Finite Element Analysis of Double Expansion Chamber Reactive Muffler with Side Outlet.

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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 Double Expansion Chamber Reactive (DEC) Muffler with various combinations of placement of side outlet. The approach is useful in the acoustic analysis of Double Expansion Chamber Muffler for maximizing Sound Transmission Loss. The purpose of paper is to study the effect of placement of side outlet on transmission loss of Double Expansion Chamber Reactive Muffler with the help of numerical analysis using COMSOL Multiphysics.*

Keywords: *Double Expansion Chamber Reactive muffler, Transmission Loss, Numerical analysis.*

1.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 [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 side outlet, is placed in Double Expansion Chamber Reactive Muffler. The muffler is simulated using COMSOL to predict muffler transmission loss performance.

2.Modeling

The muffler transmission loss for the Double Expansion Chamber Reactive Muffler is evaluated using finite element analysis. The software used for the analysis is COMSOL Multiphysics.[5].The design conditions used for evaluating transmission loss of muffler are listed as follows

a) The length of both expansion chamber is kept constant i.e.270mm and length of external connecting tube is 110mm.
b) The diameter of expansion chamber is kept constant i.e.120mm
c) The diameter of inlet and outlet pipe connected to expansion chamber is kept constant i.e.44mm

d) The expansion chamber volume is kept constant for all modeling work.

3.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. [5]

The sound pressure P is calculated using Helmholtz equation

$$\nabla.\left(\frac{1}{\rho_0}\nabla_p - q\right) + \frac{k^2}{\rho_0}p = 0 \qquad (1)$$

Where,$k = \frac{2\pi f}{c_0}$ is the wavelength,$\rho_0$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

$$TL = 10\ log\left(\frac{p_{in}}{p_{out}}\right) \qquad (2)$$

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

$$p_{in} = \int_{\Omega}^{1} \frac{{p_0}^2}{2\rho c_0} dA \qquad (3)$$

$$p_{out} = \int_{\Omega}^{1} \frac{|p_c|^2}{2\rho c_0} dA \qquad (4)$$

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

$$\left(-\frac{\nabla_p}{\rho}\right).n=0 \qquad (5)$$

The Numerical analysis is carried out for the frequency range of 1-1600 Hz.

Model-1 DEC muffler with side outlet at L/2 distance from the end plate of second chamber

In this model (refer figure 1) the central inlet and side outlet double expansion chamber muffler is presented. The position of side outlet is taken as (L/2) distance from end plate of second chamber. The length of inlet and outlet tube is 95 mm and diameter is 44 mm.The diameter of chamber is 120 mm.

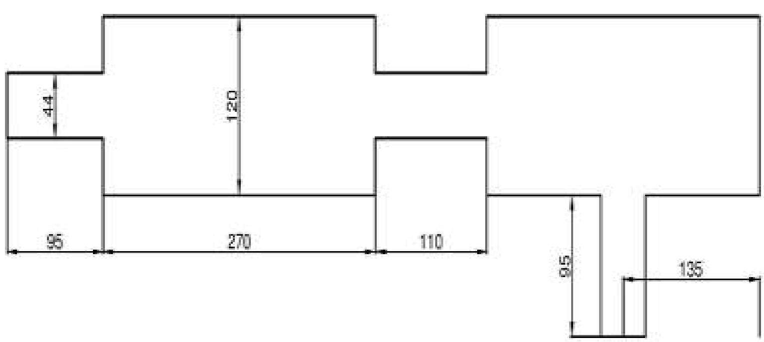

Figure 1: Double Expansion Chamber Muffler with side outlet

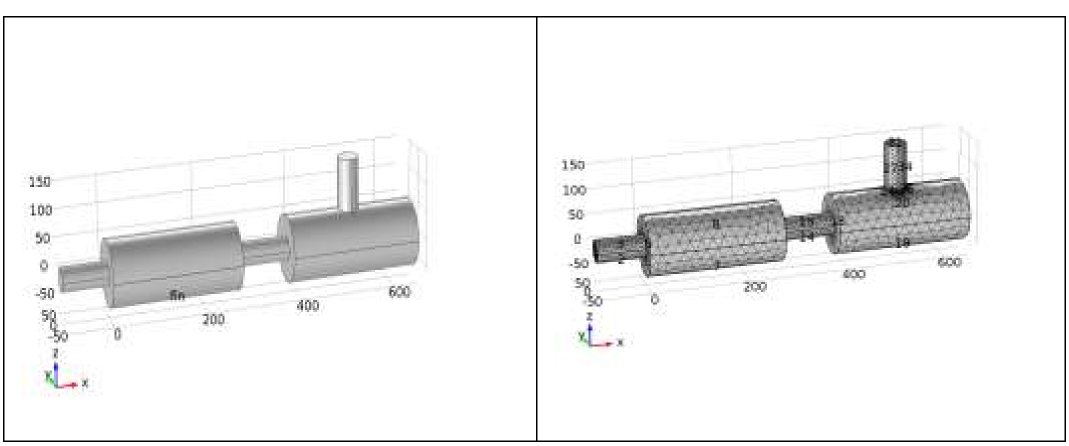

Figure 2: COMSOL Model for DEC muffler with side outlet at L/2 distance from end plate of second chamber

The figure 2 shows the COMSOL model and meshed model. Total 19206 Tetrahedral elements are used for meshing, the maximum element size is 41 mm and minimum element size is 2.98 mm.

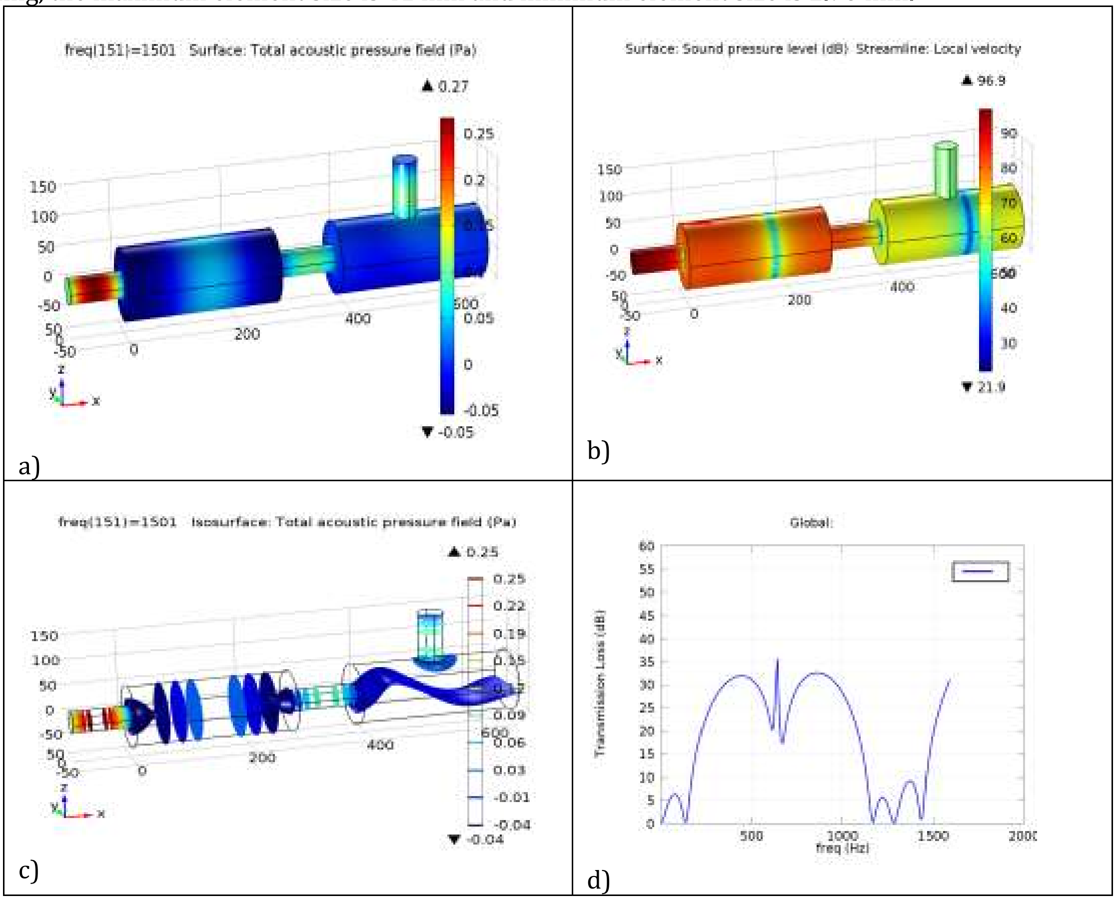

Figure 3: Results of FEM analysis for Model-1

The figure 3 shows the results of finite element analysis for model -1.The distribution of total acoustic pressure field is shown in a) part of the figure. The maximum total acoustic pressure field of 0.25 pa is observed in Inlet pipe.The distribution of sound pressure level is shown in b) part of the figure. The maximum sound pressure level of 96.9 dB is observed in Inlet pipe. At the outlet of the DEC chamber sound pressure level of around60 dB is observed. The c) part of the figure shows the isosurface distribution of total acoustic pressure field. The d) part of the figure shows the transmission loss curve. The broad band transmission loss is observed after the region of low attenuation.

Model-2DEC muffler with side outlet at L/3 distance from end plate of second chamber

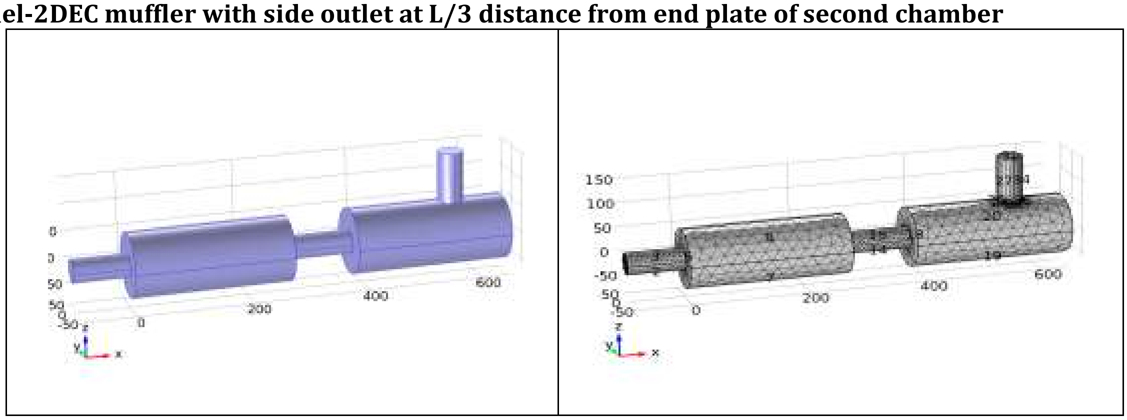

Figure 4:COMSOL Model for DEC muffler with side outlet at L/3 distance from end plate of second chamber

The figure 4 shows the COMSOL model and meshed model. Total 19264 Tetrahedral elements are used for meshing, the maximum element size is 41 mm and minimum element size is 2.98 mm.

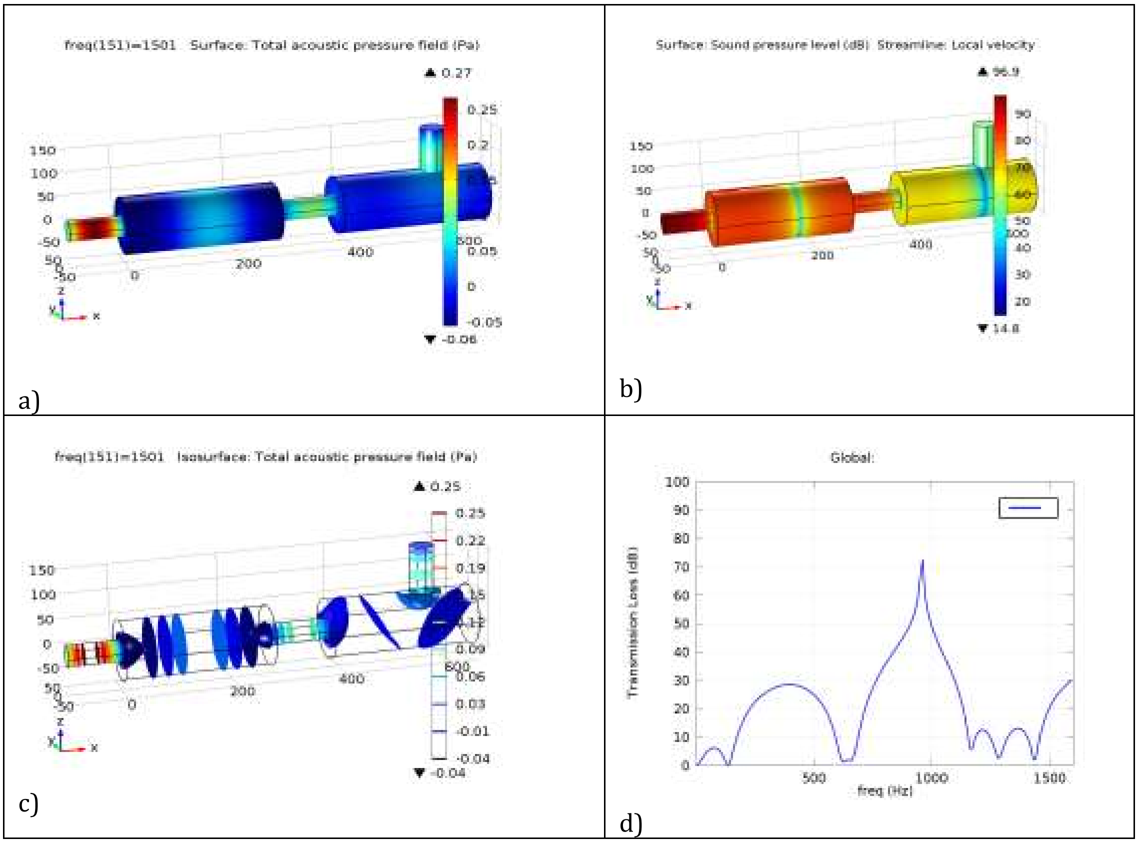

Figure 5: Results of FEM analysis for Model-2

The figure 5 shows the results of finite element analysis for model -1.The distribution of total acoustic pressure field is shown in a) part of the figure. The maximum total acoustic pressure field of 0.27 pa is observed in Inlet pipe.The distribution of sound pressure level is shown in b) part of the figure. The maximum sound pressure level of 96.9 dB is observed in Inlet pipe. At the outlet of the DEC chamber sound pressure level of around 60 dB is observed. The c) part of the figure shows the isosurface distribution of total acoustic pressure field. The d) part of the figure shows the transmission loss curve. The transmission loss is observed to increase in mid frequency region.

Model-3DEC muffler with side outlet at L/6 distance from end plate of second chamber

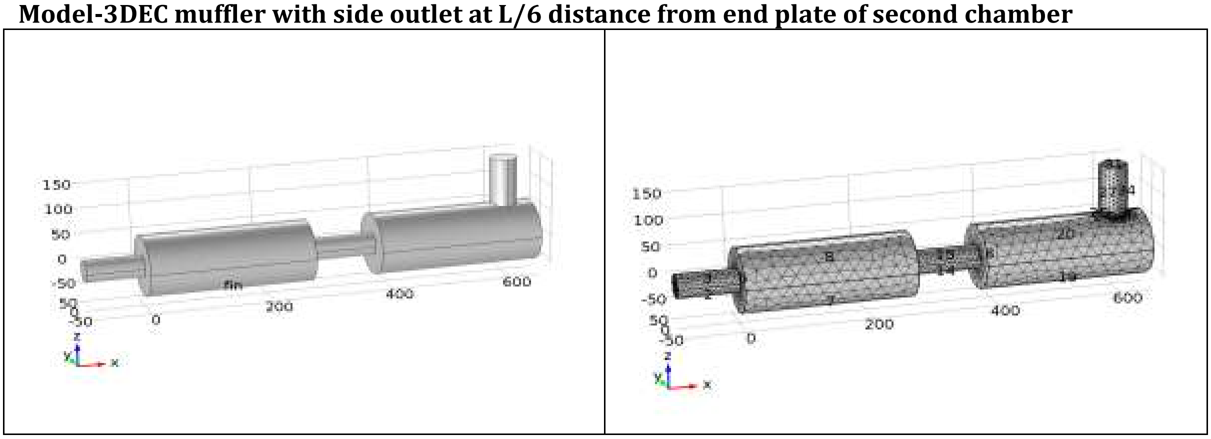

Figure 6:COMSOL Model for DEC muffler with side outlet at L/6 distance from end plate of second chamber

The figure 6 shows the COMSOL model and meshed model. Total 19063 Tetrahedral elements are used for meshing, the maximum element size is 41 mm and minimum element size is 2.98 mm.

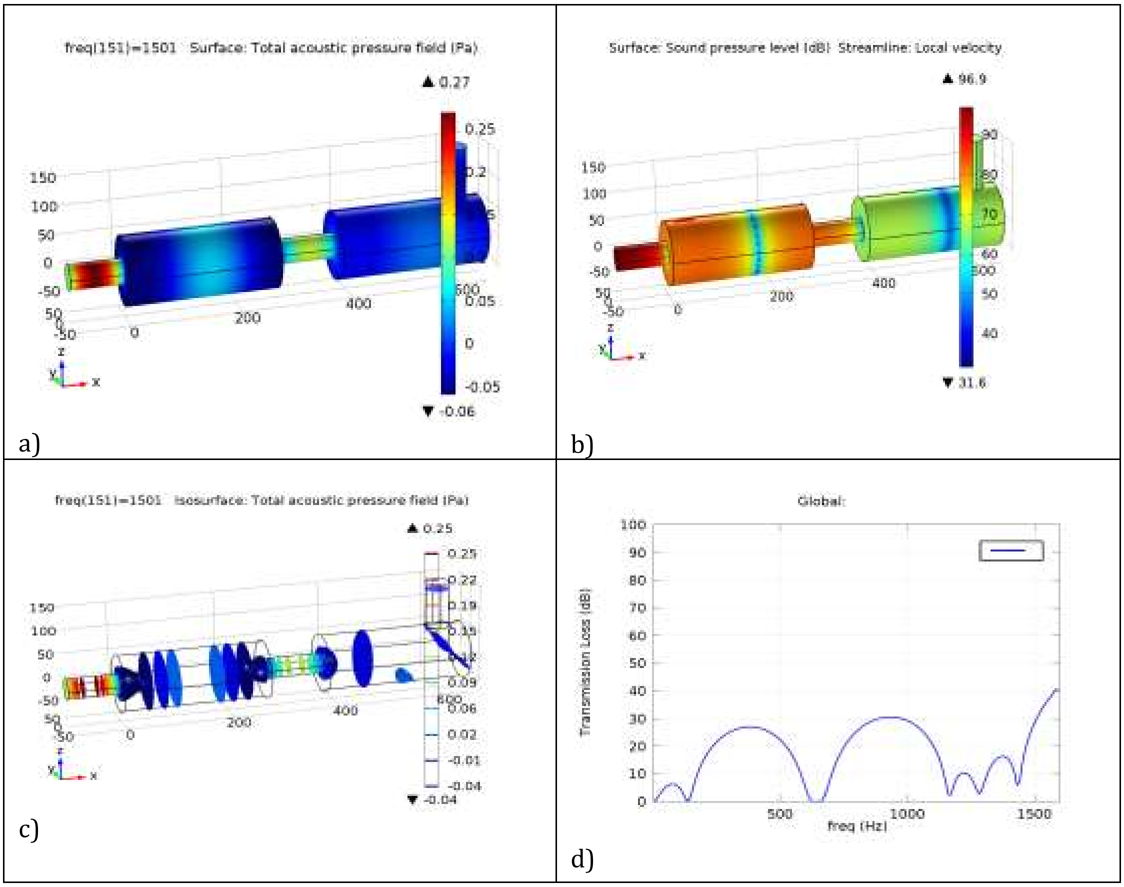

Figure 7: Results of FEM analysis for Model-3

The figure 7 shows the results of finite element analysis for model -3.The distribution of total acoustic pressure field is shown in a) part of the figure. The maximum total acoustic pressure field of 0.27 pa is observed in Inlet pipe.The distribution of sound pressure level is shown in b) part of the figure. The maximum sound pressure level of 96.9 dB is observed in Inlet pipe. At the outlet of the DEC chamber sound pressure level of around 60 dB is observed. The c) part of the figure shows the isosurface distribution of total acoustic pressure field. The d) part of the figure shows the transmission loss curve. The transmission loss is observed to increase in low to mid frequency region.

Model-4DEC muffler with side outlet at 2L/3 distance from end plate of second chamber

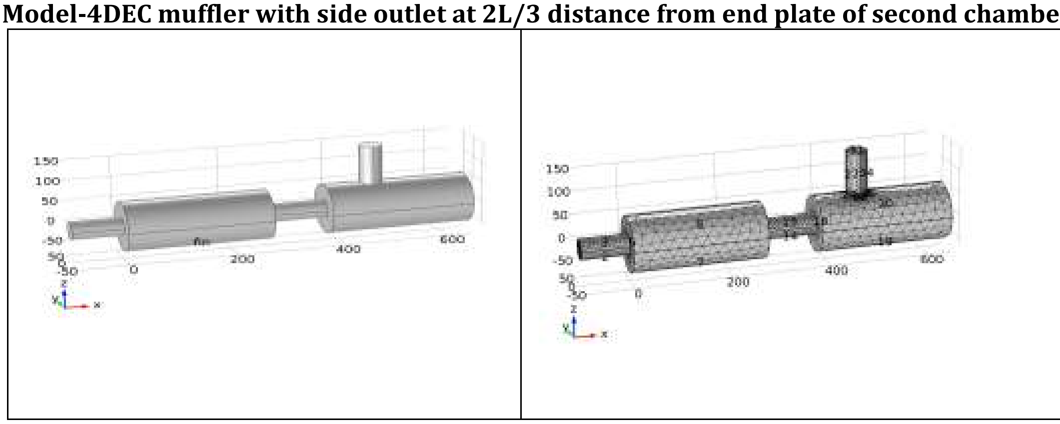

Figure 8: COMSOL Model for DEC muffler with side outlet at 2L/3 distance from endplate of second chamber

The figure 8 shows the COMSOL model and meshed model. Total 19430 Tetrahedral elements are used for meshing, the maximum element size is 41 mm and minimum element size is 2.98 mm.

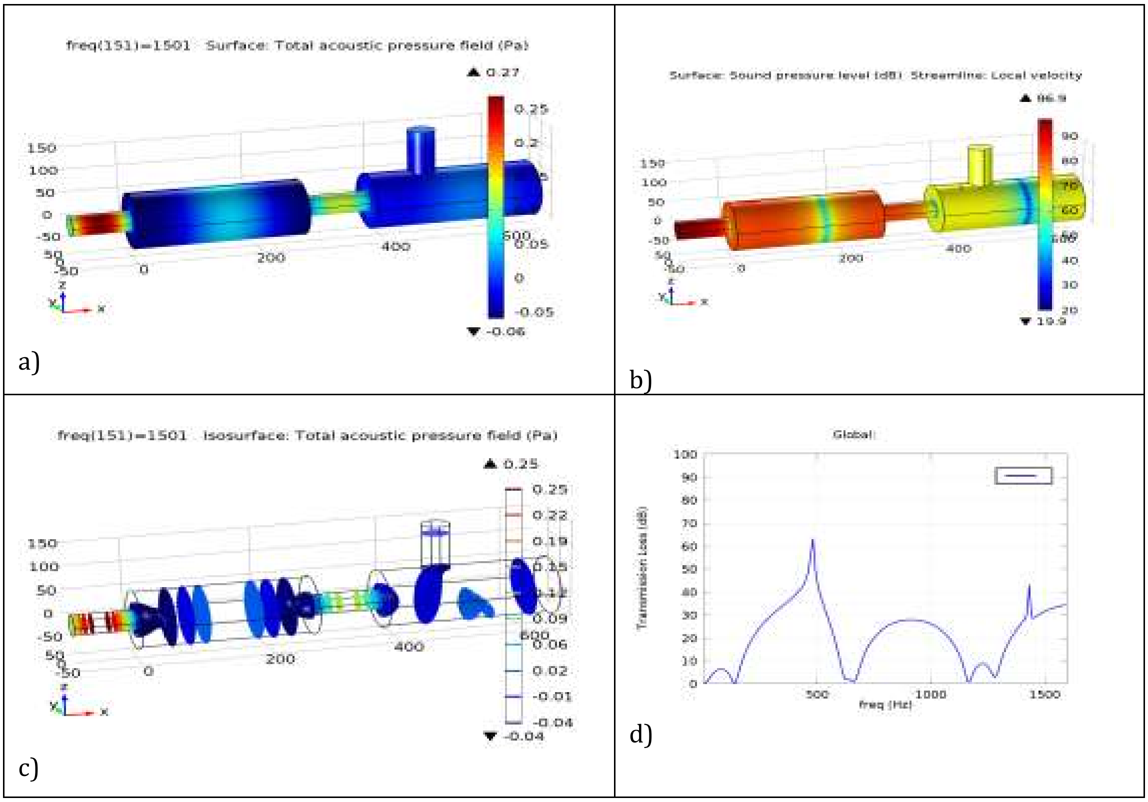

Figure 9: Results of FEM analysis for Model-4

The figure 9 shows the results of finite element analysis for model-4.The distribution of total acoustic pressure field is shown in a) part of the figure. The maximum total acoustic pressure field of 0.27 pa is observed in Inlet pipe.The distribution of sound pressure level is shown in b) part of the figure. The maximum sound pressure level of 96.9 dB is observed in Inlet pipe. At the outlet of the DEC chamber sound pressure level of around 70 dB is observed. The c) part of the figure shows the isosurface distribution of total acoustic pressure field. The d) part of the figure shows the transmission loss curve. The transmission loss is observed to increase in low to mid frequency region.

4. Results and conclusion

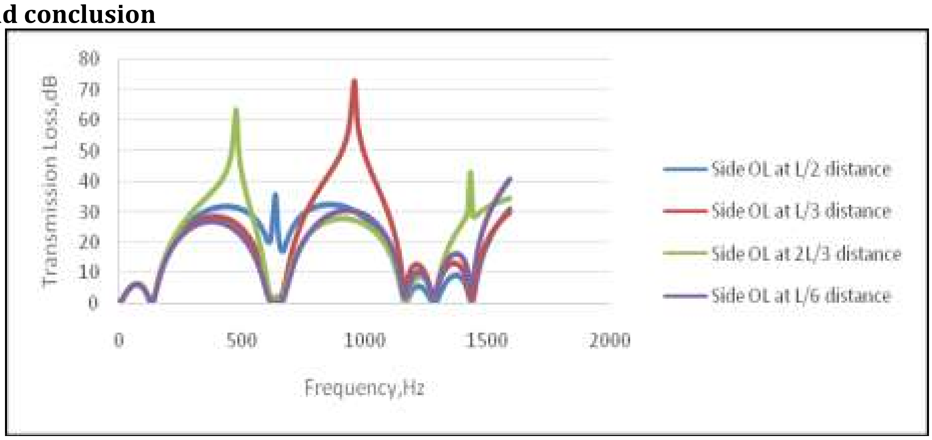

Figure 10: Comparison of Transmission Loss for all models

The figure 10 shows the comparison of transmission loss for all the models. It can be observed that model-1 shows the optimum acoustic performance, because it shows the broad band transmission loss over the frequency region of consideration.Model-1 also shows the excellent acoustic performance, because the trough after first low attenuation region is lifted and the objective of maximum transmission loss with uplift of trough is achieved. From the analysis carried out in this research, it can be concluded that, the COMSOL Multiphysics is the excellent Numerical tool to analyse the acoustic performance of the reactive muffler, because it shows the distribution of total acoustic pressure field, sound pressure level and isosurfaces of total acoustic pressure field in addition to transmission loss.

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