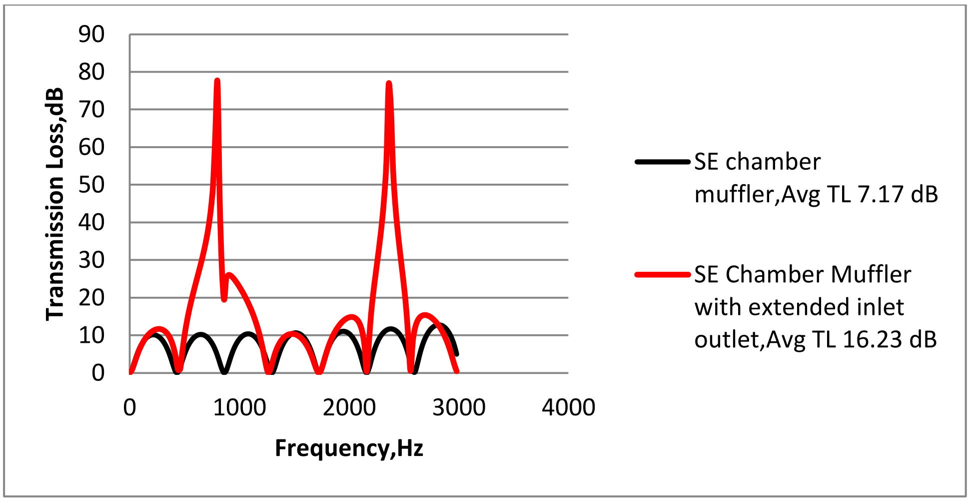


Figure8: Comparison of TL of Singe expansion chamber and chamber with extended inlet and outlet

6. Conclusion

In this research paper, acoustic analysis of extended inlet & outlet tube parameters in the single expansion chamber reactive muffler is analysed using different methodologies Viz theoretical analysis, numerical analysis and experimental analysis. In the theoretical analysis the MATLAB program is prepared based on the empirical relation for transmission loss. For numerical analysis the COMSOL Multiphysics is used for modelling, meshing and analysis. The frequency domain is used for the analysis. In the experimental analysis, two load methods are used. Here loads are changed without changing position of source. It is observed that, incorporation of extended inlet and outlet in the muffler increases the Transmission Loss. The results of numerical analysis are validated with experimental analysis and it is perceived that, results of numerical and experimental analysis are in good agreement with each other.

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