Design Development and Analysis of a Single Expansion Chamber for a Diesel Engine

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Abstract - *The exhaust noise is one of the major contributors to the noise pollution caused by combustion engines. Due to stringent norms, reduction in the exhaust noise levels is of utmost importance. Mufflers attenuate the exhaust noise to an acceptable decibel. In this study, a reactive muffler for a single cylinder diesel engine is designed for maximum transmission loss. The amount of transmission loss in a muffler is a determinant factor of its performance and efficiency. The muffler performance varies based on its shape and dimensions. The length, expansion ratio and number of resonating chambers determine the amount of transmission loss obtained at the muffler outlet. An attempt to upsurge the acoustic performance and efficiency of a muffler based on an optimum design of its length and expansion ratio for the given manufacturing constraints is made. The transmission loss for a chosen optimum length and expansion ratio is modelled mathematically and is computed analytically and both the models are compared. The mathematical model is based on the Transfer Matrix Method. The acoustic performance analysis is done using Finite Element Method. Both the models are verified based on the transmission loss obtained for the designed muffler. This methodology will help obtain a relation between the attenuation across the muffler with respect to a variation in the length and expansion ratio for a given firing frequency and its harmonics.*

Key Words: Muffler, Transmission Loss, Expansion Ratio Variation, Length Variation, Single Expansion Chamber

1. INTRODUCTION

In today's age, with the advent of technology, a need for sustainable development has arisen. Stringent norms have made environmentally sound technology mandatory and thus the industry is striving for greener alternatives. Noise pollution being a huge adversity of the mechanical industry, immense research is being conducted to make quieter machines. The study NVH parameters to reduce the noise and vibrations produced in machines is known as acoustics.

Acoustics is the interdisciplinary science that deals with the study of all mechanical waves in gases, liquids, and solids including vibration, sound, ultrasound and infrasound and its applications can be seen in almost all aspects of modern society with the most obvious being the audio and noise control industries. It revolves around the generation, propagation and reception of mechanical waves and vibrations.

A silencer or a muffler is an absorptive device which reduces the noise of the engine exhaust of an internal combustion engine. While an extensive research on mufflers has been conducted in the earlier years, study of muffler characteristics for an optimum silencer is potent now considering the need in the reduction of noise. A single expansion chamber for a diesel engine is extensively studied in this project to get a better clarity on the design of mufflers and its performance based on variation of its parameters.

2. LITERATURE SURVEY

The US Military NACA report is an extensive study on 77 variations in muffler designs and the various kinds of applications based on these designs. Methods and charts are proposed for further improvements in muffler performances. Key insights of the paper include the infinite tail theory which tile proposes a method to calculate the transmission loss in a muffler, the calculation of attenuation loss based on frequency alone and the detailed study of a single expansion chamber performance curves based on change in various parameters of length and size. It provides scope for research in the domain of muffler efficiency and design optimization for maximum attenuation loss. [1]

In the ISMSIT 2017 paper a mathematical model for the calculation of transmission loss is proposed which is carried out for mufflers with different cross sectional geometries. By using transfer matrix method with four poles the noise transmission loss is determined. [2]

Young and Crocker propose the finite element method in their study to plot the transmission loss curves. An analytical approach on the design optimization of a muffler, it provides with another solution method which is precise and can be used widely for simple expansion chambers [3]

Modeling of a muffler for better analysis and using an experimental test rig for testing of an automobile exhaust muffler, dynamic modal analysis of this exhaust muffler using CAE for stresses, strains and deformations is researched on. CFD and Heat transfer models of mufflers are well known and is worked upon. [4]

The experimental methods of measuring the four-pole parameters of passive and active vibration isolators is studied. Setup of a rig, its background study and various facilities are researched. [4], [5], [6] The provision of precise boundary conditions, comparison of various muffler designs for the most feasible ones, effect of parameters like back pressure and usage of softwares like MATLAB and other modelling softwares are few domains of current research. [8], [9], [10]

3. RESEARCH GAP

While studying the above papers, a gap noticed includes the study of mufflers based on expansion ratio and length simultaneously for optimized cross section diameter and transmission loss. A comparison of an analytical and mathematical model is also lacking. This has been the basis for research of the current project.

4. THEORY

4.1 Single Expansion Chamber

A passive muffler, the single expansion chamber consists of a resonating chamber parallel to the exhaust pipe to which it is attached. In this design, the construction of flat walls are avoided since they have a tendency to vibrate.

The basic working principle of a single cylinder expansion chamber is that from the inlet port when the gas is let into the chamber, due to the sudden change in the area of cross section, the gas expands. This causes a decrease in the pressure and a decrease in the velocity. A change in the length and the expansion ratio of the chamber results in a change in the attenuation capacity.

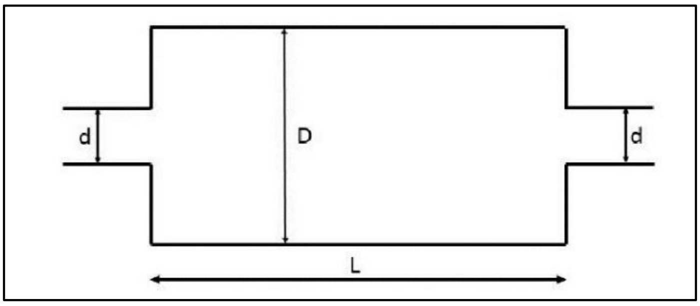

Fig 1 – Single Expansion Chamber Layout

4.2 Muffler Terms –

a. Attenuation

Difference in sound between two points in an acoustic system.

b. Sound Transmission Loss

A logarithmic ratio of the sound power incident on one side of a partition to the sound power transmitted on the other side.

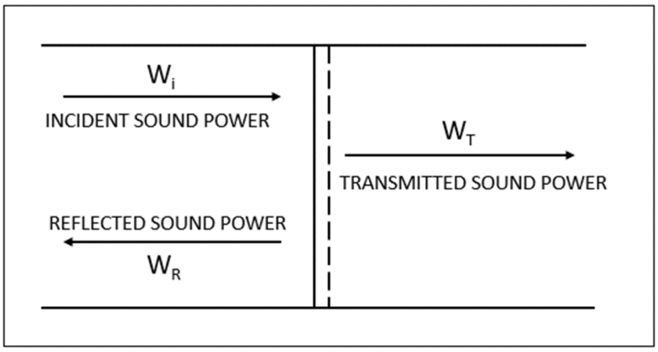

Fig 2 - Propagation of Sound over a Barrier

$TL = 10 \log (W_T/W_I) = 10\log (1/W_R)$

$TL = 10 \log10 (1 + (1/4) (m - 1/m)^2 \sin (KL)^2)$

c. Expansion Ratio

The expansion ratio of a silencer or a muffler is the ratio of the cross sectional area of the chamber to the cross sectional area of inlet pipe.

$A1 = \pi d2/4$ and $A2 = \pi D2/4$

$\text{Expansion ratio } m = A2/ A1$ [7]

5. METHODOLOGY

Following method was followed to design and develop the muffler –

i. The firing frequency and its harmonics are determined from the engine rpm.

ii. Thus for the firing frequency, length is determined.

iii. For this length, a set of values for expansion ratios are determined.

iv. Lengths feasible for these set of expansion ratios are determined.

v. Transmission Loss for varying set of lengths and expansion ratios is determined.

vi. Optimized values of length and expansion ratio are calculated by varying them simultaneously to obtain maximum transmission loss.

vii. Analysis of the muffler was done with the help of Ansys Acoustics

6. DESIGN AND MODELLING

For the given engine, following values of Transmission Loss for varying expansion ratios and lengths are obtained –

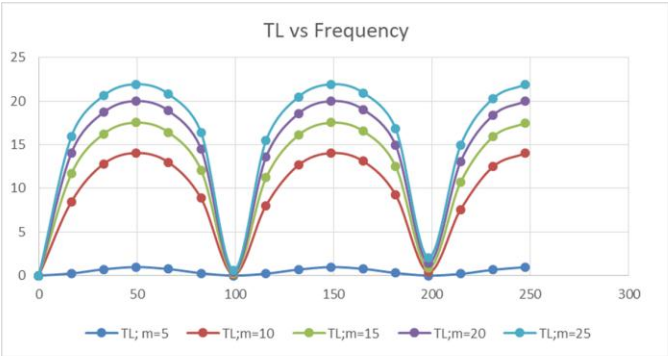

Chart 1 – TL vs Frequency (L is constant)

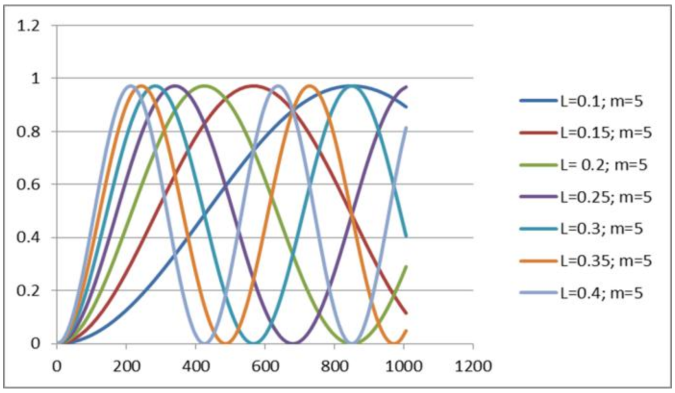

Chart 2 – TL vs Frequency (m = 5)

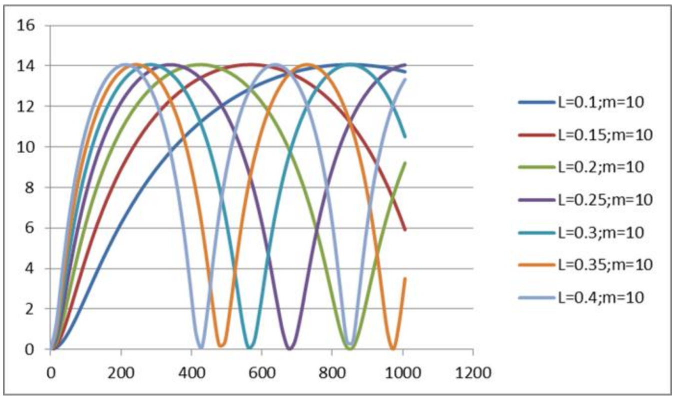

Chart 3 – TL vs Frequency (m = 10)

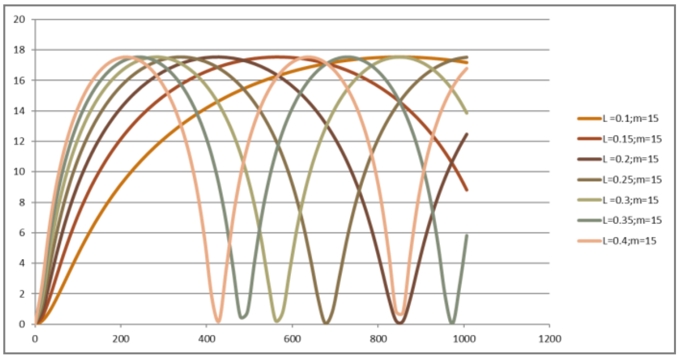

Chart 4 – TL vs Frequency (m = 15)

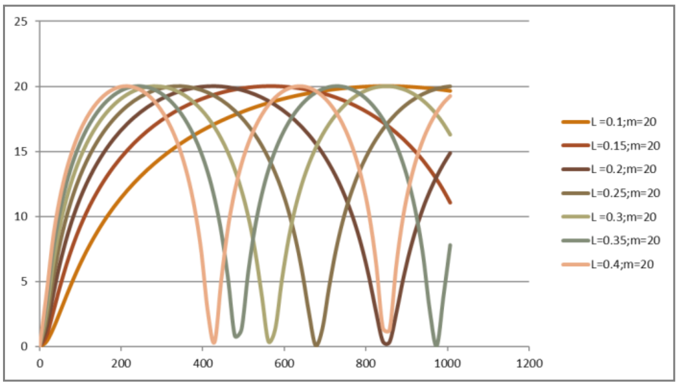

Chart 5 – TL vs Frequency (m = 20)

Varying all Lengths with respect to Frequencies and plotting the Transmission Loss curves –

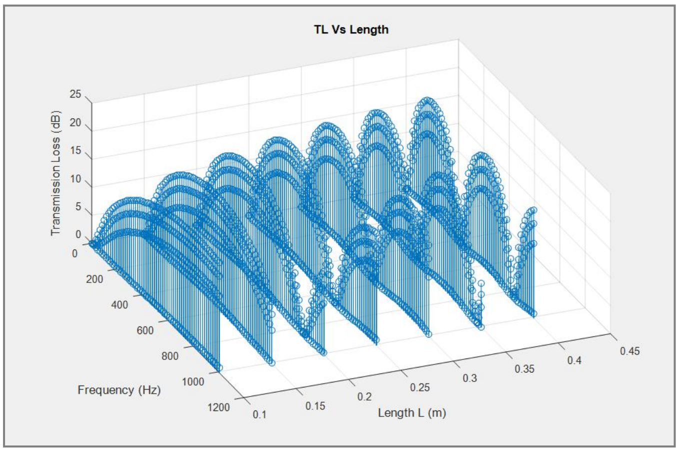

Chart 6 – TL vs Frequency vs Length

Varying all expansion ratios with respect to Frequencies and plotting the Transmission Loss curves:

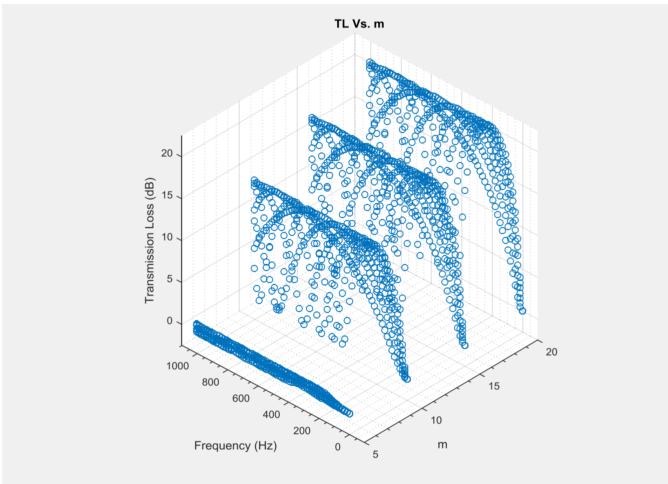

Chart 7 – TL vs Frequency vs Expansion ratio

Thus, from the above graphs along with considering manufacturing constraints -

m = 15 and L = 0.25m is chosen as the muffler dimensions for the given engine.

20dB is the maximum transmission loss incurred using this design. To increase the Transmission Loss, materials with an absorptive lining (e.g. Rockwool) can be used.

Using these dimensions the single expansion chamber is modelled as follows –

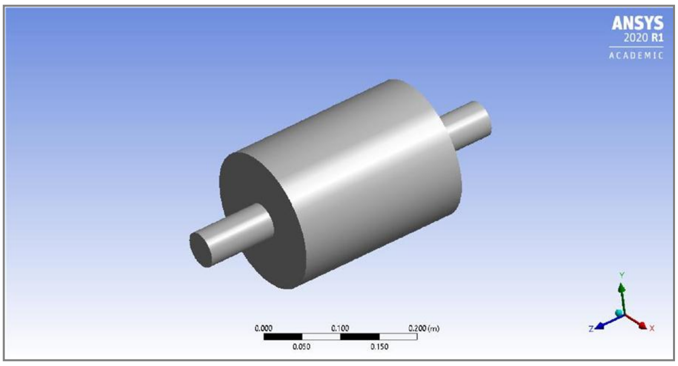

Fig 3 - Model of the Single Cylinder Expansion Chamber

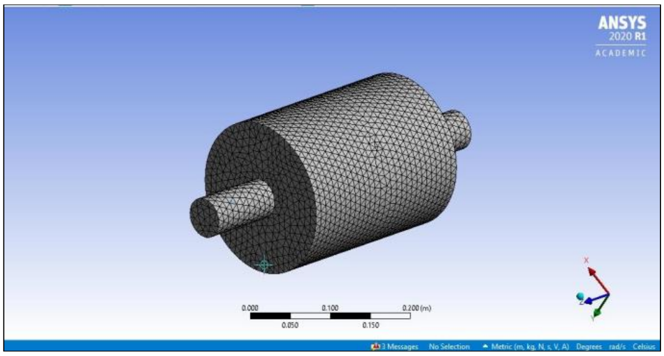

Fig 4 – Meshed Model

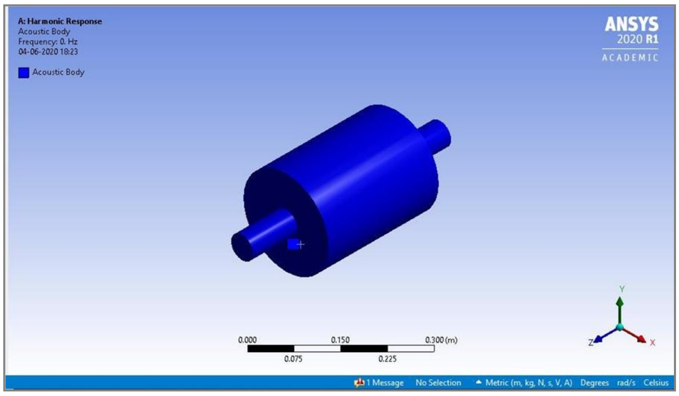

Fig 5 – Acoustic Body

The transmission loss obtained by acoustic modelling is 21.456 dB.

Thus, mathematical and analytical results are verified.

7. RESULTS AND DISCUSSION

From the graphs, we come to know the following –

i. From Charts 1 and 7, we can infer that as the expansion ratio increases, there is an increase in the transmission loss obtained.

ii. From Charts 2, 3, 4, 5 and 6, we can conclude that as the length increases, the value of transmission loss increases.

iii. Peak attenuation is obtained at the firing frequency (here 50 Hz) and its harmonics.

iv. The transmission loss obtained is zero at the resonance and its harmonics of the acoustic body.

8. CONCLUSIONS

The results show that transmission loss for a single cylinder expansion chamber is dependent on the muffler length and expansion ratio.

➢ Transmission loss increases with increase in muffler length.

➢ Transmission loss increases with an increase in the expansion ratio.

For the given problem statement, maximum attenuation loss obtained is 20 dB. The results are verified analytically and mathematically.

9. ACKNOWLEDGEMENT

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10. REFERENCES

[1] Dox D. Davis Jr, George M. Stokes, Dewey Moore and George L. Stevens Jr, “Theoretical and Experimental Investigation of Mufflers with Comments on Engine-Exhaust Muffler Design”, NACA Report 1192.

[2] Mostafa Ranjbar, Hakan Arslan, Burak Dalkilic, Emin Calik, Mehmet Cem Arslan, “On Muffler Design for Transmitted Noise Reduction”, Nov 2017.

[3] Cheng-I James Young, Malcolm J. Crocker, “Prediction of transmission loss in mufflers by the finite-element method”, J. Acoustical Society America, Vol. 57.

[4] J. D. Dickens, “Methods to measure the Four - Pole Parameters of Vibration Isolators”, Acoustics Australia, Vol. 28 (2000).

[5] S.R. Meshram, Devarashi, R. Nazirkar, A. Namdas, S. Navagire, "Design & Optimization of Exhaust Muffler & Design Validation", 10th IRF International Conference, Pune, India, 01st June-2014.

[6] P. Srinivas, Venkata Ramesh Mamilla, G. Lakshmi Narayana Rao, Sowdager Moin Ahmed, "Design and Analysis of an Automobile Exhaust Muffler", Industrial and Systems Engineering Vol. 1, July 2017.

[7] M. L. Munjal, Noise and Vibration Control, World Scientific Publishing Co. Pte. Ltd, 2013.

[8] Nitinkumar Anekar, Kalpana Girase, Shrikant Nimbalkar, Santosh Sandanshiv, "Vibration and Noise in Reactive Muffler: A Study", Advances in Mechanical Engineering Techniques (AMET-2015), March12-13, 2015.

[9] Anant W. Wankhade and Dr. A. P. Bhattu, "Optimization and Experimental Validation of Elliptical Reactive Muffler with Central Inlet Central Outlet", International Journal of Engineering Research & Technology (IJERT), Vol. 4 Issue 05, May-2015.

[10] Prasad V. Shinde, P. M. Gavali, R. A. Barawade, Y. B. Mohite, P. B. Shinde, "A Review on Muffler Design for Exhaust Noise Attenuation", International Journal of Engineering and Technology (IJET)