Transmission Losses in Simple Expansion Chamber of Reactive Muffler Analysis by Numerical & Experimental Method

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Abstract
One of the components in the exhaust system of vehicle is muffler. The purpose of the muffler is to reduce the exhaust noise produce by the engine. The main objective of this study is modelling and performance evaluation of a simple reactive muffler of vehicles using matlab. Simple expansion chamber muffler has been modelled numerically using matlab in order to determine its acoustic response. In experimental method- two load method only load are changed without changing position of source. The experimental results show good agreement with numerical results. From results it can be concluded that from the development of experimental setup it's possible to measure TL of muffler. The small deviation of the experimental results against the numerical results may be due to leakage of sound from the surrounding and problems in generating to true random noise from FFT. The results of this study will be used as a reference to be able to design new mufflers.

Keyword: Acoustic, Experimental, Reactive Muffler, Analysis

I. INTRODUCTION

Reactive silencers, which are commonly used in automotive applications, reflect the sound waves back towards the source and prevent sound from being transmitted along the pipe. Reactive silencer design is based either on the principle of a Helmholtz resonator or an expansion chamber, and requires the use of acoustic transmission line theory.

In a Helmholtz resonator design a cavity is attached to the exhaust pipe. At a specific frequency the cavity will resonate and the waves in the exhaust pipe are reflected back towards the source [3]. However there are also pass band frequencies where the resonator has no effect and so resonator muffler design is targeted to specific frequencies where the majority of the attenuation is required. In some designs, the muffler has several resonators of different sizes to target a range of frequencies

Expansion chamber mufflers reflect waves by introducing a sudden change in cross sectional area in the pipe. They do not have the high attenuation of the Helmholtz resonator, but have a broadband frequency characteristic, with pass bands when half the acoustic wavelength equals the cavity length. Their performance also deteriorates at higher frequencies when the cross axis dimension of the muffler is 82% of the acoustic Wavelength. Some expansion chamber muffler systems are also packed with sound absorbing material, which helps to improve the high frequency attenuation.

In all muffler designs the tailpipe length can have an important effect. The tailpipe itself acts as a resonant cavity that couples with the muffler cavity. The attenuation characteristics of a muffler are modified if the design tailpipe is not used. Also, the effect of exhaust gas flow speed has a detrimental effect on the muffler performance. In typical industrial or diesel truck engine applications the exhaust flow speed can be 164 ft/sec to390 ft/sec. The effect of flow is related to the interaction of sound with turbulence and will be dependent on the internal design of the muffler.

1.1 Need Of A Mufflers

Mufflers are used to reduce the combustion noise present at the exit of the exhaust. As the noise norms becoming more stringent, it's necessary for the entire automotive manufacturer to give more attention in the design of mufflers. Designing mufflers have been a challenging task for the designer for many years as it is not only reducing the noise but it also creates backpressure, which reduces the overall efficiency of the engine. Noise creates annoyance, sleep disturbance and if it is too loud then it can damage our hearing capability. Hence it is necessary to install muffler in every automotive so that noise emission can be controlled and remain within the noise norms.

II. REACTIVE MUFFLER

Reactive silencers generally consist of several pipe segments that interconnect with a number of larger chambers. The noise reduction mechanism of reactive silencer is that the area discontinuity provides an impedance mismatch for the sound wave traveling along the pipe. This impedance mismatch results in a reflection of part of the sound wave back toward the source or back and forth among the chambers. The reflective effect of the silencer chambers and piping (typically referred to as resonators) essentially prevents some sound wave elements from being transmitted past the silencer. The reactive silencers are more effective at lower frequencies than at high frequencies, and are most widely used to attenuate the exhaust noise of internal combustion engines.

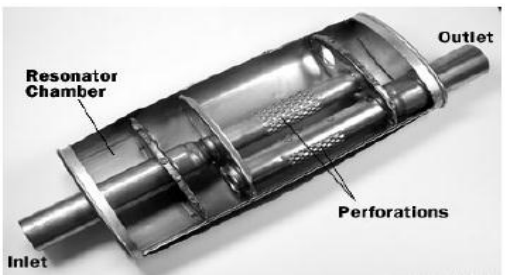


Figure 2.1 – Reactive Muffler

In most applications the final selection of an exhaust silencer is based on a compromise between the predicted acoustical, aerodynamic, mechanical and structural performance in conjunction with the cost of the resulting system. Sound transmission characteristic of a structure can be measured in terms of the one of the following parameters

1. INSERTION LOSS, IL
2. TRANSMISSION LOSS, TL

Insertion loss is defined as the difference between the acoustic power radiated without the structure and that with the structure. Symbolically,

IL= 10 log W1/W2 dB

where W1 and W2 denote the acoustic power without the structure and with the structure.

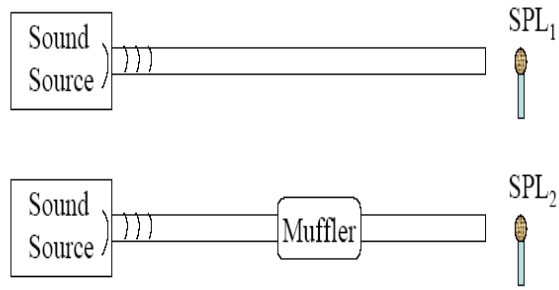


Figure 2.2 – Concept picture of Insertion Loss

1) Transmission loss (TL)

Transmission loss is defined as the ratio of the incident power and transmitted power from the structure. Symbolically,

TL= 10 log Wi / Wt dB

Where Wi and Wt denote the incident acoustic power and transmitted acoustic power. TLis used in this work to evaluate the performance of the muffler wall

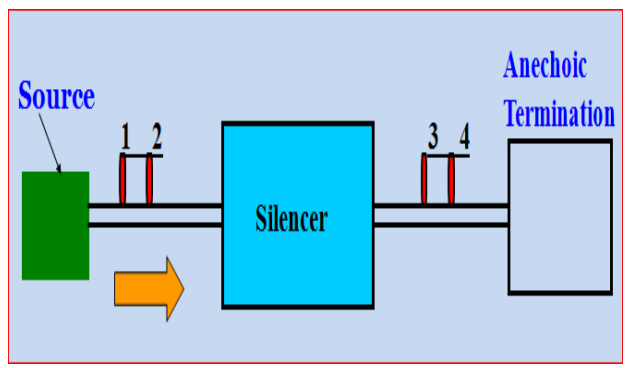


Figure 2.3 – Concept picture of Transmission Loss

III. ACOUSTIC ANALYSIS OF MUFFLER

3.1. Calculation of TL by Analytical Method :

Analytical approach is purely based upon the one dimension wave equation and empirical formula of TL. The pressure and particle velocity continuity equations are applied at the junction where area discontinuity occurs. The following assumptions are considered for the this analysis,

- The sound is propagation is in free field and in one direction only, plane wave theory.
- There is no mean flow of the fluid. That is sound is propagating while the fluid in the muffler is stationary (zero Mach number).

- The mean density and mean pressure are uniform and steady throughout the fluid. The acoustic

Pressure is the excess pressure from the mean pressure.

- Analysis is limited to relatively small acoustic pressures so that the changes in density are small compared with the mean density.

- Muffler wall neither conducts nor transmit the sound and viscosity effect at wall is neglected.

Analytical methods are good for calculating the TL of SEC, complex geometry models are very difficult to evaluate. The following formula is used to calculate TL in dB of given model over a frequency range 0 to 3000 Hz. This formula is valid for SEC with single chamber and derived from logarithmic pressure difference of acoustic power of the incident wave and the transmitted wave.

3.2. Transfer Matrix Method (TMM)

Design of a complete muffler system is usually, a very complex task because each of its elements is selected by considering its particular acoustic performance and its interaction effects on the entire acoustic system performance. For the frequency analysis of the muffler, it is very convenient to use the transfer matrix method.

The most popular traditional method for calculating the transmission loss is Transfer Matrix Method. The transmission loss of any acoustical filter is calculated by determining the four poles parameters of a transfer matrix. The 2×2 transfer matrix relates the pressure and the normal particle velocity at inlet and outlet of the muffler. The essence of the transfer matrix methods is its ability to break the system into discrete elements, which can be modeled by using basic acoustic principles. The boundary conditions of pressure and volume flow continuity results into the following equation in matrix form.

$$\begin{Bmatrix} p_0 \\ U_0 \end{Bmatrix}_{inlet} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{2\times 2} \begin{Bmatrix} p_1 \\ U_1 \end{Bmatrix}_{outlet}$$

$$TL = 20\log_{10}\left(\frac{1}{2}\left|A + \frac{B}{Y} + CY + D\right|\right)$$

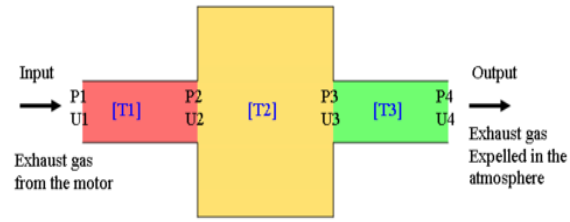


Figure 3.1: Discretization of expansion chamber for TMM

For Transfer Matrix of Simple Expansion Chamber

$$[TM] = [T_1][T_2][T_3]$$

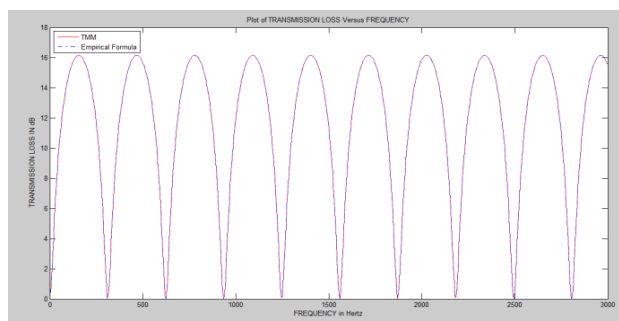
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos kl_1 & jY_1 \sin kl_1 \\ j\frac{1}{Y_1}\sin kl_1 & \cos kl_1 \end{bmatrix} \begin{bmatrix} \cos kl_2 & jY_2 \sin kl_2 \\ j\frac{1}{Y_2}\sin kl_2 & \cos kl_2 \end{bmatrix} \begin{bmatrix} \cos kl_3 & jY_3 \sin kl_3 \\ j\frac{1}{Y_3}\sin kl_3 & \cos kl_3 \end{bmatrix}$$

where,

$$k = \frac{\omega}{c}$$

$$Y_i = \frac{\rho c}{S_i}$$

A transfer matrix is calculated for a simple expansion chamber with above dimension is calculated with a simple MATLAB program. The TL of simple expansion chamber model is calculated for 0 to 3000 Hz. The graph shows the TL versus frequency for simple expansion chamber with both empirical relation and TMM. The MATLAB code [19] is included in appendix-A.



4.2 Figure: Plot of TL Verses Frequency by TMM for simpler expansion chamber

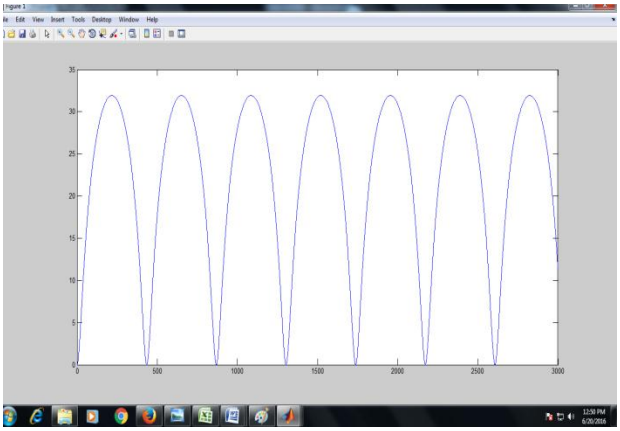
IV. NUMERICAL METHOD

The simulation on muffler is carried out to determine its theoretical performance. The simulation is focused on Transmission loss (TL) and Back pressure. MATLAB is used to carry out the simulation. MATLAB is a high-performance language for technical computing.

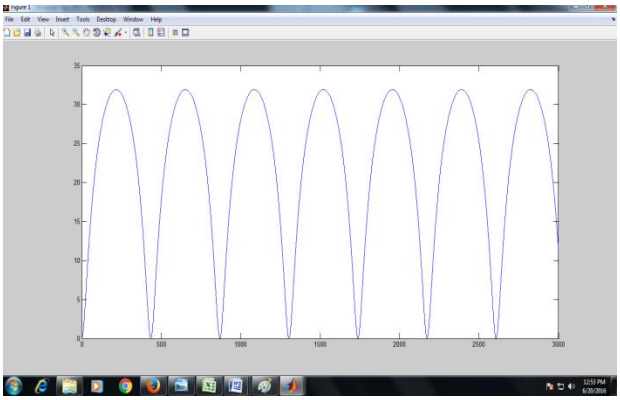
MATLAB is used to determine the transmission loss of the simplified model muffler. It is simple and user friendly software. The input parameters used in the simulation are as follows:

4.1. RESULT BY STIMULATION METHOD:

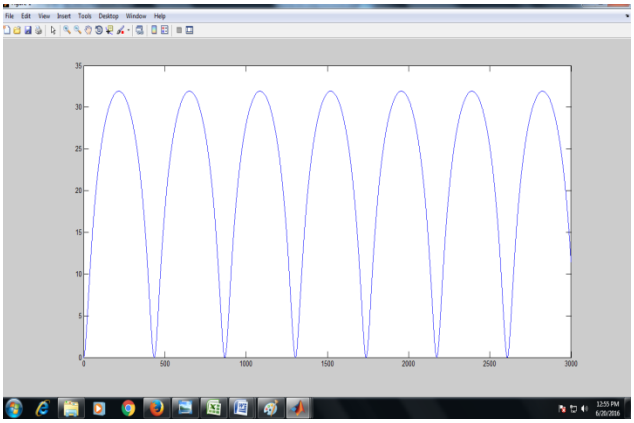
A) Length of Expansion Chamber 0.540m



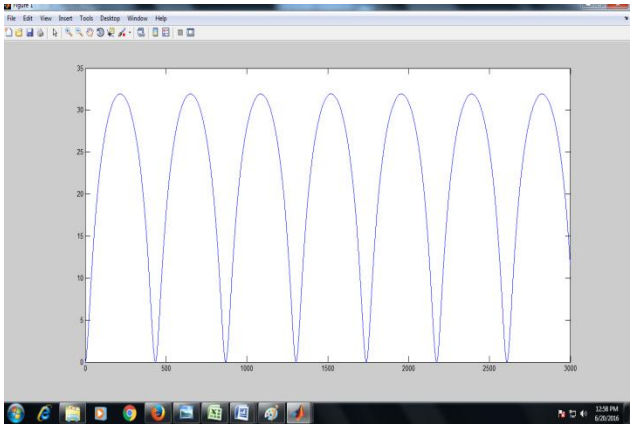
B) Length of Expansion Chamber 0.28m



C) Length of Expansion Chamber 0.4m



D) Length of Expansion Chamber 0.1m



V EXPERIMENTAL SETUP:-

A schematic diagram of experimental set up for calculating TL of perforated simple expansion muffler and actual setup . It consists of a noise generation system, noise propagation system and noise measurement system. The TL is measured by transfer function method. The setup has the following main components.

- Impedance Tube
- Data acquisition system
- Noise source with amplifier
- Sound pressure measuring microphones

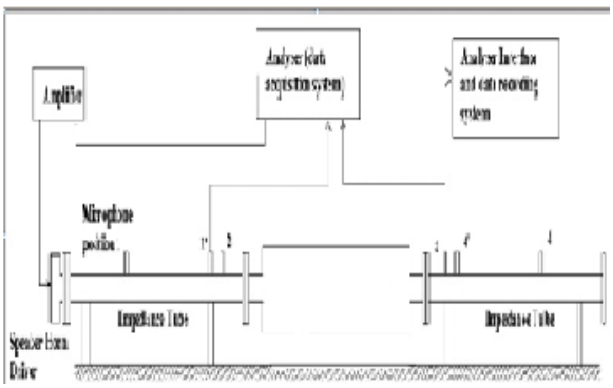


fig 5.1- experimental setup

A.TWO-LOAD METHOD:-

In Equation above, one can see that there are four unknowns, A_{23}, B_{23}, C_{23} and D_{23}, but there are only two equations. Instead of moving the sound source to the other

end to get two additional equations, the same result can be obtained by changing the end condition, changing the end condition effectively changes the impedance at the termination from Z_a to Z_b. Equations 5.1 Fig experimental setup can be used again, and the four-pole parameters of element 2-3 can be obtained, as can the TL from above Equation. In the two-load method, it is obvious that if two loads are very similar, the result will be unstable. Generally, two loads can be two different length tubes, a single tube with and without absorbing material, or even two different mufflers. In this research, two loads were achieved by a tube with and without absorbing material.

B. EXPERIMENTAL PROCEDURE:

Experimentation for pressure measurement mainly consists of analyzer setting and data processing for TL calculation. The experiment is performed for frequency range of 50 to 3400 Hz. The measurements are taken in two slots with two locations 1-1' and 4-4' as shown in figure respectively to cover desired frequency range. The locations 1-2-3-4 are used for measuring pressure in frequency range 50-400 Hz, while the locations 1'-2-3-4' are used for measuring pressure in frequency range of 400-3400 Hz. The first set of readings is taken for no load condition with both frequency range and same procedure is repeated for with load condition. Two microphones are used for measurement, which are sufficient for measurement of transfer function between sound pressures measured at two locations. One microphone is placed at location 3 and other placed at location 1, 2 and 4 respectively to get transfer function H31, H32 and H34 with respected locations.

All other locations except locations where microphone are inserted are sealed with pins to avoid sound leakage. The sound leakage is tested and wax is used to seal these leaks. The obtained transfer functions are then directly used in four-pole element calculations to get TL

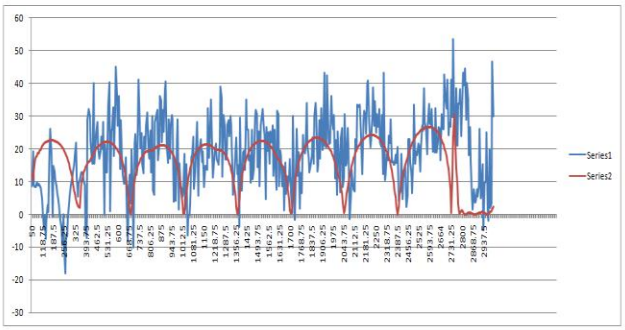
C. DYNAMIC FREQUENCY ANALYZER OR FFT ANALYZER:

For the experimental work the PC based FFT analyzer was used. Facilities of selecting various parameters such as scale (linear or logarithmic), windows, base band, filter and zoom analysis is available with this model. It is a full function, yet portable, time/frequency single analyzer. Simple front panel controls, setup condition storage and flexible display format make analyzer easily adaptable to measurement conditions from laboratory. The specifications of FFT analyzer are as follows:

- Make and Model B&K Photon+ 986A0186
- Memory 512K
- Inputs / Outputs 4/1
- Measuring range 10-200 dB
- Frequency limit 1Hz to 20 KHz
- Weight 227 g
- Operating temperature range 10^0C to 50^0C

5.3 FFT Analyser

VI RESULT



The Comparison of Experimental and Numerical Transmission loss results of the present muffler are shown in above Fig. It is commonly known that reactive mufflers are effective in low Frequency Bandwidth. The cutoff frequency of the muffler is approximately calculated as 800 Hz with the Equation of fc=1.84c/(πd), where fc is the cut of frequency, c is sound speed and d is the diameter of muffler. Therefore, the frequency axis of the attained graphs was cut at this value.

Experimental results show three attenuation picks, which occur approximately between 1-3000Hz. These picks are results of the three expansion chambers within the muffler.

VII CONCLUSION

In this research results of known model are verified by experimental method. In two load method only loads are changed without changing the position of source.

The experimental result show good agreement with the numerical result. From results it can be concluded that from development of experimental setup it's possible to measure TL of muffler. The small deviation of experimental results from the Numerical results may be due to Leakage of sound from the surrounding and problems in generating true random (white) noise from the FFT.

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