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Acoustics analysis of single expansion chamber reactive muffler with single baffle for maximum transmission loss

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ABSTRACT
Noise pollution is an important factor affecting environment. Diesel generators are one of the major concern for noise pollution, nowadays diesel generators are available in industries, schools, hotels, offices, etc. CPCB ha consigned the permissible noise level in India for various zones. Therefore, it is required to reduce the noise coming from generators. The noise from the generators can be reduced by doing soundproofing or by using muffler. In this paper transmission loss characteristic is been drawn with internal geometry as baffle inside muffler, where baffle positions are varied for attenuation of transmission loss.

Keywords: CPCB, backpressure, mufflers, acoustic enclosures, efficiency.

I. INTRODUCTION

Nowadays generators have become an easy alternative source for energy generation. Generators are easily available in market and are mostly seen in offices, schools, colleges, hotels, etc. Most of the generators make noise while they are operational which is not good for human ear and also increases noise pollution. CPCB has drawn few guidelines for sound limit in various zones. The tolerable limit in industrial areas is 75 dB for daytime and 70 dB at night. And in business area, the tolerable limit is 65 dB and 55 dB, while in residential areas it is 55 dB and 45 dB during daytime and night respectively. Additionally, areas within 100 meters of the premises of schools, colleges, hospitals and courts are categories as the 'silent zone' areas. In silent zone areas at day time the tolerable noise limit is 50 dB and during the night time the tolerable limit is 40 dB.[1] According to the CPCB guidelines the maximum permissible limit for new diesel generators for upto 1000 KVA rated capacity is around 75dBA. To prevent noise pollution and to attain noise attenuation generators should have proper acoustics enclosures to reduce noise. Such enclosures are usually made of sound proof materials which help in reduce noise. So as a part of this research it was desired to make modifications in the present available designs in muffler in order to attain primary noise conditions. So in this paper acoustics analysis is done on single expansion reactive muffler with single baffle where baffle is placed at various positions to attain maximum transmission loss, where functional parameters like size, position of baffle, transmission loss, sound pressure level are been included.

II. RESEARCH GAP:

Various papers are available on acoustics analysis of single expansion chamber muffler where design methodology, optimization techniques for increasing transmission loss, etc are given. Very few articles are available on acoustics analysis of single expansion chamber with baffles for maximum transmission loss. In this paper acoustics analysis have been done on single expansion chamber muffler for maximum transmission loss by using baffles and varying baffle position from inlet and outlet. Results of the above cases are drawn and compared for determining the best combination.

III. THEORY:

Exhaust Mufflers are the mechanical devices engineered to attenuate engine noise before it reaches to the surrounding atmosphere. The integrated sound cancellation phenomenon of expansion chambers inside exhaust muffler makes it possible to attenuate high frequency noise and generate sounds below critical level. Though mufflers can reduce high frequency noise, it gradually decreases engine performance by generating heavy back pressure. Hence it is essential to design a muffler which reduces engine noise without affecting the performance. Design and analysis of mufflers is a complex work that affects noise attributes, emission and fuel efficiency of an internal combustion engine.

3.1 Muffler Terminology:

There are many requirements that should be used while designing a muffler relaying upon the application. Functional requirements such as adequate insertion loss, backpressure, size, durability, desired sound, cost, weight, compact shape and style. In various application the ultimate selection of an exhaust muffler is based on a conciliation between the predicted acoustical, aerodynamic, mechanical and structural performance in conjunction with the cost of the resulting system. Some of requirements are defined below and the structure of sound transmission characteristics can be measured in terms of the one of the following parameters.

3.1.a. Insertion loss (IL) :-

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

IL = 10 log (W1/W2)dB (1)

Where, W1 - the acoustic power without the structure

W2 - the acoustic power with the structure

3.1.b.Transmission loss:

Transmission loss is known as the relation of the incident power and transmitted power from the structure. Symbolically,

TL=10logWi/Wt(dB) (2)

Where,

Wi and Wt - the incident acoustic power and transmitted acoustic power

TL - evaluate the performance of the muffler wall.[2]

3.1.c. Backpressure:

Backpressure is known as the extra static pressure exerted by the muffler on the engine through the restriction in flow of exhaust gasses. Normally, the better a muffler is at attenuating sound the more backpressure is generated. In a reactive muffler where good attenuation is realized the exhaust gasses are forced to pass through numerous geometry changes and a fair amount of backpressure possibly generated, which reduces the power output of the engine. To avoid power losses the backpressure should be kept to a minimum especially for better performance of vehicle.[3] [4]

IV. MODELLING:

For finding the transmission loss of single expansion chamber finite element analysis method is used. For this software used is COMSOL Multiphysics. Design conditions for this analysis is listed below.

a. The length of the expansion chamber is 520mm.
b. The diameter of the expansion chamber is 214mm.
c. The diameter of the inlet and outlet pipe connected to the expansion chamber is 44mm.
d. The length of the inlet and outlet pipe connected to the expansion chamber is 160mm.
e. The expansion chamber volume is kept constant for all modelling work.

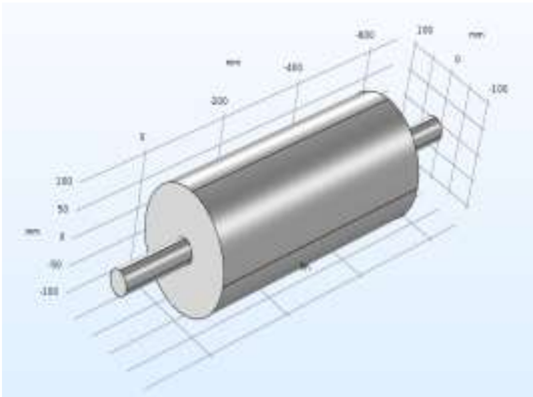

Fig.1. Model of Single Expansion Chamber

4.2 Meshing:

Meshing is defined as a process to discretize an infinite geometric domain into finite numbers of elements and nodes. The maximum element length is calculated considering the wavenumber and wavelength. For Finite Element Analysis it is necessary to maintain four elements per each wavelength.

Wavelength calculation

$$\lambda = \frac{c}{f}$$

Where

λ = Wavelength of speed
c = Velocity of Sound = 343 m/sec
f = Maximum Frequency = 1600 Hz

$$\lambda = \frac{343}{1600} = 0.214 \text{ m}$$

According to the theory y, there has to be four elements per wavelength
Maximum element length

$$\frac{\text{Wavelength}}{4} = \frac{0.214}{4} = 0.0535\text{m}$$

= 53.5mm

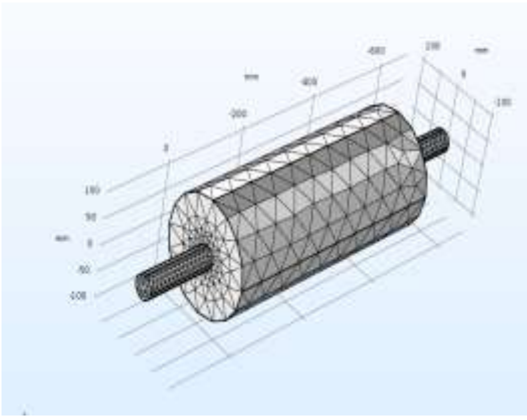

Fig.2. Meshed Model of Single Expansion Chamber

4.3 Boundary Conditions:

a. Analysis settings: - The frequency range 0 to 1600 Hz is going to be divided into intervals to calculate the results. The results can be calculated at every 10Hz by defining solution intervals to 160. For acoustic analysis, only "Full harmonic" solution method can be used.
b. Defining acoustic body: - Acoustic Body can be defined by selecting the model, this will define Mass Density and Sonic speed. In this case, air is used as a medium in muffler.
c. Mass Density = 1.2041Kg/m3
d. Sound Speed = 343.24 m/s
e. Mass Source: - Incident pressure is assumed to be 1Pa. Mass source boundary condition is used to capture the effect of reflection. If Pressure boundary condition is selected instead of mass source, it will not capture the effect of reflection at inlet. If pressure equal to 1pa, the mass source = 2/Sonic Speed = 0.005826 kg/m3 .s
f. Radiation Boundary- "Radiation Boundary" is assigned for both inlet and outlet faces to define anechoic ends at inlet and outlet.
g. Solver output- After saving the project, solving can be started to run and execute the analysis. Analysis will be accomplished within 3min depending upon the computer configuration.[5]

4.4 Results for Numerical Analysis:

The finite element simulation results of transmission loss verses Frequency are plotted together results in Fig.3. The plotted FE results show that the maximum attenuation obtained is 23dB.

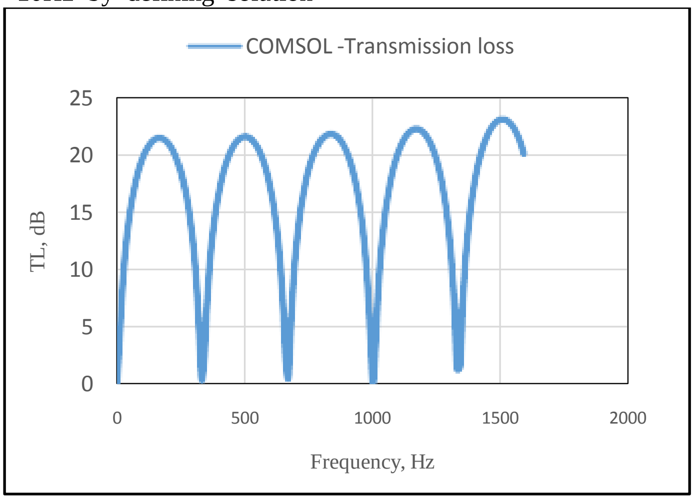

Fig.3. Frequency Vs Transmission Loss Chart for Single Expansion Muffler Numerical Analysis in COMSOL Multiphysics.

V. THEORETICAL ANALYSIS:

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 1600 Hz.

For calculating Transmission Loss for Single Expansion Chamber a MATLAB Program is made using the above mathematical equations of uniform tube, sudden expansion and extended inlet, sudden contraction and extended outlet.

5.2 Results for Theoretical Analysis:
After the MATLAB program we got the result as shown in the fig.4.The graph shows the TL versus frequency for simple expansion chamber with both empirical relation and TMM.

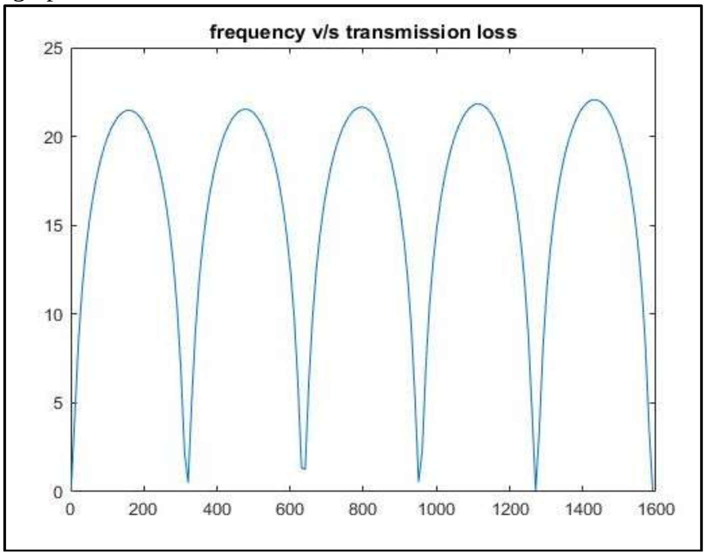

Fig.4. Frequency Vs Transmission Loss Chart for Single Expansion Muffler Theoretical Analysis in MATLAB.

The Maximum Transmission Loss for the designed muffler is 22 dB. Hence without any baffle the muffler can reduce the noise up to 22dB. [6]

VI. RESULTS FOR THEORETICAL ANALYSIS:

The simulation on muffler is carried out to determine its theoretical performance. The simulation is focused on Transmission loss (TL) and Back pressure

When steady air flow passes through mufflers, there will have steady pressure drop which is related to flow and geometry of air passages. Pressure drop in an exhaust muffler plays an important role for the design and development of mufflers. Predication of pressure drop will be very useful for the design and development of muffler. To predict the pressure, drop associated with the steady flow through the muffler CFD has developed over the last two decades.

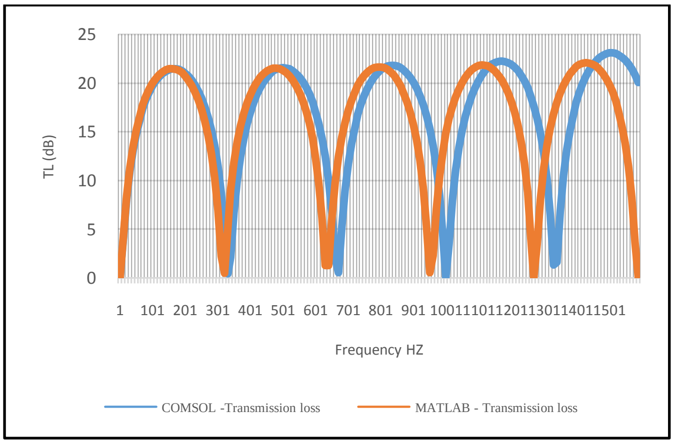

Fig.5. MATLAB and COMSOL results comparison chart for single expansion muffler.

Fig.5. shows a good agreement of the FEA results with the analytical results. But the error increases as the frequency increases. Generally analytical results shows close agreement with FEA results at frequencies below 1800 Hz.[7] The FEA results is in excellent agreement with the experimental results at all frequency range. As a result, the modeling procedure can be confidently

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used in acoustic analysis of other reflective mufflers geometries.

VII. INTRODUCTION OF BAFFLE INSIDE MUFFLER:

Traditional,there is use of perforated pipe inside the muffler for maximizing transmission loss but for further increase of transmission loss we have to find some other measures.For this purpose we can use baffles instead of perforated pipe.For the use of baffle we have to determine diameter of baffle for passage of exhaust air also we have to determine the position of baffle. During this determination process we have consider effect on back pressure and increase in transmission los[8][9]

7.1. Determination of hole diameter:

Before Starting analysis of position and number of baffles, determination of hole diameter of baffle is important as it provide restricted passage for air to pass out and also remain surface for reflection of exhausted air which helps to maximize transmission loss.

In this paper we have determinedhole diameter by doing number of iterations of different diameter in COMSOL Multiphysics. Firstly, we choose diameter of hole as 44mm which is equal to inlet diameter of muffler as we can't minimize diameter below inlet diameter of muffler as it will apply more backpressure on engine though it will increase transmission loss. During project we have done calculation for diameter 44mm,50mm,60mm for baffle positioned at 40mm from inlet of muffler (with reference to above calculation). Below graph is compared for transmission loss of various hole diameter. From the results obtained hole diameter of 44mm is chosen which has max. TL for 800Hz frequency.[10]

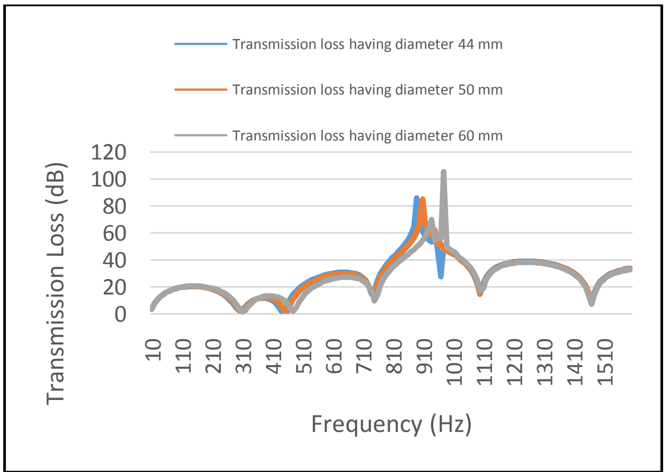
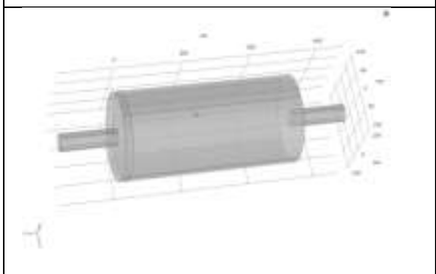
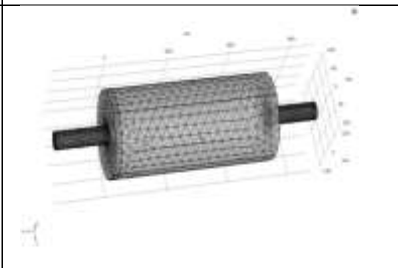
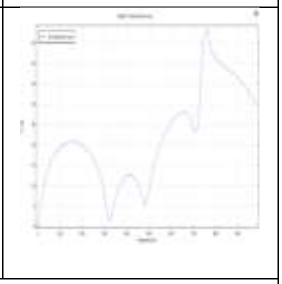


Fig.6. Hole diameter comparison chart

7.2. Determining baffle position:

The total length of the muffler chamber is 520mm. So considering different baffle positions from 0mm to 520mm at an interval of 20mm from inlet. The total iterations will be performed are 25. The diameter of the hole on baffle is 44mm.

Geometry	Meshed model	Transmission loss
		
Baffle position at 20mm from inlet		

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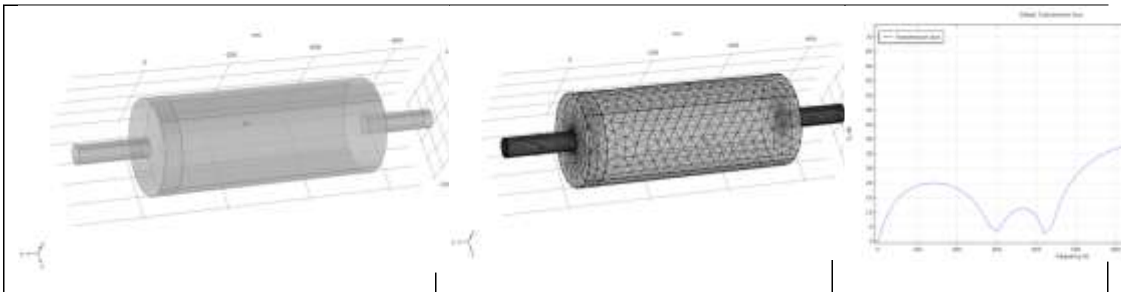
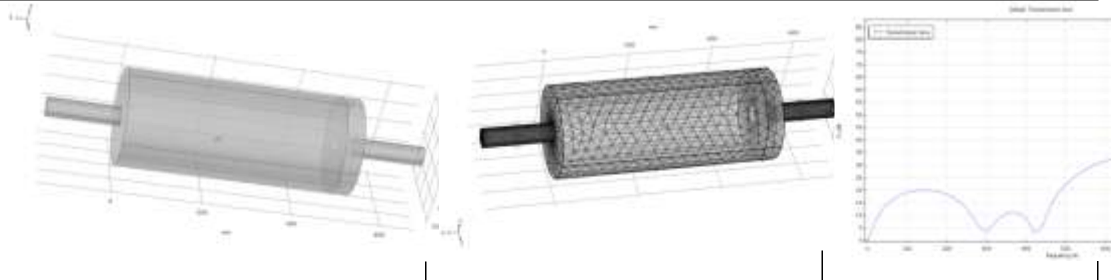
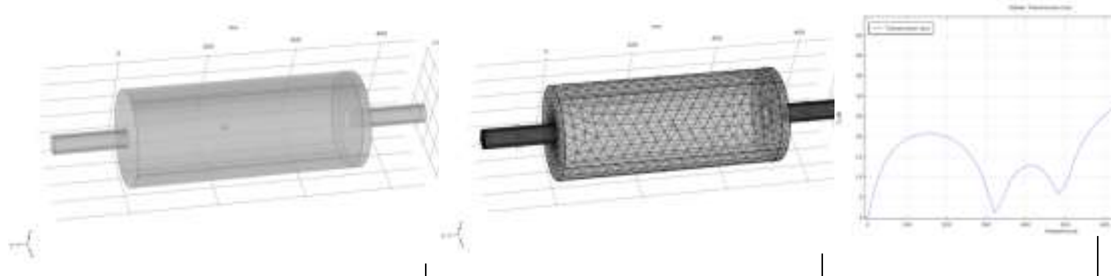


Baffle position at 40mm from inlet



Baffle position at 480mm from inlet



Baffle position at 500mm from inlet

Four positions are selected where maximum transmission loss is achieved. The maximum transmission loss observed is at baffle position 480mm from the inlet, followed by 40mm, 20mm and 500mm from the inlet.

VIII. RESULTS:

Different cases were analysed for transmission loss. Model of single expansion chamber muffler without internal geometry was analysed for transmission loss and the results we got was not optimum with a maximum transmission loss between 20dB to 24dB approx. Later various iterations were carried out for single baffle positioning at 20mm intervals from the inlet. All the results for transmission loss was plotted and top four results were finalised depending upon the requirement. The finalised baffle positions are baffles placed at 20mm, 40mm, 480mm and 500 mm from the inlet of the single expansion reactive muffler. Below graph is drawn for different baffle positioning and muffler without internal geometry.

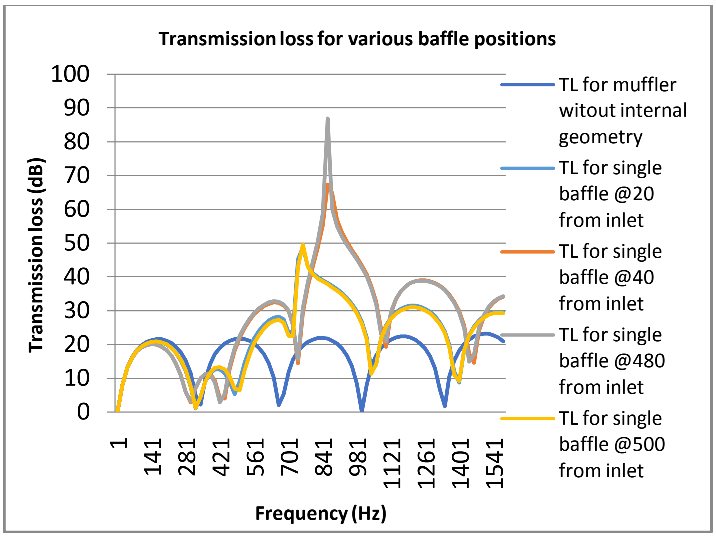


Fig.6. Transmission loss for various baffle positions

IX. CONCLUSION:

In this research article,there is comparison between theoretical and numerical analysis and they show similarity which simplifies the process of muffler analysis.During the use of baffles, the transmission loss increases with decrease in hole diameter of baffle but back pressure increases which limits the smallest diameter equal to inlet diameter.For baffle position, transmission loss increases nearer to inlet and outlet position of baffle.

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