



Investigation on Effect of Extended Inlet and Outlet Tubes on Single Expansion Chamber muffler for Noise Reduction

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Abstract: The major source responsible for noise pollution is internal combustion engine. These engines are used for various purposes such as, in automobiles, locomotives, and in various manufacturing machineries. In an engine, the exhaust noise and the noise produced due to friction of various parts of the engine share maximum contribution to noise pollution. 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. The paper describes the acoustic Analysis of Single Expansion Chamber Reactive Muffler having extended inlet and extended outlet. The approach is useful in the acoustic analysis of single expansion chamber muffler for maximizing Sound Transmission Loss. The purpose of paper is to study the effect of extended inlet and extended outlet on transmission loss of Single Expansion Chamber reactive muffler with the help of theoretical as well as numerical analysis.

Keywords: Single Expansion Chamber Reactive muffler, Transmission Loss, Theoretical analysis, Numerical analysis

I. Introduction

Sound waves propagating along a duct can be attenuated using either an absorptive or a reactive muffler. Absorptive muffler uses sound absorbing material to absorb energy from the acoustic in the wave, when it propagates through the muffler, while reactive muffler works on impedance mismatch principle. Muffler is a device used for reducing the amount of noise produced by the exhaust of an internal combustion engine. The acoustic analysis of exhaust muffler is characterized by numerous parameters like insertion Loss (IL), Transmission Loss (TL). The frequently used parameter to evaluate the sound radiation characteristics of muffler is Transmission loss (TL) [1]. Transmission Loss is defined as difference between power incident on muffler proper and power transmitted downstream into an-echoic termination. The transmission loss is independent of source and it presumes an-echoic termination at tail pipe. [2] Exhaust noise from engines is one of the components of noise pollution to the environment. Exhaust systems are developed to attenuate noise meeting required dB levels and sound quality, emissions based on environment norms. Noise levels of more than 80 dB are injurious for human beings. Design of mufflers is a complex function that affects noise characteristics, emission and fuel efficiency of engine. Hence muffler design becomes important for noise reduction [3].

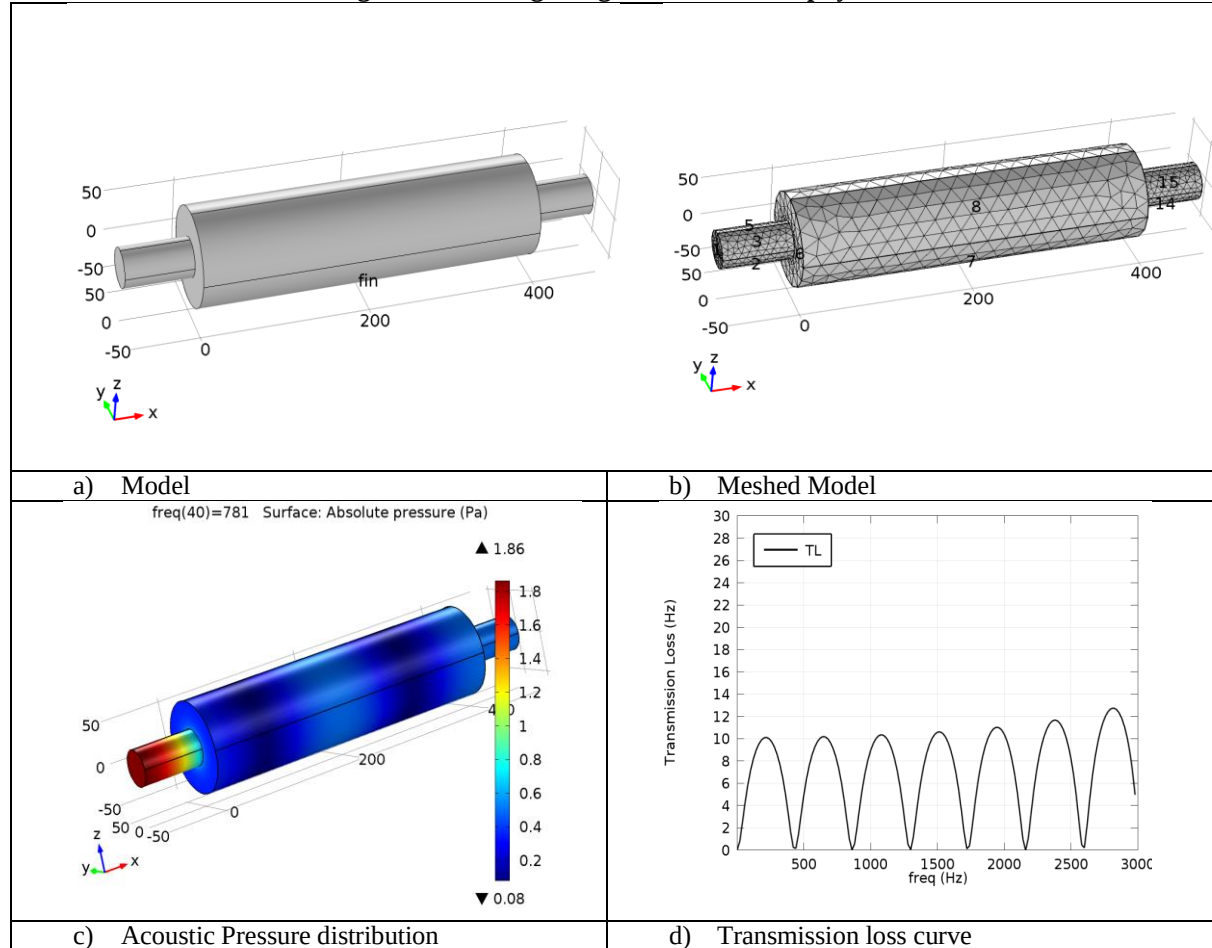
Hence to reduce noise from internal combustion engines they are equipped with an important noise control element known as silencer or exhaust muffler which reduces the acoustic pulse generated by the combustion processes [4]. Numerical methods are often useful for optimization of model with complicated shapes and also where the cost is involved. So it is essential to optimize the model by Numerical Analysis and validate it by experimental methods [2]. The internal changes in the geometry of the muffler are made to develop the impedance mismatch for maximizing the transmission loss. In this study, the extended inlet and extended outlet, is placed in single expansion chamber reactive muffler. The muffler is simulated using COMSOL to predict muffler transmission loss performance.

II. Modeling

The muffler transmission loss for the single expansion chamber reactive muffler is evaluated using finite element analysis. The software used for the analysis is COMSOL Multiphysics.[8].The design conditions used for evaluating transmission loss of single expansion chamber reactive muffler are listed as follows

- The length of expansion chamber is kept constant i.e.400mm
- The diameter of expansion chamber is kept constant i.e.110mm
- The diameter of inlet and outlet pipe connected to expansion chamber is kept constant i.e.44mm
- The length of inlet and outlet pipe connected to expansion chamber is kept constant i.e. 80mm
- The expansion chamber volume is kept constant for all modeling work.

Figure 1 Modeling using COMSOL Multiphysics



III. Theoretical analysis

A. Mathematical Equations

i) Mathematical Equations

Transmission loss of muffler containing n elements is found out by using Transfer Matrix method. The overall transfer matrix for n elements is given by

$$\begin{bmatrix} p_n \\ v_n \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} p_1 \\ v_1 \end{bmatrix} \quad (1)$$

And the Transmission Loss is calculated using following equation

$$TL = 20 \log \left[\left(\frac{y_1}{y_n} \right)^{\frac{1}{2}} \left| \frac{T_{11} + \frac{T_{12}}{y_1} + y_n T_{21} + \left(\frac{y_n}{y_1} \right) T_{22}}{2} \right| \right] \quad (2)$$

Following mathematical equations are used for developing MATLAB code. [10]

1) Uniform tube

The Transfer Matrix for uniform tube taking into account the acoustic variables such as acoustic pressure p , mass velocity v and corresponding characteristic impedance Y is given as

$$\begin{bmatrix} p \\ v \end{bmatrix}_{z=0} = e^{-jMk_c l} \begin{bmatrix} \cos k_c l & jY \sin k_c l \\ j/Y \sin k_c l & \cos k_c l \end{bmatrix} \begin{bmatrix} p \\ v \end{bmatrix}_{z=l} \quad (3)$$

Where, M =Mean flow Mach number= V/c ,

k_c = convective wave number = $\frac{k}{(1-M^2)}$, (rad/m)

k = Acoustic wave number (rad/m) = ω/c , ω is angular frequency (rad/s)

j = Square root of -1

2) Sudden expansion and contraction

$$\begin{bmatrix} p_{c,2} \\ v_{c,2} \end{bmatrix} = \begin{bmatrix} 1 & KM_1Y_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} p_{c,1} \\ v_{c,1} \end{bmatrix} \quad (4)$$

For the stationary medium, the transfer matrix reduces to a unity matrix

3) Sudden contraction and extended outlet

$$\begin{bmatrix} p_{c,3} \\ v_{c,3} \end{bmatrix} = \begin{bmatrix} 1 & KM_1Y_1 \\ \frac{C_2S_2}{C_2S_2Z_2+S_3M_3Y_3} & \frac{C_2S_2Z_2-M_1Y_1(C_1S_1+KS_3)}{C_2S_2Z_2+S_3M_3Y_3} \end{bmatrix} \begin{bmatrix} p_{c,1} \\ v_{c,1} \end{bmatrix} \quad (5)$$

For the stationary medium, the transfer matrix reduces to $\begin{bmatrix} 1 & 0 \\ 1/Z_2 & 1 \end{bmatrix}$

Where $Z_2 = -jY_2 \cot K_0 l_2$

4) Sudden expansion and extended inlet

$$\begin{bmatrix} p_{c,3} \\ v_{c,3} \end{bmatrix} = \begin{bmatrix} 1 & KM_1Y_1 \\ \frac{C_2S_2}{C_2S_2Z_2+S_3M_3Y_3} & \frac{C_2S_2Z_2-M_1Y_1(C_1S_1+KS_3)}{C_2S_2Z_2+S_3M_3Y_3} \end{bmatrix} \begin{bmatrix} p_{c,1} \\ v_{c,1} \end{bmatrix} \quad (6)$$

Where $Z_2 = -jY_2 \cot K_0 l_2$, K = stagnation pressure loss coefficient,

The stagnation pressure loss coefficient (K) is chosen from the table 1

Table 1 Stagnation pressure loss coefficient (K)

Element	K
Sudden contraction and extended outlet	$\left(1 - \frac{S_d}{S_u}\right)/2$
Sudden expansion and extended inlet	$\left[\left(\frac{S_d}{S_u}\right) - 1\right]^2$
Reversal cum expansion	$\left(\frac{S_d}{S_u}\right)^2$
Reversal cum contraction	0.5

C_1 and C_2 are constants and are chosen from the table 2

Table 2 Constants

Element	C_1	C_2
Extended outlet	-1	-1
Extended inlet	-1	+1
Reversal -expansion	+1	-1
Reversal -contraction	+1	-1

IV. Numerical Analysis

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.[8]

The sound pressure P is calculated using Helmholtz equation

$$\nabla \cdot \left(\frac{1}{\rho_0} \nabla p - q \right) + \frac{k^2}{\rho_0} p = 0 \quad (7)$$

Where, $k = \frac{2\pi f}{c_0}$ is the wavelength, ρ_0 is 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

$$TL = 10 \log \left(\frac{p_{in}}{p_{out}} \right) \quad (8)$$

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

$$p_{in} = \int_{\Omega} \frac{1}{2\rho c_0} p_0^2 dA \quad (9)$$

$$p_{out} = \int_{\Omega} \frac{1}{2\rho c_0} |p_c|^2 dA \quad (10)$$

The inlet pressure value p_0 is set to 1 bar.

The model uses sound hard wall boundary conditions at the solid boundaries as per following equation

$$\left(-\frac{\nabla p}{\rho}\right) \cdot \mathbf{n} = 0 \quad (11)$$

V. Simulations for Extended inlet and outlet mufflers

Figure 2 Simulations for extended inlet and outlet mufflers

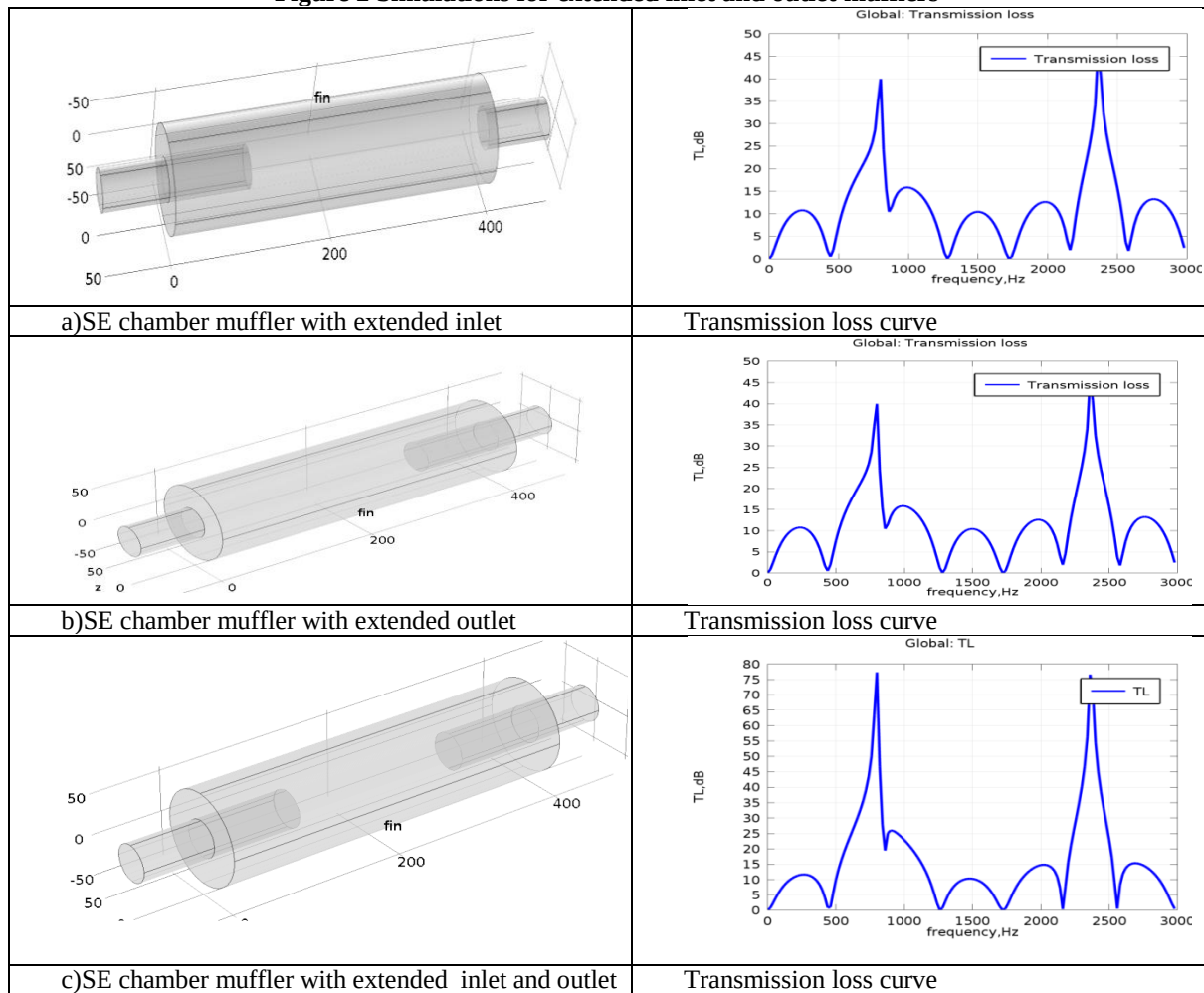
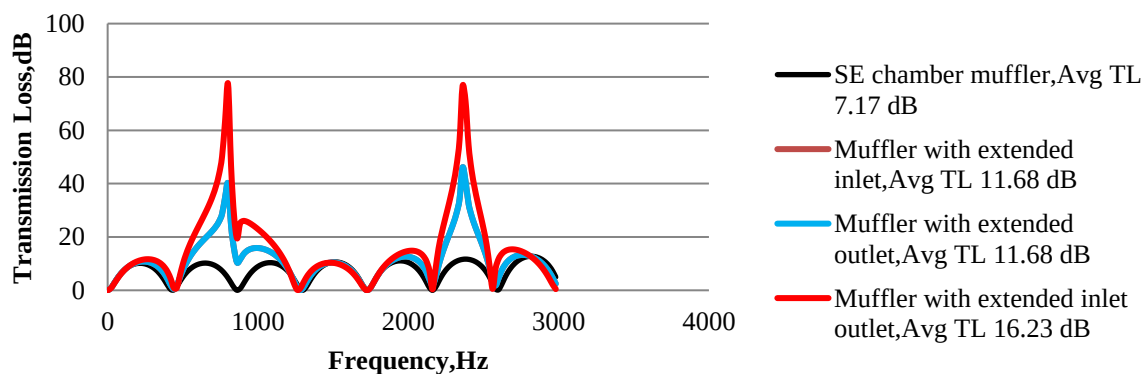


Figure 3 Numerical Analysis using COMSOL

Numerical Analysis



VI. Results and Discussion

The transmission loss is evaluated in the four cases of Single Expansion chamber, Chamber with Extended Inlet, Chamber with Extended Outlet, Chamber with Extended Inlet and Outlet analytically as well as numerically. Figure 3 shows the results obtained by using Numerical analysis using COMSOL. The result shows that the maximum Transmission Loss is achieved in case of Chamber with Extended Inlet and Outlet (16.23 dB) as compared to other cases. Figure 4, 5 and 6 shows the comparison of results for Extended Inlet muffler, Extended Outlet muffler and Extended Inlet Outlet muffler respectively. The average transmission loss obtained by theoretical as well as Numerical analysis is nearly same. This shows that the trends for the transmission loss curve are in good agreement with each other. From the results it can be concluded that, the maximum transmission loss is achieved with extended inlet and extended outlet muffler. Also the transmission loss curve represent that, the transmission loss is same in both the cases, where chamber is either with Extended Inlet or with Extended Outlet.

Figure 4 Result Comparisons for Extended Inlet Muffler

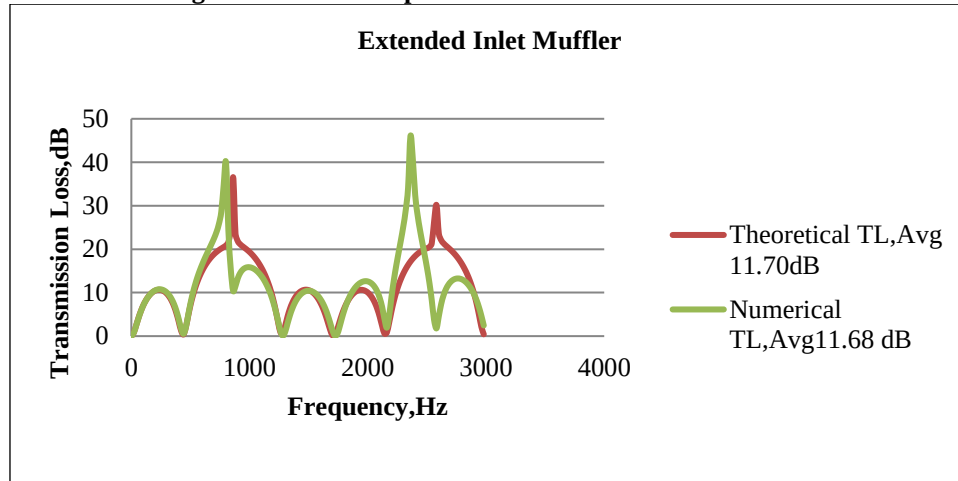


Figure 5 Result Comparisons for Extended Outlet Muffler

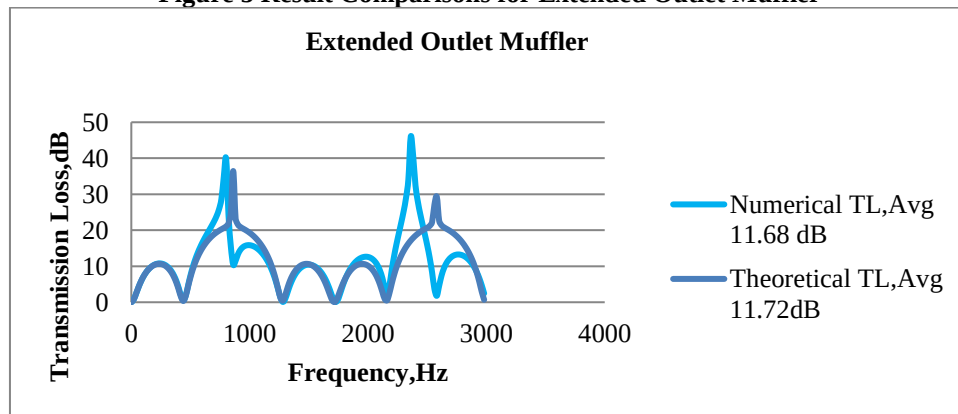
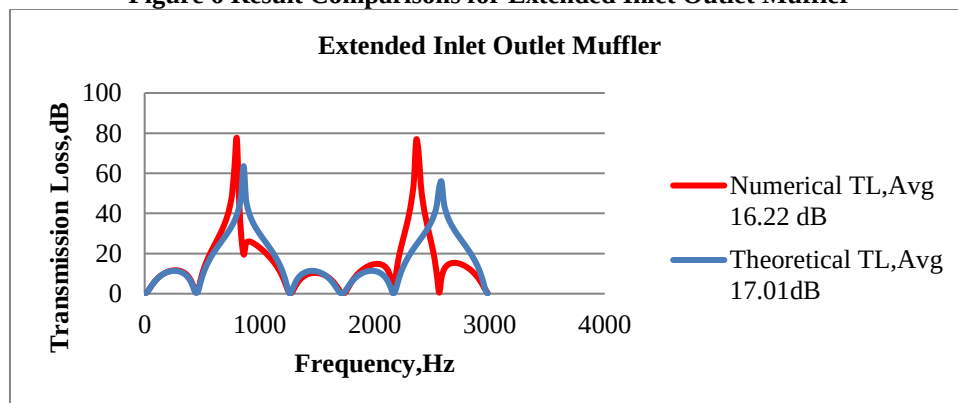


Figure 6 Result Comparisons for Extended Inlet Outlet Muffler



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