

# Design, Assessment and Optimization of Automotive Muffler

Shubham Naikwad<sup>1</sup>, Aditya Salunkhe<sup>2</sup>, Mukund Bamane<sup>3</sup>, Akash Bhoite<sup>4</sup>

U.G. Student, Department of Mechanical Engineering, Sinhgad College of Engineering, Pune, Maharashtra, India<sup>1</sup>

U.G. Student, Department of Mechanical Engineering, Sinhgad College of Engineering, Pune, Maharashtra, India<sup>2</sup>

U.G. Student, Department of Mechanical Engineering, Sinhgad College of Engineering, Pune, Maharashtra, India<sup>3</sup>

U.G. Student, Department of Mechanical Engineering, Sinhgad College of Engineering, Pune, Maharashtra, India<sup>4</sup>

**ABSTRACT:** Mufflers are important part of engine system and commonly used in exhaust system to minimize sound transmissions caused by exhaust gases. Design of mufflers is a complex function that affects noise characteristics, emission and fuel efficiency of engine. Therefore muffler design becomes more and more important for noise reduction. The objective of the paper is to propose a design of simple reactive muffler for effective sound attenuation and for getting highest transmission losses. The paper contains two optimization problem to get optimize model which can further optimize by using Taguchi method. The problem were built and analysed by using 'COMSOL MULTIPHYSICS' in pressure acoustic analysis domain for getting Maximum Transmission Losses and minimum Sound Pressure Level (SPL). First optimization problem contain muffler in which perforation diameter and pipe diameter are varied which again optimizes by eliminating perforation and by varying pipe lengths in second optimization problem. Among the best problem is further optimized by using Taguchi method. The effect of SPL on the walls of the muffler is not considered. The material of the muffler is also not considered. This optimized model of elliptical muffler is manufacture and then validate with the experimental analysis.

**KEYWORDS:** Transmission Losses, Sound Pressure Level, Acoustic, Optimization

## I. INTRODUCTION

Muffler is necessary component to reduce the noise level in the vehicle. Due to stringent norms for sound level at the tail pipe of exhaust, it is necessary to develop, design and optimized mufflers which full-fill that norms. Accurate prediction of sound radiation characteristics from reactive muffler is of significant importance in automotive exhaust system design. The most commonly used parameter to evaluate the sound radiation characteristics of muffler is transmission loss (TL). Transmission loss is one of the most frequently used criteria of muffler performance because it can be predicted very easily from the known physical parameters of the muffler. Mufflers are typically arranged along the exhaust pipe as the part of the exhaust system of an internal combustion engine to reduce its noise. The expansion chambers with various cross section like Circular, Elliptical, Square & Rectangular are commonly used for noise attenuation. Attenuation can also be effectively achieved up to the greater extent by improve in the design of muffler parameters such as pipe diameters, perforation diameters, length of inlet/outlet pipe, length of chamber, Holes in baffles etc.

There are a number of methods currently used to model and investigates the acoustic performance (TL) of mufflers including analytical methods such as the TMM, computational methods including the use of FEM & BEM & experimental measurement techniques. The use of finite element method (FEM) & the boundary element method (BEM) can aid in the prediction & design. This study proposes an optimal design scheme to improve the muffler capacity of

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noise reduction of the exhaust system by FEM and Taguchi method. Performance of a muffler is measured by performance prediction software (COMSOL MULTIPHYSICS 5.2).

In this paper two optimization problems were taken and best of among two is optimized using Taguchi method. In first problem diameter of inlet/outlet pipe, diameter of perforated pipe, diameter of holes on baffles, diameter of perforation are varied to check the performance of muffler. From this best pipe size diameter were select and used for second optimization problem. In the second optimization problem perforation on pipe are eliminated and length of pipe are varied to get the highest transmission losses. After second problem length of inlet extended pipe and two length of outlet extended pipe are select as three control factors Then, L-9 table of orthogonal arrays is adopted to extract the effective main factors. The transmission losses which obtain by FEM are compared with experimental method, demonstrating that transmission losses can be determined reliably with the setup which is prepared. In general, experimental results are required for verifying the FEM and also for evaluating the overall performance of a system configuration so as to check if it satisfies the design requirements [1]. In these research paper two load methods is used for measuring transmission loss by experimental method.

### III. RELATED WORK

Anant W. Wankhade & Dr. A. P. Bhattu, [2] the objective of this The objective of the paper is to propose a simple in construction, effective silencing device, which can achieve good results in minimizing the noise. The acoustic analysis is one of the methods which help to analyse the sound level at the tail pipe. This optimization revises acoustic analysis of muffler using Finite Element Analysis. The muffler is modelled in 'PRO E Wildfire 5.0 and 'COMSOL MULTIPHYSICS' is used for acoustic analysis. Effect of extrusion of inlet and outlet pipe inside the chamber and also the position of the extra inlet tube (i.e. divided inlet) to the chamber and then optimized this parameter to get the minimum sound pressure level (SPL) or maximum transmission loss (TL). The effect of SPL on the walls of the muffler is not considered. The material of the muffler is also not considered. This optimized model of elliptical muffler is manufacture and then validate with the experimental analysis.

Vijay M Mundhe & Prof. Eknath R Deore, [3] The objective of this paper is to reduce exhaust gas noise level. The performance of the muffler is assessed by analysing pressure variation, exhaust gas flow pattern, length of expansion chamber, transmission loss. The K-epsilon method is used to obtain desired outputs by inputting sinusoidal nature of pressure wave. The modelling of muffler is done by using modelling software CATIA V5 and performance parameters are estimated using Star CCM+ software. This study helps to improve reduce the noise level and environmental noise pollution. The results obtained from software are compared with analytical method and they are found close agreement with each other.

Vaibhav D. Prajapati & Ankit J. Desai, [4] In this paper a conventional muffler of Maruti-Suzuki Wagon R is taken as reference and depending upon parameters new muffler is designed and modeled in software and analysis will be done numerical codes. Analysis ease the design parameters to be change, so that an appropriate design can be generate and maximum amount of noise reduction and pressure drop takes place with minimum back pressure. Comparison of conventional muffler and proposed designed muffler is based on amount of noise reduction, pressure drop and muffler life. In experimental setup pressure drop calculated by the water manometer tube and sound intensity measured by Sound Level Meter (SLM) device.

Zeynep Parlar, [5] In this paper, a reactive perforated muffler is investigated numerically, experimentally and by the analysis. For an acoustical analysis, the transmission loss which is independent of sound source of the present cross flow, the perforated muffler was analysed. To be able to validate the numerical results, transmission loss was measured experimentally. Back pressure was obtained based on the flow field analysis and was also compared with experimental results. Numerical results have an approximate error of 20% compared to experimental results.

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M.B. Jadhav, A. P. Bhattu, [6] In this paper experimental setup is developed to predict the acoustic performance of reactive silencer by using two load method and it is validated by determination of transmission loss (TL) of known reactive muffler model by using finite element method (FEM). For the model experimental measured transmission loss was compared with that obtained from the finite element method (FEM). From the result it can be concluded that developed setup is reliable to determine TL by experimental method from low to mid frequency range.

M.L.Munjal [7] has discussed the various topics related to acoustics of ducts. It discusses the topic like propagation of waves in the ducts theory of acoustics filters, acoustic filter performance parameters, Helmholtz resonators, performance evaluation of ducts by using transfer matrix method etc. It also covers the various methods in order to predict the transmission loss of the ducts. This book also thoroughly discusses the finite element method for mufflers.

## IV. MODELING AND OPTIMIZATION OF ELLIPTICAL MUFFLER

Prediction of transmission loss virtually is an important analysis required for the development of muffler at an initial design stage. There are different software packages available in market for predicting the transmission loss. We have used COMSOL MULTIPHYSICS for Transmission loss measurements. COMSOL MULTIPHYSICS is an FEM/BEM based computational acoustics program that allows users to input a geometry, impose boundary conditions, select environment parameter, and solve the system of resulting equation in one, two or three dimensions. Once the system has been solved, a host of post-processing options are available to determine the various performance characteristics. Basic procedure for analysis is started from CAD geometry. Muffler with given dimensions is modeled in COMSOL MULTIPHYSICS. COMSOL MULTIPHYSICS itself used for meshing the solid models and then harmonic acoustical FEM analysis is done [2]

### Optimization problem 1

The dimensions and a schematic illustration of the first optimization case representing a muffler with perforations inside the resonant chamber are given in fig.1 Geometry of the muffler is determined by twenty four parameters, eighteen of which are fixed, and six are varied to optimize the transmission loss.

The fixed parameters are as follows,

- Length of Inlet pipe = 120 mm
- Length of outlet pipe = 100 mm
- Length of elliptical muffler (L) = 360 mm
- Length of each of three chamber = 120 mm
- Minor diameter of elliptical muffler = 130 mm
- Major diameter of elliptical muffler = 200 mm
- Extended Inlet/Outlet pipe length inside the chamber (5) = 120 mm
- No. of perforations = 176 (on each pipe)

The design variables with their admissible ranges are as follows,

- Diameter Inlet/outlet pipe (ID) = (D1) = varied as (20-22-25-30 mm)
- Diameter of Inner Pipe (ID) = (D2) = varied as (20-22-25-30 mm)
- Diameter of Holes in Baffle (ID) = (D3) = varied as (20-22-25-30 mm)
- Diameter of Holes in pipe (ID) = (D4) = varied as (2.2-2.5-2.7-3 mm)

In pilot experiment,

• In first step  $D1=D2=D3$  are fixed at 20 mm and  $D4$  is varied as (2.2-2.5-2.7-3 mm). For perforation on pipe we used area porosity method in COMSOL to reduce computation time. Using these dimensions, models were tested in COMSOL. Maximum transmission losses occurs at  $D4 = 2.5$  mm.

• In second step  $D1=D2=D3$  are fixed at 22 mm and  $D4$  is varied as (2.2-2.5-2.7-3 mm). For perforation on pipe we used area porosity method in COMSOL to reduce computation time. Using these dimensions, models were tested in COMSOL. Maximum transmission losses occurs at  $D4 = 2.2$  mm.

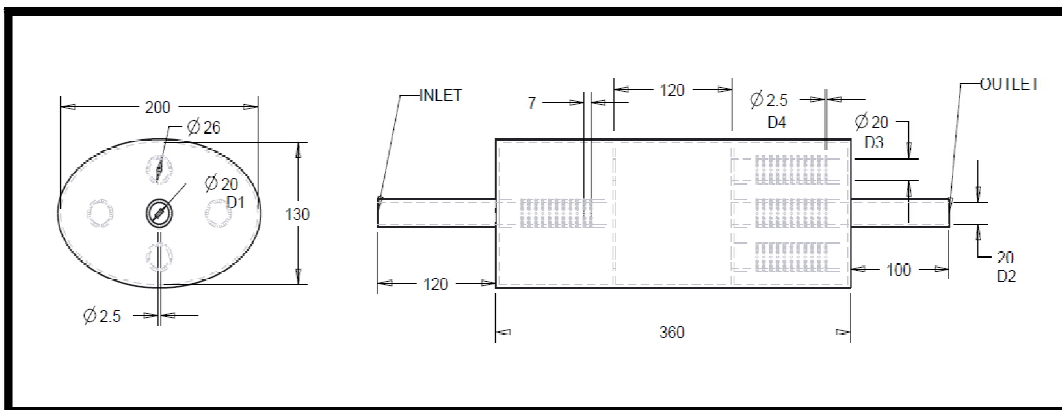
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- In third step  $D1=D2=D3$  are fixed at 25 mm and  $D4$  is varied as (2.2-2.5-2.7-3 mm). For perforation on pipe we used area porosity method in COMSOL to reduce computation time. Using these dimensions, models were tested in COMSOL. Maximum transmission losses occurs at  $D4 = 2.5$  mm.
- In final step  $D1=D2=D3$  are fixed at 30 mm and  $D4$  is varied as (2.2-2.5-2.7-3 mm). For perforation on pipe we used area porosity method in COMSOL to reduce computation time. Using these dimensions, models were tested in COMSOL. Maximum transmission losses occurs at  $D4 = 2.2$  mm.



**Fig.1: The diagram of a muffler component used in optimization problem 1**

**Table 1: For the comparison of various model names are given**

Sr no.	$D1=D2=D3$	$D4$	Model
1	20	2.2	Model 1
2	20	2.5	Model 2
3	20	2.7	Model 3
4	20	3	Model 4
5	22	2.2	Model 5
6	22	2.5	Model 6
7	22	2.7	Model 7
8	22	3	Model 8
9	25	2.2	Model 9
10	25	2.5	Model 10
11	25	2.7	Model 11
12	25	3	Model 12
13	30	2.2	Model 13
14	30	2.5	Model 14
15	30	2.7	Model 15
16	30	3	Model 16

Following fig. 2 shows transmission losses by keeping  $D4 = 2.2$  mm constant and varying  $D1=D2=D3$  as (20-22-25-30 mm)

Following fig. 3 shows transmission losses by keeping  $D4 = 2.5$  mm constant and varying  $D1=D2=D3$  as (20-22-25-30 mm)

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Following fig. 4 shows transmission losses by keeping  $D4 = 2.7$  mm constant and varying  $D1=D2=D3$  as (20-22-25-30 mm)

Following fig. 5 shows transmission losses by keeping  $D4 = 3.0$  mm constant and varying  $D1=D2=D3$  as (20-22-25-30 mm)

From the following figures it concluded that transmission losses are varies significantly by changing  $D1=D2=D3$  & by keeping  $D4$  constant.

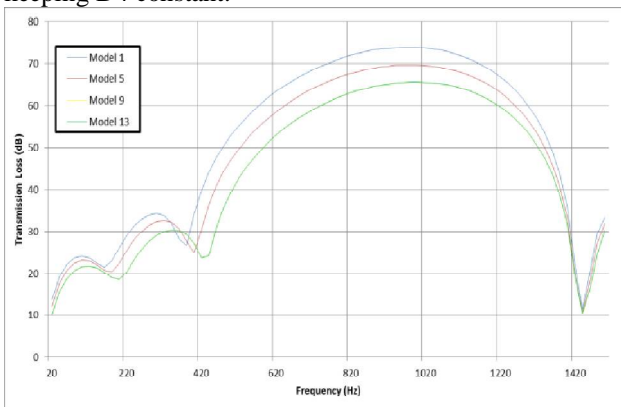


Fig 2: TL for  $D4 = 2.2$  mm

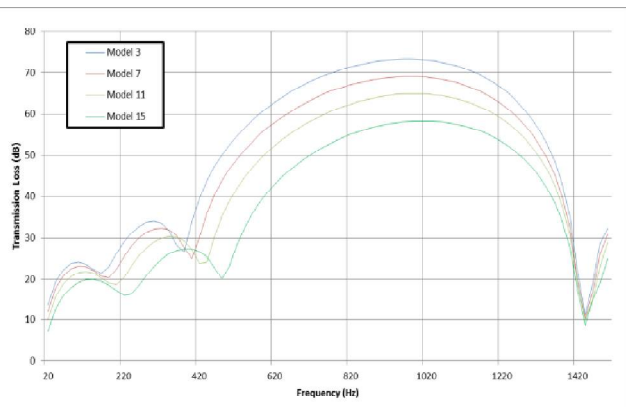


Fig 4: TL for  $D4 = 2.7$  mm

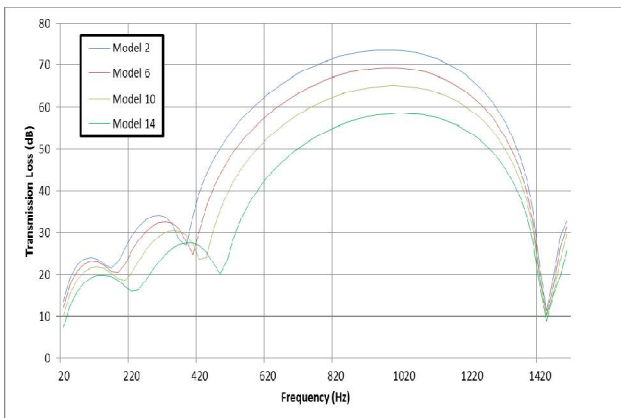


Fig 3: TL for  $D4 = 2.5$  mm

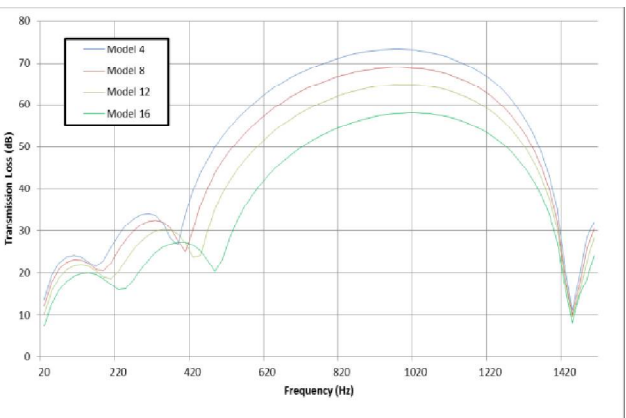
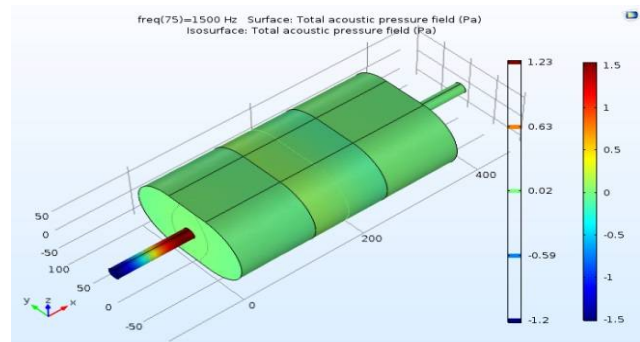
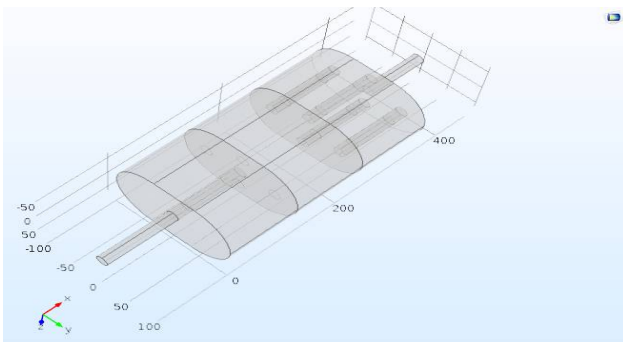


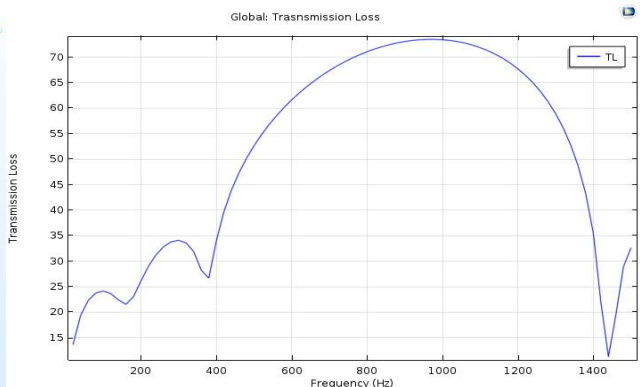
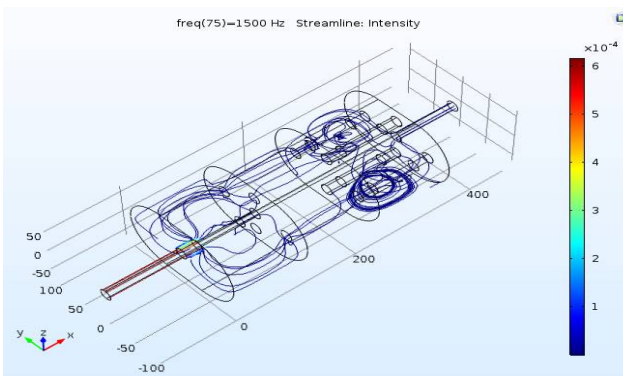
Fig 5: TL for  $D4 = 3.0$  mm

Finally dimensions obtained from pilot experiments were  $D1=D2=D3=20$  mm &  $D4= 2.5$  mm has maximum transmission loss is 51.2273 dB.



**Fig 6: The Optimized CAD model of optimization Problem 1**      **Fig 7: Optimized COMSOL model showing Acoustic Pressure**

Fig.7 shows the acoustic pressure of optimized model at the frequency 1500 Hz in which there is no negative pressure at outlet which satisfies the condition of requirement of muffler.



**Fig 9: Optimized COMSOL model showing Streamline Intensity**

**Fig 10: Graph for optimized model TL Vs. Frequency**

Fig.9 shows Streamline Intensity in the muffler at frequency 1500 Hz. Fig.7 shows the transmission loss (TL) versus frequency plot for the first optimized problem. Basically this optimization is to maximize the average transmission loss (TL) in the frequency range 1-1500 Hz. The average optimized transmission loss for this model is 51.22753 dB.

### Optimization problem 2

The dimensions and a schematic illustration of the second optimization case representing a muffler with an extended inlet and extended outlet duct are given in Fig. Geometry of the muffler is determined by twelve parameters, nine of which are fixed, and three are varied to optimize the transmission loss.

The fixed parameters are as follows,

- Diameter Inlet/outlet pipe (ID) = 20 mm
- Length of Inlet pipe = 120 mm
- Length of outlet pipe = 100 mm
- Length of elliptical muffler (L) = 360 mm
- Length of each of three chamber = 120 mm
- Minor diameter of elliptical muffler = 130 mm
- Major diameter of elliptical muffler = 200 mm

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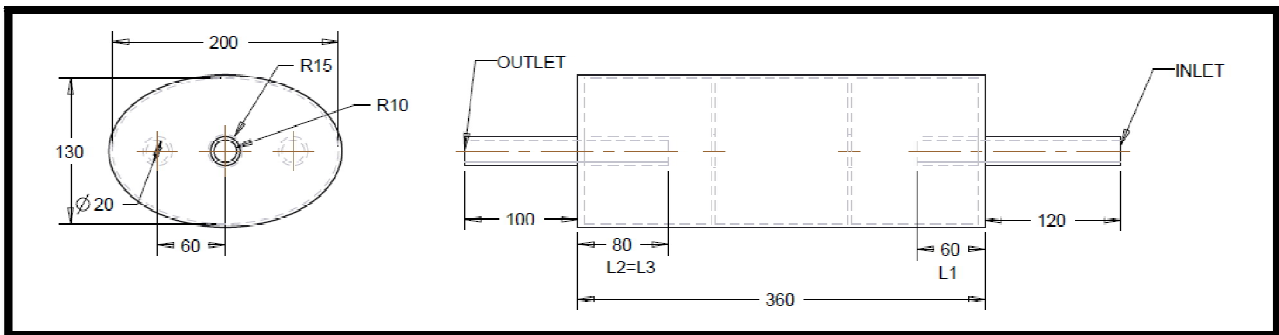
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- Diameter of perforation on Baffle = 30 mm
- The three design variables with their admissible ranges are as follows,
- Extended Inlet/Outlet pipe length (L1/L2/L3) = (0 – 110 mm)

In pilot experiment,

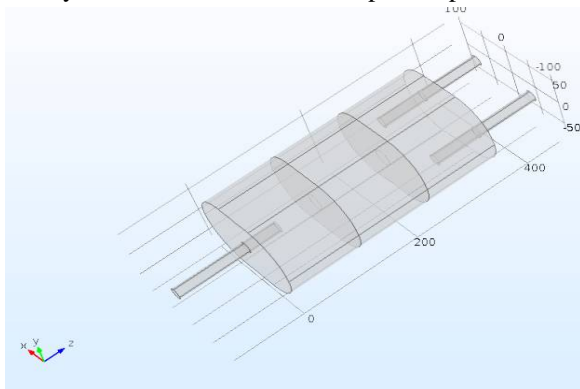
1. Lengths of L2 & L3 kept fixed at L/4 (30 mm) and L1 is varied from 0 to 110 mm with step size of 10 mm. Using this dimensions, models were tested in COMSOL. Maximum transmission losses occurs at L1 = 60 mm.
2. In second trial, L1 is fixed at 60 mm and both L2 & L3 are varied from 0 to 110 mm. with step size of 10 mm. Using this dimensions, models were tested in COMSOL. Maximum transmission losses occurs at L2 = L3 = 80 mm.
3. In third trial, L1 is fixed at 60 mm and L2 is fixed at 80 mm & L3 is varied from 0 to 110 mm. with step size of 10 mm. Using this dimensions, models were tested in COMSOL. Maximum transmission losses occurs at L3 = 80 mm.
4. In fourth trial, L1 is fixed at 60 mm and L3 is fixed at 80 mm & L2 is varied from 0 to 110 mm. with step size of 10 mm. Using this dimensions, models were tested in COMSOL. Maximum transmission losses occurs at L2 = 80 mm.
5. Finally, L2 & L3 are fixed at 80 mm & L1 is again varied from 0 to 110 mm. with step size of 10 mm. Using this dimensions, models were tested in COMSOL. Maximum transmission losses occurs at L1 = 60 mm.

Figure 11 shows geometrical diagram of a muffler component used in optimization problem. In which L1, L2 & L3 are shows the parameters of muffler.

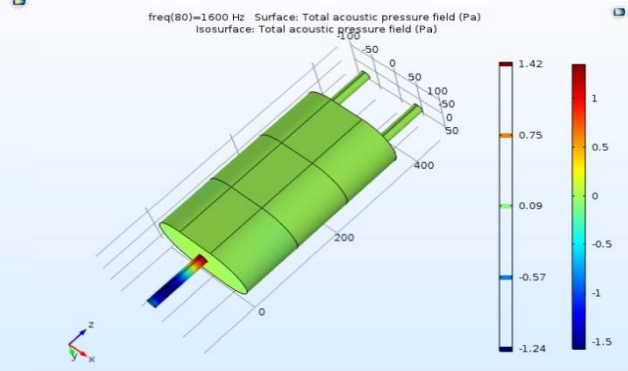


**Fig 11: The diagram of a muffler component used in optimization problem**

Finally dimensions obtained from pilot experiments were L1 = 60 mm, L2 & L3 = 80 mm



**Fig 12: The Optimized CAD model of optimization problem 2**



**Fig 13: Optimized COMSOL model showing Acoustic Pressure**

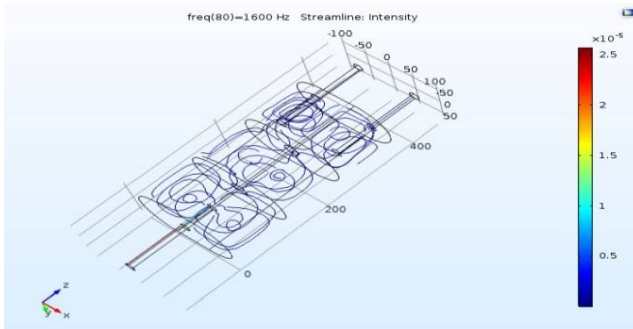
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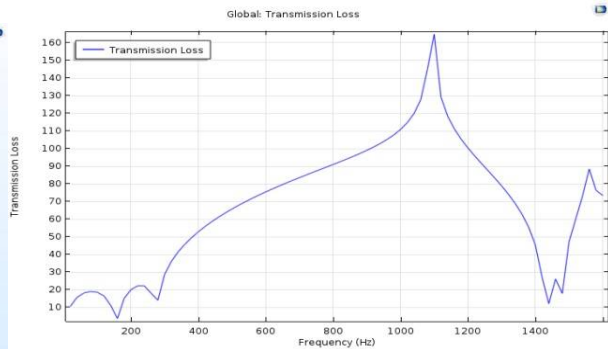
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Fig.13 shows the acoustic pressure of optimized model at the frequency 1500 Hz in which there is no negative pressure at outlet which satisfies the condition of requirement of muffler.



**Fig 14: Optimized COMSOL model showing Streamline Intensity**



**Fig 15: Graph for optimized model TL Vs. Frequency**

Fig.14 shows Streamline Intensity in the muffler at frequency 1500 Hz. Fig.15 shows the transmission loss (TL) versus frequency plot for the second optimized model. Basically this optimization is to maximize the average transmission loss (TL) in the frequency range 1-1500 Hz. The average optimized transmission loss for this model is **68.43494 dB**. For the final optimization or to find the best combination of the above optimized parameters of central inlet central outlet elliptical muffler the Taguchi Method is used.

## V. TAGUCHI METHOD

The Taguchi method is a powerful tool for the design of high quality systems. It provides a simple, efficient and systematic approach to optimize designs for performance, quality, and cost. 8-Steps in Taguchi Methodology:

1. The main function, side effects, and failure mode
2. Identify the noise factors, testing conditions, and quality characteristics
3. Identify the objective function to be optimized
4. Identify the control factors and their levels
5. Select the orthogonal array matrix experiment
6. Conduct the matrix experiment
7. Analyse the data; predict the optimum levels and performance
8. Perform the verification experiment and plan the future action.

**Table 2: L9 Table of Taguchi Method**

Treatment Condition	A	B	C	Response
1	1	1	1	Y <sub>111</sub>
2	1	2	2	Y <sub>122</sub>
3	1	3	3	Y <sub>133</sub>
4	2	1	2	Y <sub>212</sub>
5	2	2	3	Y <sub>223</sub>
6	2	3	1	Y <sub>231</sub>
7	3	1	3	Y <sub>313</sub>



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8	3	2	1	Y <sub>321</sub>
9	3	3	2	Y <sub>332</sub>

The 9 in the designation L9 represents the number of rows, which is also the number of treatment conditions (TC) and the degree of freedom. Across the top of orthogonal array is the maximum number of factors that can be used, which in our case are four. The levels are designated by 1 and 2. If more levels occur in the array, then 3, 4, 5, etc., are used. Other schemes such as -, 0, and + can be used.

### ANALYSIS USING TAGUCHI METHOD:

The transmission loss (TL) values used in this Taguchi analysis are the average transmission loss value in the frequency range of 1-1500 Hz. The four variable parameters are used for the analysis or optimizations of the transmission loss (TL) by using Taguchi Method are as follows:

1. Length of inlet pipe extended in elliptical chamber (L1)
2. Length of first outlet pipe extended in elliptical chamber (L2)
3. Length of second outlet pipe extended in elliptical chamber (L3)

**Table 3: L9 Table for frequency ranges**

Trial	L <sub>1</sub>	L <sub>2</sub>	L <sub>3</sub>	TL
111	55	75	75	70.3182
122	55	80	80	70.2806
133	55	85	85	70.0003
212	60	75	80	67.4982
223	60	80	85	67.4394
231	60	85	75	67.0592
313	65	75	85	65.7140
321	65	80	75	66.0398
332	65	85	80	65.9018

For present work “Larger the Best condition was used”. This is because the best transmission loss is one with higher value which gives lower sound level. Thus (S/N) ratio of this TL needs to be maximized. From the above graph the maximum transmission loss value for L1 occurs at L55, L2 occurs at L75 & L3 occurs at L75 positions.

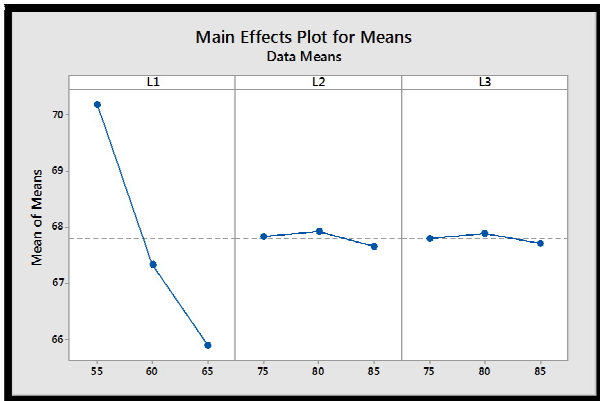


Fig 16: Main Effect plot for Means for frequency Ranges

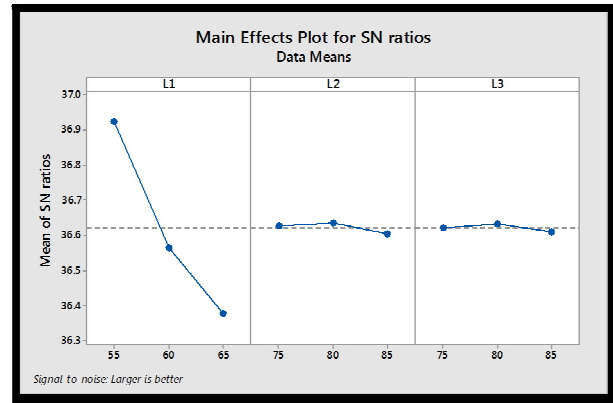


Fig 17: Main Effect plot for SN ratios for frequency ranges

The final optimized parameters for central inlet central outlet elliptical muffler are as follow:

1. Length of inlet pipe extended in elliptical chamber (L1) = 55 mm
2. Length of first outlet pipe extended in elliptical chamber (L2) = 75 mm
3. Length of second outlet pipe extended in elliptical chamber (L3) = 75 mm

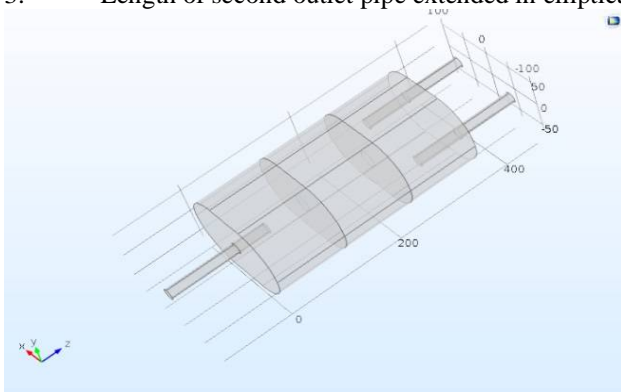


Fig 18: The Optimized CAD model of optimization model

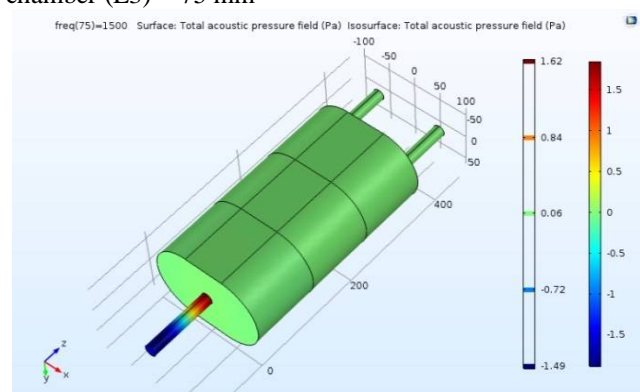
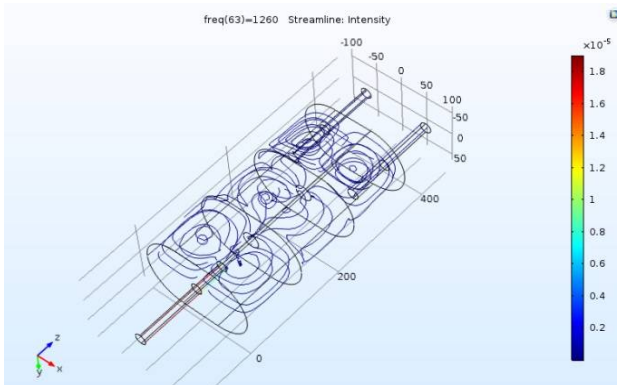
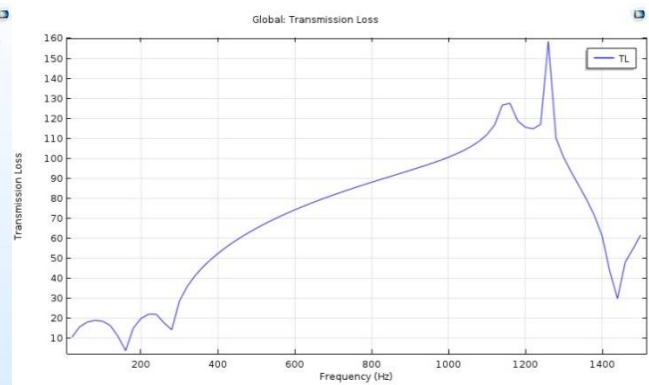


Fig 19: Optimized COMSOL model showing Acoustic Pressure

Fig.13 shows the acoustic pressure of optimized model at the frequency 1500 Hz in which there is no negative pressure at outlet which satisfies the condition of requirement of muffler.



**Fig 20: Optimized COMSOL model showing Streamline Intensity**



**Fig 21: Graph for optimized model TL Vs. Frequency**

Fig.20 shows Streamline Intensity in the muffler at frequency 1500 Hz. The fig.21 shows the graph of transmission loss vs. frequency. Basically the aim of this optimization is to maximize the transmission loss in the frequency range of 1-1500 Hz. The average transmission loss for the final optimized case with Taguchi Method in the frequency range 1-1500 Hz is 70.3182 dB.

## VI. EXPERIMENTAL VALIDATION

Models which got highest TL by Taguchi analysis are experimentally validated by using two-load method. Experiments are conducted for simple expansion chamber muffler, elliptical chamber muffler with extended inlet and two extended outlet.

### Experimental Setup

A schematic diagram of experimental set-up for calculating TL of simple expansion muffler is shown in Figure 1. It consists of a noise generation system, noise propagation system and noise measurement system. The TL is measured by transfer function method. The set-up has the following main components.

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

Impedance tube is a rigid tube through which sound propagates and reflects from test sample which results in creation of standing waves in it. It has measuring locations at specific distances from test sample where the acoustic main purpose served by impedance tube is providing guidance to sound wave as required for plane wave propagation. The data acquisition system used is a four channel FFT analyser with an interface for the control and setting of analyser. It collects the pressure data from microphones and feed it to data recording storage system. It also has a single output channel which is fed to speaker through analyser. A random noise signal is generated in same analyser and directed to the speaker via amplifier. The reason behind using random noise (white noise) is that it contains equal power density of noise for each frequency. Sound source used is of high power to produce at least 120 dB of noise. Pressure field microphones are used for measurement. The two microphones are sufficient as transfer function method is used. Transfer function is evaluated for each set of reading. The actual test setup with required components is shown in Figure. Two configurations of set up are used with respect to boundary conditions. [2, 6]

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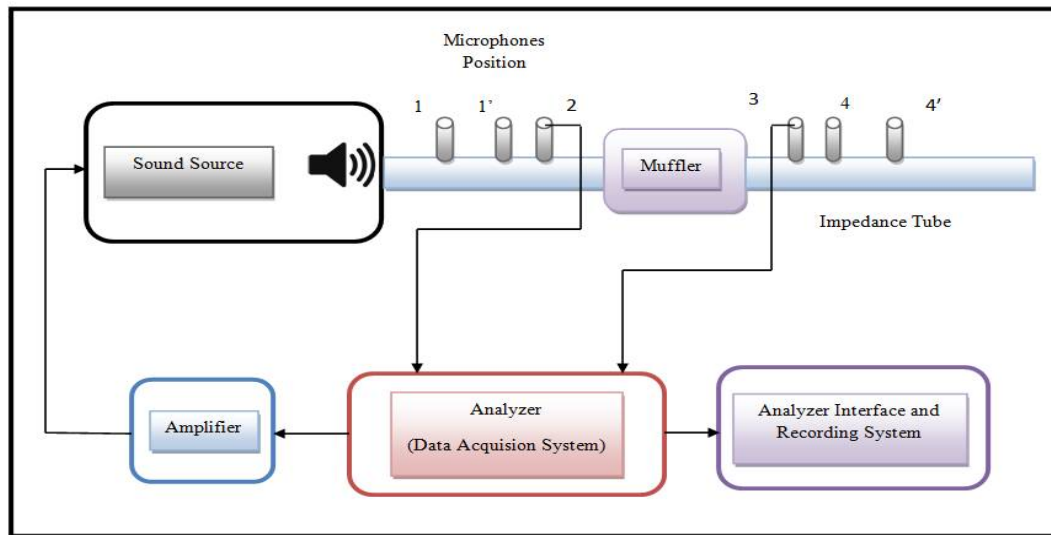


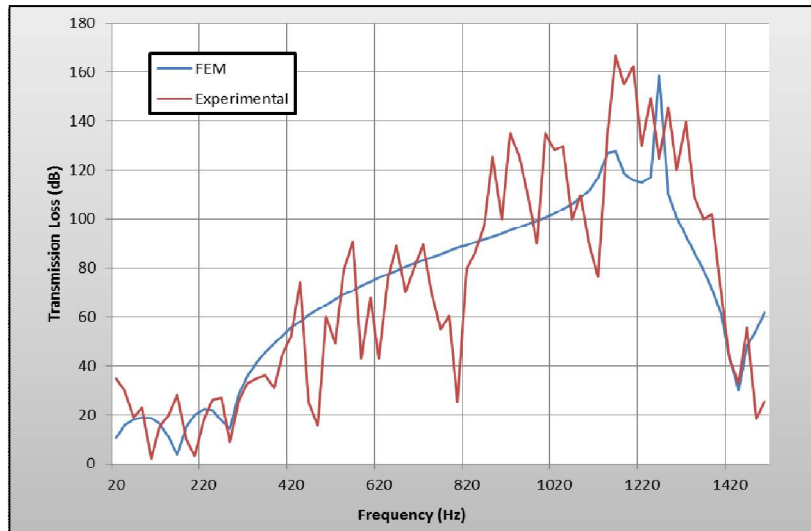
Fig 22: Experimental Set Up with its Components

## VII. EXPERIMENTAL PROCEDURE

Experimentation for pressure measurement mainly consists of analyser 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 [4]. 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  $H_{31}$ ,  $H_{32}$  and  $H_{34}$  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. [6]

## VIII. RESULTS AND DISCUSSION

The elliptical chamber muffler with extended inlet, double extended outlet and is analysed by using FEM (COMSOL MULTIPHYSICS 5.2) and model shown in figure 17 found out as optimum model by using Taguchi analysis which gives high transmission loss among others. This model is manufactured and experiment was conducted on it to calculate average transmission loss. The average transmission loss obtained by experiment is 70.3182 dB and by FEM is 71.80933 dB. A figure 23 show the comparison between experimental TL curve and FEM TL curve and it is seems to be very similar in nature.

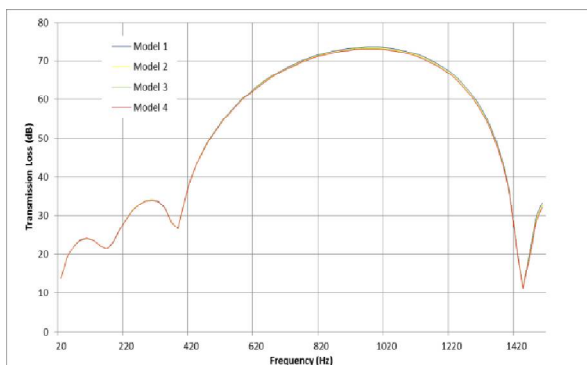


**Fig 23: Comparison of Frequency Vs. Transmission loss for FEM and Experimental**

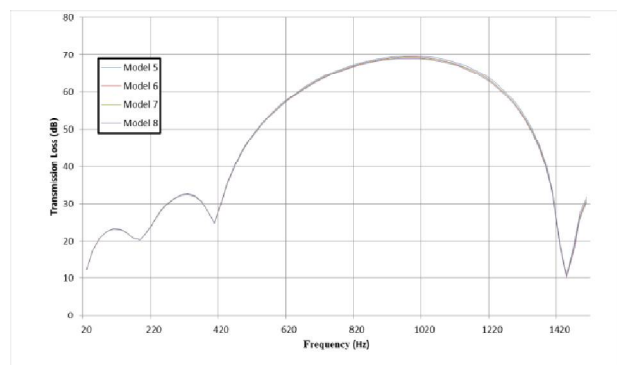
### IX. CONCLUSIONS

Comparison of model by using FEM analysis shows that there is good agreement between experimental and FEM results. From the optimization problem and optimized model following conclusions are made:

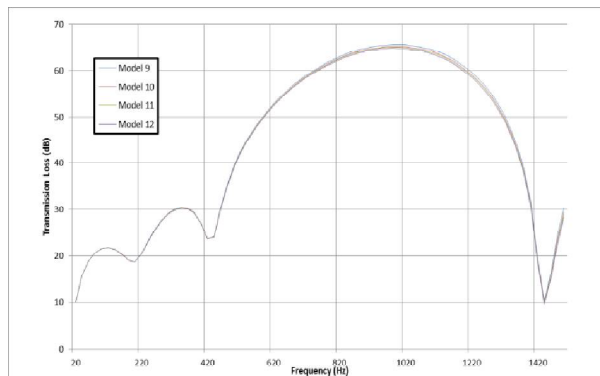
1. From the first optimization problem it concluded that decrease in the D1, D2, D3 diameters transmission losses are increases. But changing in D4 diameter there is no significant change occurs in transmission losses showing in the figures 24, 25, 26, 27. Thus by varying the D1, D2, D3 changes in the transmission losses are occur. So we used optimized D1, D2, and D3 for the second optimization problem.



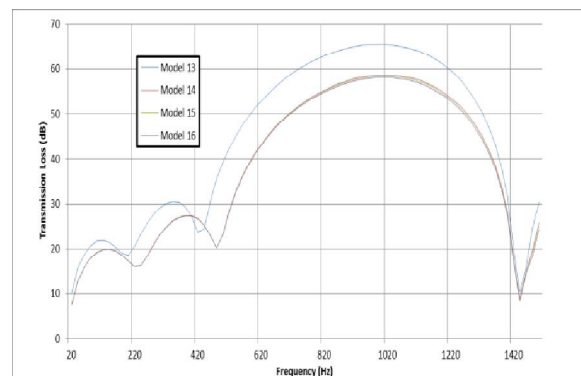
**Fig 24: TL for D1=D2=D3= 20 mm**



**Fig 25: TL for D1=D2=D3= 22mm**



**Fig 26: TL for D1=D2=D3= 25 mm**



**Fig 27: TL for D1=D2=D3= 30 mm**

(Note: In above figures graphs are plotted by varying D4 and D1=D2=D3 kept constant)

2. From the second optimization problem it concluded that single extended inlet and double extended and double outlet muffler for the particular length of L1, L2, and L3 transmission losses are high as compared to first optimization problem. Thus among the two optimization problem we select second one for further optimization using Taguchi method.
3. Single extended inlet and double extended and double outlet muffler is analyzed by L9 Taguchi OA. S/N ratio analysis gives optimum value of dimensions of muffler which gives maximum transmission. By using two outlets the optimized model gives highest transmission losses in the frequency ranges 1- 1500 Hz.

#### X.ACKNOWLEDGEMENT

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