Comparative Analysis of EIEO Muffler and Conventional Baffle Plate Type Muffler

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***Abstract*— In the world today when we are talking about the ill effects of increasing pollution due to emission through automobiles and the noise created by them. It has made mandatory to maintain the control on both these parameters. In addition, the new improved regulation standards released by government imposes automobile manufacturers to make certain modifications in the silencers. In this paper, a comparative study between the existing silencer of Eicher Tractor i.e. a baffle plate silencer and modified ExtendedInlet and Extended Outlet (EIEO) muffler have been done. These modifications were suggested to the geometry of the silencer to meet current standards and with a minor increase in cost to the company. The silencer was designed analytically compared in COMSOL Multiphysics Software. It was observed that the transmission loss of the modified muffler is better than the existing and hence meeting the current norms.**

***Index Terms*— Reactive Muffler, EIEO, Muffler analysis in Comsol, Muffler design principle.**

I. INTRODUCTION

NOWADAYS automobiles are one of the major sources of noise pollution, and when it is focused on urban areas, the automobiles appears to be the largest source. It is often observed that tractors are one of the noisiest vehicles on the road. This is mainly due to their low power/weight ratio, which makes them operate almost at full power during agricultural work or towing loads. In addition, for the same power rating diesel engines create more noise than petrol engines, since, on combustion of diesel, engines produce more harmonics than the slower combustion of gasoline. An un-muffled petrol engine radiates exhaust noise in the range from 90 to 100 dB(A), whereas, an un-muffled diesel engine under same operating conditions radiates exhaust noise in the range of 100 to 125 dB(A). To analyze the performance of a muffler,few parameterslike transmission loss and backpressure are to be considered. The transmission lossrepresents the ability of the muffler to attenuatethe noise. The transmission loss is independent of the source of noise.Hence, this property of muffler does not changeon the noise source. New design to enhance the acoustical properties of a muffler cause a resistance against the flow of exhaust gasses and this resistance staggered the flow. This is called the backpressure, and it causes an increase in pressure inside the engine. Due to the backpressure, volumetric efficiency of the engine consumption increases. Therefore, every manufacturer has to consider the maximum allowable backpressure [1, 2].

Often researchers have worked on acoustics of the automobile and persisted to enhance the tuning of the silencer. For a stable system or industrial machine, it is commonly observed that high noise level and unpleasant sound causes fatigue to the human ear and fall decrease the efficiency of the workers. Traditionally mufflers have been designed by various numerical techniques like B.E.M (boundary element method) or F.E.M (finite element method), transfer matrix equations, Eigen value method,etc. [3]. However, they could be designed by numerical model generation, but it is lengthy and time-consuming also they constrain the user to try a variety of other design alternates. The process becomes challenging as it involves a more iteration with the different prototype. CAD & CAE software like ANSYS, WAVE, CMM+, FLUENT, SIDLAB and COMSOL Multiphysics are amongst some widely used software for the analysis of muffler in the case of both thermal and acoustic computational fluid dynamics.

II. LITERATURE REVIEW

Since decades, engineers and researchers have worked on modifying the muffler design in all aspects viz. mechanical, acoustic, aesthetic and ergonomics. Also, the cost and reliability have been important factors. Hak-Son Hanu et al. worked on theanalytical design of muffler based on transmission loss calculation. They designed muffler after taking into account the exhaust gasses temperature, exhaust noise through the pipe. Then they calculated the transmission loss required and the dominant frequencies for the design. They conducted the experiment with KODOS and WAVE, analyzing the program and predicted for intake and exhaust system. They also used two microphones method for error analysis while conducting experiments [3].

Zeynep Parlar et al. worked on different analysis software including COMSOL and found that there occurs approximately 20 percent error with computer based and experimental results. Daniel et al.focused on the general design principles of a muffler and advantages of different types of mufflers. Mo and Huh et al.worked on the acoustic transmission loss of muffler with simple and complexstructure using NASTRAN and the obtained results werecompared with the experimental results [4]. Munjal found the backpressure of a perforated, cross-flow and reactive muffler with CFD method and estimated the effects of different parameters such as diameter and, area expansion ratio [5].

Paritosh Bhattacharya et al. worked on reactive muffler for two cylinders four stroke diesel engine. He computed the transmission loss analytically and was able to reduce noise by 15 dB. They also increased the BSFC of the engine by certain level [6]. Rahul D. Nazirkar et al. worked on the simple single and double expansion chambers by using CATIA V5 and ANSYS and find out the natural frequency of the muffler. The purpose of the study was to analyze the single and double expansion chamber performance and ability to avoid resonance. According to their study, the double expansion chamber gives better noise attenuation as compared to single-expansion chamber muffler. The double expansion chamber type muffler has higher natural frequency as compared to the operating frequencies. Hence, the double expansion chamber mufflers seems to be more effective but they also increase cost of manufacturing [7].

Takashi Yasuda et al. did research on muffler with low pass filter and Helmholtz resonator. He discovered that the holes which inter connects each other, enabled the muffler to reach noise attenuation performance similar to Helmholtz resonator. Therefore, this type of muffler can effectively attenuate the low frequency as well as the high frequencies at the same time.He also concluded that:

- The chamber volume at both sides of the return pipe should be equal to obtain a lowest cut-off frequency.
- The tail pipe of the muffler should be long enough to attain lower cut-off frequency.
- Continuous holes should be located on the front of tail pipe for better attenuation of lower frequencies. [8]

In another study, Yadav P. S et al. conducted Noise Source Identification (NSI) Test for air born noise in the tractor and identified that the silencer, the hydraulic pump and the timing gears are the major sources of noise. He did some design modification and structural optimization to reduce noise using CAE and successfully reduced noise by 6 dB (A) [9].

Before going into depth of muffler design and its principle one should understand some of the relevant terms often used.These are the requirements of engine exhaust muffler.

A. Sound pressure level:

It is known as the logarithmic measure of the effective pressure of the sound to the reference value. The SPL is denoted by “Lp” and its unit is dB (decibels). Mathematically, the total acoustic power radiated by a source ‘W’ can be found by integrating the intensity over a hypothetical closed surface enclosing the source.

$$W = \oint I\ dS.$$

The corresponding logarithmic units are:

Sound pressure level

$$SPL = 20 \log \frac{P_{rms}\ N/m^2}{2\times10^{-5}\ N/m^2}\ \text{dB.}$$

Intensity level

$$L_I = 10 \log \frac{I\ W/m^2}{10^{-12}\ W/m^2}\ \text{dB.}$$

B. Insertion Loss

It is defined as the difference between the acoustic power radiated without any muffler and that with muffler.

$$IL = L_{w1} - L_{w2}\ \text{dB.}$$

$$= 10 \log (W_1/W_2)\ \text{dB}$$

C. Transmission Loss

It is known as the difference in the sound pressure levelof the incident entering wave and leaving wave transmitted through muffler when the muffler termination is anechoic. The TL is the property of muffler only. [10]

D. Backpressure:

Backpressure represents the extra static pressure imposed on the engine due to restrictions in the flow of exhaust gasses in the muffler. This should be kept minimum in order to maximize the engine performance. Extra backpressure eventually affects the brake specific fuel consumption (BSFC) of the engine.

Effects of Increased Back Pressure:

- At highbackpressure, the engine has to compress the exhaust gasses to a higher pressure, which involves additional mechanical work and/or less energy extracted by the exhaust which can affect intake manifold boost pressure. This may lead to an increase in fuel consumption, PM and CO emissions and exhaust temperature.
- Increase in exhaust temperature could result in overheating of the exhaust valve. Increase NOx emission is also possible due to the increase in engine load.
- Increased backpressure could affect the performance of the turbocharger, causing changes in the air to-fuel ratio-usually enrichment; which may affect the engine performance. The magnitude of the effects depends on the type of charge air systems.
- Increased exhaust pressure can also restrict some exhaust gasses to leave the cylinder, creating an internal exhaust gas recirculation (EGR).
- All the engines have a maximum allowable backpressure specified by the manufacturer. The operation of the engine at high backpressure might hamper the engine warranty.
- It is generally accepted that for every inch of Hg of backpressure , approximately 1-2 HP is lost depending on the displacement and efficiency of the engine, the combustion chamber design, etc.

E. Size:

A muffler which is larger in size could cause accommodation problems, increased weight, and cost.

F. Durability:

The material of the muffler should be so durable to handle the high acoustic pressure and temperature. It must also be corrosion resistive.

G. Spark – arresting:

The muffler should have spark arresting capability, particularly for agricultural use.

III. METHODOLOGY

Since many studies have revealed that the extended inlet and extended outlet mufflers have more sound attenuation properties as compared to simple baffle plate mufflers of the same volume [10]. Hence, we chose to compare both types under same conditions and parameters in comsol multiphysics.

Taking into the reference of muffler design procedure by Shital Shah in his paper titled as A practical approach towards muffler design, development and prototype validation [11].

Step 1: Benchmarking

Consider following engine parameters [12]

Engine data: for Eicher 485 super DI

Bore (D) = 100 mm

Stroke (L) = 125 mm

No. Cylinders (n) = 3

Engine power (P) = 45HP

Max. RPM (N) = 2250 rpm

Allowable back pressure for muffler = 50 mm of Hg

Transmission Loss Noise target (muffler) = 30 dB

Step 2: Target Frequencies

Cylinder Firing Rate:

CFR = Engine Speed in RPM/60 …. For a two-stroke engine.

CFR = Engine Speed in RPM/120 ….For a four-stroke engine.

Therefore,

$$CFR = \frac{2250}{120} = 18.75 \text{ Hz}$$

Engine Firing Rate (EFR):

$$EFR = 3 \times 18.75 = \mathbf{56.25\ Hz.}$$

Step 3: Muffler Volume Calculations

Volume swept by each cylinder

$$V_s = \frac{(\pi \times D^2 \times L)}{4}$$

$$= \frac{(3.14 \times 100^2 \times 125)}{4} = 0.98 \text{ ltr}$$

Total swept volume = $3 \times 0.98 = 2.94$ ltr

Volume to be considered

$$V = (n) \times \frac{V_s}{2} = 1.47 \text{ ltr}$$

Considering Silencer value as 5 times the total volume considered.

$$V_m = 1.47 \times 5 = 7.35\text{ltr} = 0.00735 \text{ m}^3$$

Step 4: Internal configuration of muffler

Diameter of muffler can be calculated as

$$V_m = \frac{\pi}{4} \times d^2 \times l$$

$$0.00735 = \frac{\pi}{4} \times d^2 \times 0.5$$

$$d = 0.136\text{m}$$

$$d = 136 \text{ mm}$$

Calculating open area and porosity

$$d_1 = \frac{1.29}{\sqrt{N}}$$

$$\sigma = \frac{(\frac{\pi}{4} \times d_1^2)}{C^2}$$

Where,

d_1 = diameter of holes punched

N = RPM of engine

σ = porosity

C = Velocity of sound i. e.

Step 4: CAD and CAE of obtained

Now as we have the calculated parameters of modified muffler. First of all, we should stimulate the existing muffler of the Eicher Tractor under certain parameters and then the modified with the same conditions.

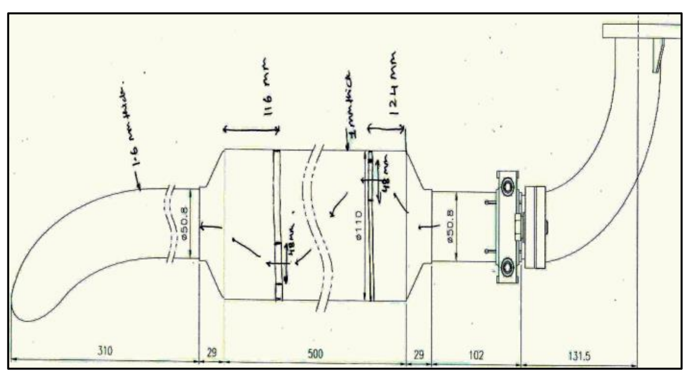
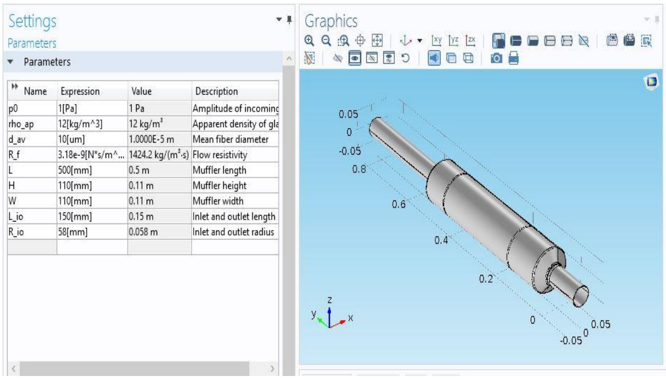


Fig1. *Existing Muffler Geometry*

The above muffler geometry was plotted in CATIA V5 and imported in Comsol Multiphysics.

Fig 2. *CAD plot of existing muffler*



Name	Expression	Value	Description
p0	1[Pa]	1 Pa	Amplitude of incoming
rho_ap	12[kg/m^3]	12 kg/m³	Apparent density of gla
d_av	10[um]	1.0000E-5 m	Mean fiber diameter
R_f	3.18e-9[N*s/m^...	1424.2 kg/(m³·s)	Flow resistivity
L	500[mm]	0.5 m	Muffler length
H	110[mm]	0.11 m	Muffler height
W	110[mm]	0.11 m	Muffler width
L_io	150[mm]	0.15 m	Inlet and outlet length
R_io	58[mm]	0.058 m	Inlet and outlet radius

Fig 3. Import CAD and Design Parameters

Now the model is modeled for pressure acoustics frequency domain with certain modification in Helmholtz resonator equation. Which is prebuilt in the software library. [13]

$$\nabla \cdot \left(-\frac{\nabla p}{\rho}\right) - \frac{\omega^2 p}{c^2 \rho} = 0$$

Where,

p = Acoustic pressure
ρ = Desinty
c = Speed of sound
ω = Angular frequency.

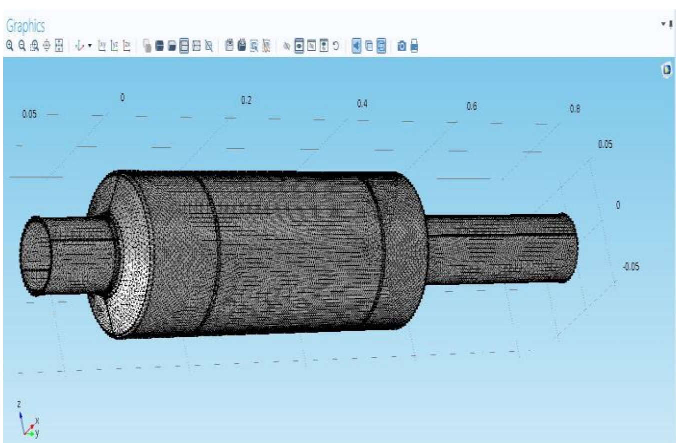


Fig 4. The Meshing of Simple Muffler.

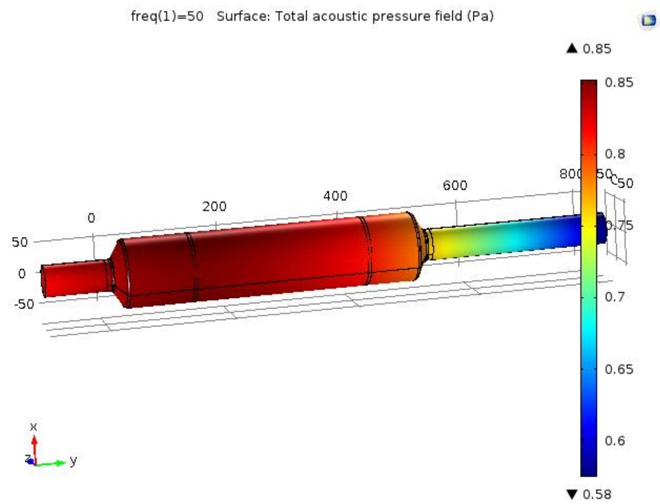


Fig 5. Surface: Total acoustic Pressure at 50 Hz

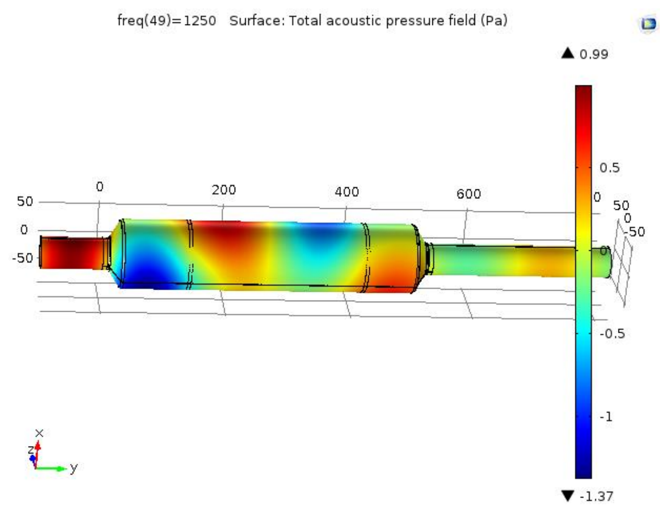


Fig 6. Surface:Total acoustic Pressure at 1250 Hz.

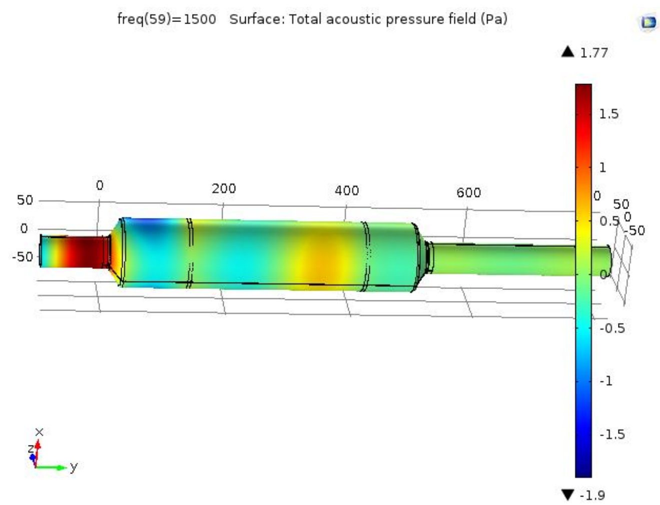


Fig 7. Surface: Total acoustic Pressure at 1500 Hz

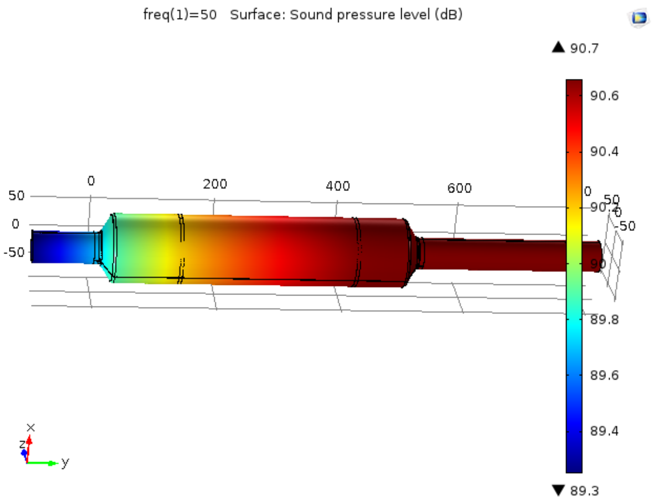


Fig 8. Sound Pressure level at 50 Hz

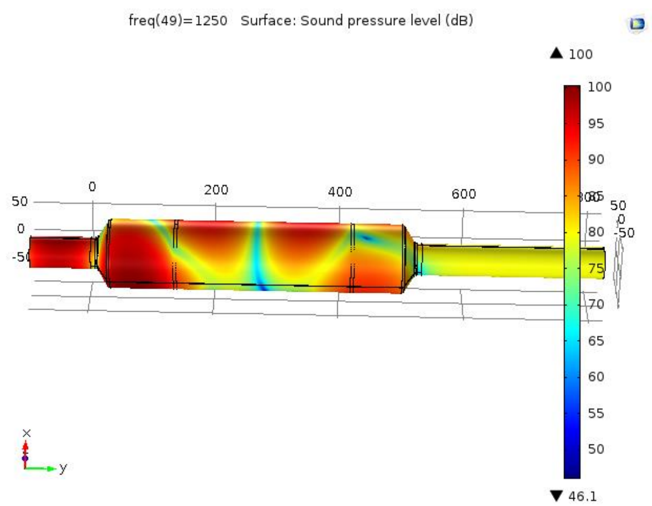


Fig 9. Sound Pressure level at 1250 Hz

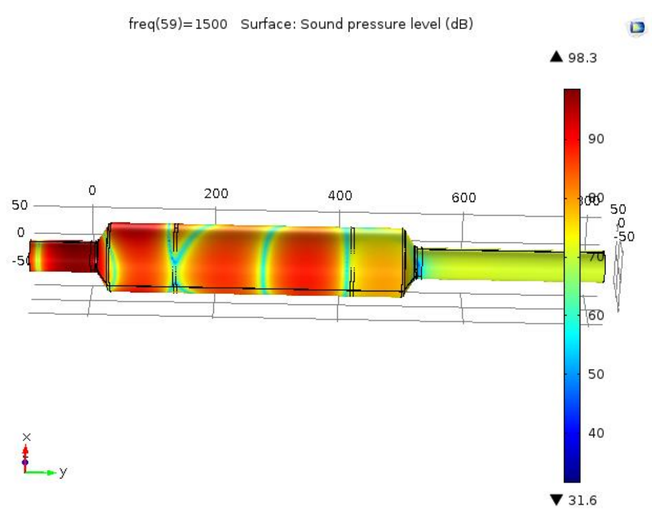


Fig 10. Sound Pressure level at 1500 Hz

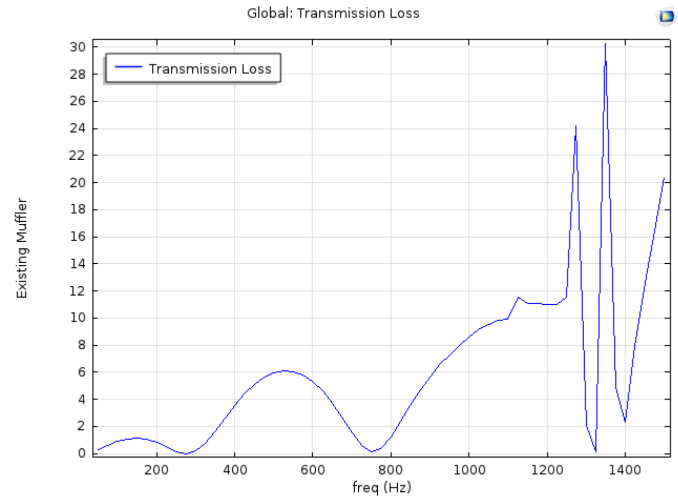


Fig 11. Transmission Loss for existing muffler.

As it can be observed from the above graph that this type of muffler produces very less attenuation for the lower range of frequencies and large attenuation at higher frequency order. The highest attenuation observed was 30 dB at around 1350 Hz.

B. Analysis of modified muffler

For justified comparison of EIEO and above muffler, both mufflers should have the same volume. Since the modified EIEO muffler is elliptical in circumference hence calculations can be done as follows.

Volume of above cylindrical muffler.

$$V_{m1} = \pi \times {r_1}^2 \times L$$

$$V_{m1} = \pi \times 55^2 \times 550$$

$$= \sim 5226825 \text{ mm}^3$$

Volume of elliptical chamber

$$V_{m2} = \pi \times a \times b \times L$$

Let b = 1.5 a

$$5226825 = \pi \times 1.5a^{2} \times 500$$

a = 47.1

b = 75

Where,

a = Minor radius of the ellipse

b = Major radius of the ellipse

The modified muffler was developed with extended inlet and extended outlet in three chambers with perforations in the center chamber.[14]

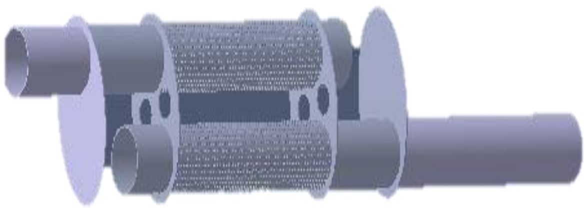


Fig. 12 CAD of EIEO muffler

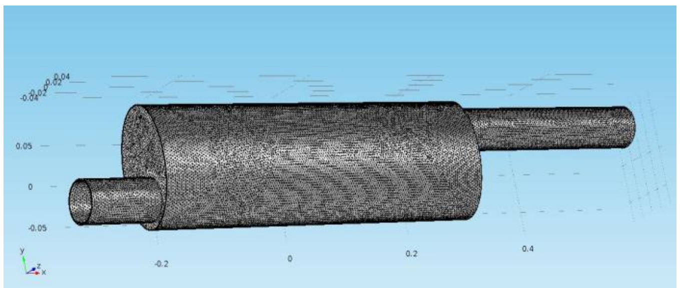


Fig. 13 Meshing of EIEO muffler

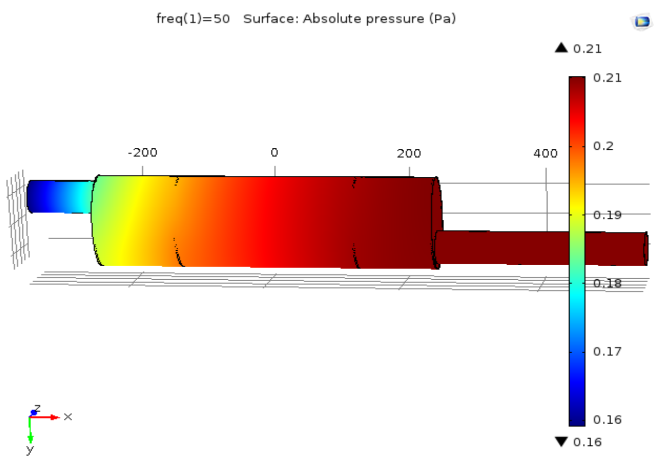


Fig. 14. Absolute Pressure at 50 Hz

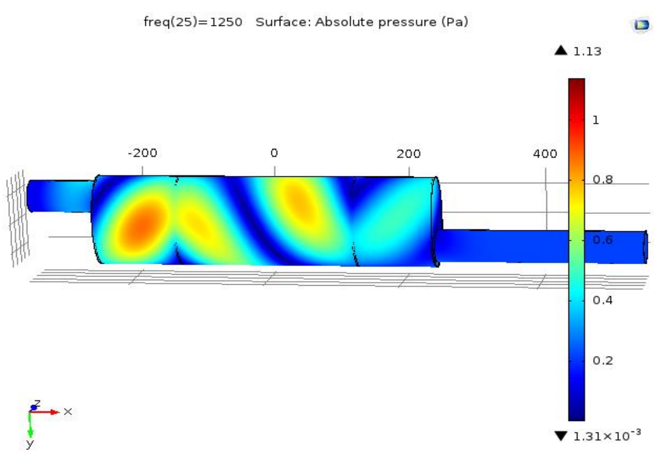


Fig. 15. Absolute Pressure at 1250 Hz

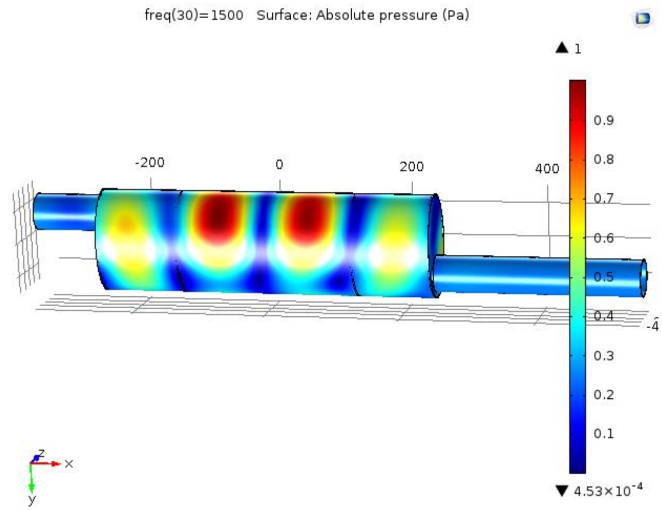


Fig 16. Absolute Pressure at 1500 Hz

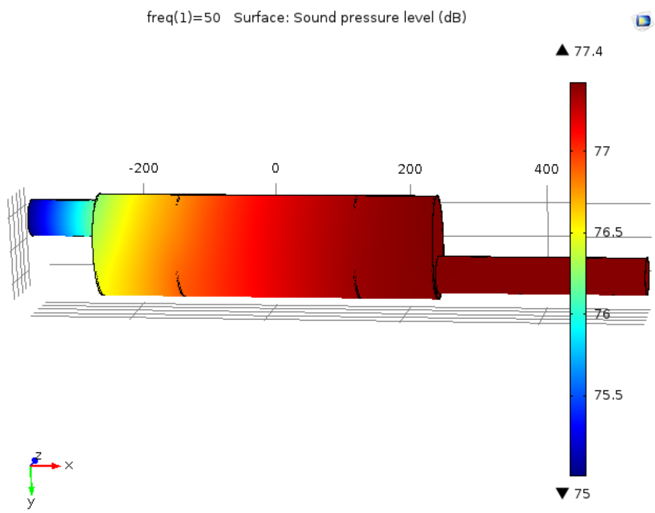


Fig 17. Sound Pressure Level at 50 Hz

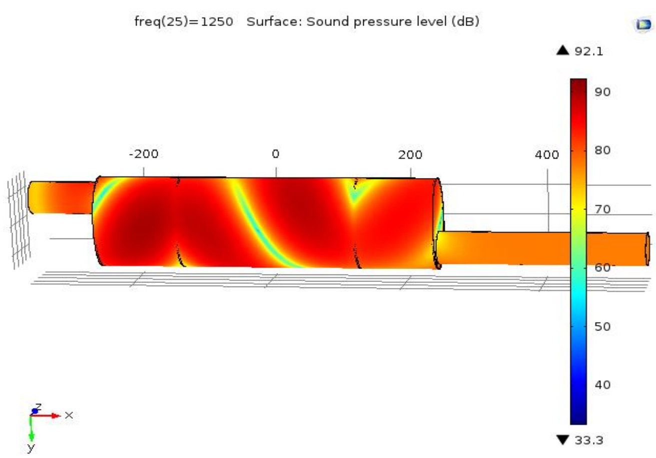


Fig 18. Sound Pressure Level 1250 Hz

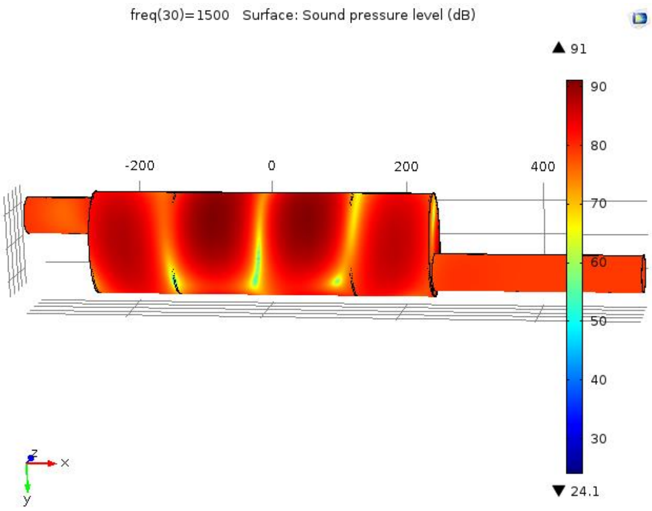


Fig 19. Sound Pressure Level at 1500 Hz.

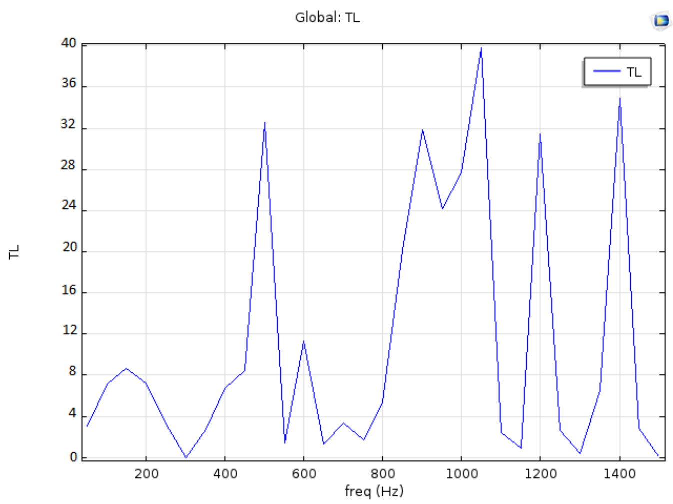


Fig 20. Transmission Loss of EIEO muffler

IV. Results and Discussions

It can be observed from above figures that the simple muffler gives very less attenuation at lower order frequencies and attenuates frequencies above 1000 Hz. Whereas the EIEO muffler offers attenuation throughout the frequency band. It could also be observed that in spite of high attenuation the EIEO muffler have more total acoustic pressure as compared to the simple muffler, which ultimately rise to back pressure in the system. Hence, it is desired that the EIEO muffler should be optimized for performance and backpressure. The attenuation of EIEO muffler could be improved marginally if a sound absorbing material lining is used inside to absorb sound and heat.

V. Conclusion

This study has shown that the EIEO muffler has more advantages over same volume simple muffler. Hence to get more noise attenuation EIEO muffler should be used with certain modifications for backpressure. Also, the muffler could be used with theacoustic liner inside to improve the effectiveness. The EIEO muffler can be bit costlier but could be cost effective if considered results.

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