Acoustic Analysis And Optimization Of Double Expansion Chamber Reactive Muffler For Maximum Transmission

Parag S. Khanzode, Mahesh V. Kulkarni

Abstract: The diesel generator sets are widely used in public areas and corporate buildings as electric source or backup. Hence it is necessary to reduce the noise produced by diesel engines of generator. Noise of diesel engine can be reduced by using muffler. Design and optimization of muffler is done by providing perforations. Perforation design is optimized for maximum transmission loss by varying three factors, i.e. perforation diameter, porosity and length over which perforations are applied. For optimization, Taguchi method is used. Acoustic performance of muffler is estimated by commercial FEA software.

Index Terms: Acoustical analysis, Optimization, Perforations, Reactive muffler, S/N Ratio, Taguchi Method, Transmission loss.

1 Introduction

The diesel generator sets are observed as common norm in public and corporate places as electric source or backup. Hence it is necessary to reduce the noise produced by diesel engines of generator. Noise of diesel engine can be reduced by using muffler. Shital Shah [1] has given a step by step procedure for muffler design. He shows how CAE tools can be beneficial in optimizing the muffler. Studies on effect of perforations on transmission loss and back pressure are done [2]. It is concluded that with change in axial pattern performance was influenced at particular frequencies and porosity produces dominant effect on transmission loss achieved. Nawaf H. Saeid [3] studied the effect of perforations on vent silencer with help of FEA software. Using CAE approach for muffler analysis are presented and verification by experimentation for such analysis is done [4]. Modelling of elements of muffler and the perforated walls for numerical analysis is presented. In this paper numerical analysis is used to analyse the performance of muffler. The pressure acoustics theory and boundary conditions necessary for numerical analysis are taken from literature survey [5][6]. The optimization of muffler performance is done by using Taguchi method [7], [8].

2 Theory and Acoustic Analysis

Reactive mufflers work on the principle of destructive interference. The sound waves are reflected from boundaries of muffler and collide with each other cancelling each other due to phase difference. Reflections occur due to geometric changes in muffler. The acoustic pressure in muffler is calculated by using Helmholtz equation [5], [6],

$$\nabla.\left(-\frac{\nabla p_t}{\rho}-\frac{k^2 p_t}{\rho}\right)=0 \qquad (1)$$

Where, ρ = density, pt = total pressure, k = 2πf/c, f = frequency, c = speed of sound. Noise reduction, insertion loss and transmission loss are three main parameters by which the performance of muffler is determined. Transmission loss is mostly used for mufflers. It is independent of source and is a property of muffler.

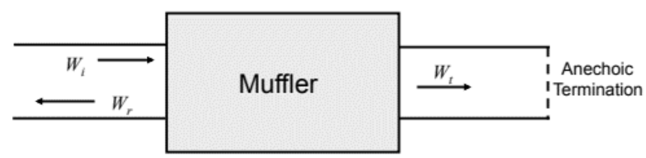

Fig. 1. Transmission loss

Transmission loss is acoustical power level difference between incident and transmitted waves with anechoic termination.

$$TL = 10\ \log_{10}\frac{W_i}{W_t} \qquad (2)$$

The sound hard wall boundaries are governed by equation,

$$\left(-\frac{\nabla p_t}{\rho}\right).n = 0 \qquad (3)$$

Also plane wave propagation condition was applied at inlet and outlet.

2.1 Meshing

The CAD model of muffler is designed with commercial CAD software and imported into FEA software. For accurate results there must be at least 6 elements per wavelength. The wavelength can be calculated as [5],

$$\lambda = \frac{c}{f} \qquad (4)$$

Where, λ = Wavelength of sound, c = speed of sound = 343 m/s, f = maximum frequency = 1600 Hz.

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

Maximum element length = wavelength/6 = 0.214/6 = 0.0357 m = 35.7 mm.

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3 Factor Selection

A basic configuration of double chamber muffler with extended inlet and outlet is considered for optimization. The frequency for optimization is considered as 800 Hz.

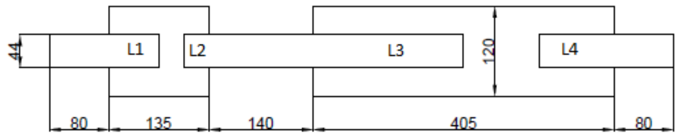


Figure 2. Basic Muffler Configurations

The perforations are provided on each extended inlet and outlet with same diameter of perforations and porosity. Then transmission loss for each case is estimated by acoustic analysis using FEA software for 800 Hz frequency. Figure 2 shows transmission loss for these cases.

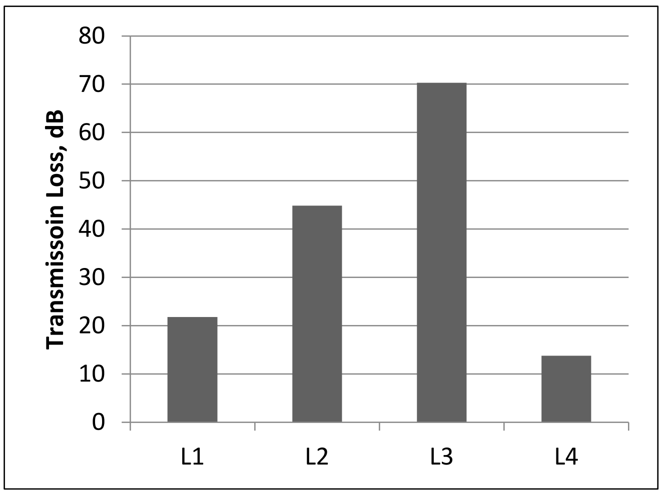


Fig. 3. TL for perforations provided on each extended inlet and outlet individually while keeping others without perforation.

From figure 3 we can see that we get maximum transmission loss when perforations are provided on extended inlet of second chamber i.e. L3.

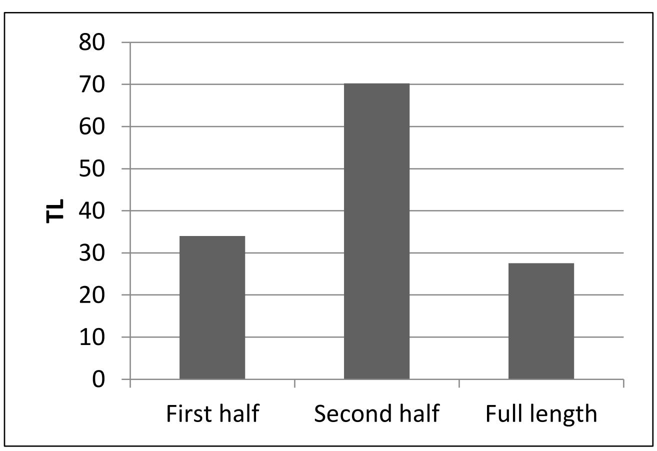


Fig. 4. TL for perforations provided on first half, second half and full length of extended inlet in 2nd chamber.

In next step acoustic performance of muffler is checked by providing perforations on first half, second half and full length of extended inlet in second chamber. From figure 4, the transmission loss is maximum with perforations on second half of extended inlet.

3.1 Range of Factors

From literature survey, the range for varying the diameter is fixed as 3 to 12 and for porosity the range is 5 to 15 percent. For deciding range of length of perforations a term relative porosity is used such as,

Relative porosity

$$= \frac{Porosity}{Length\ of\ extended\ inlet} X\ Length\ of\ perforations \quad (5)$$

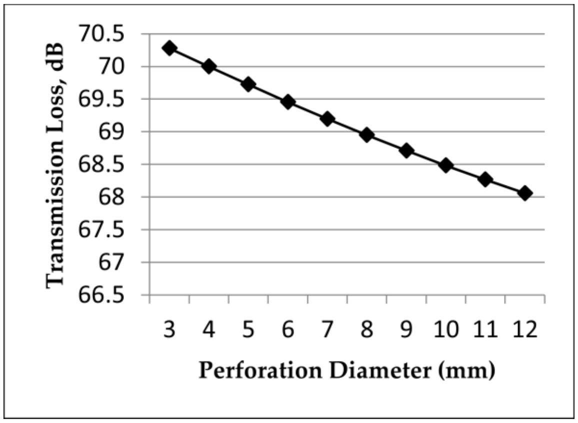
Using this relation table 1 is drawn considering 15% porosity. When relative porosity becomes too high, it becomes difficult in manufacturing stage of muffler. The higher porosity results in a greater number of perforations, hence lower the spacing between perforations; making it very difficult to implement. Hence the range for length of perforations is fixed as 80 mm to 200 mm.

TABLE 1
RELATIVE POROSITY WITH 15% POROSITY

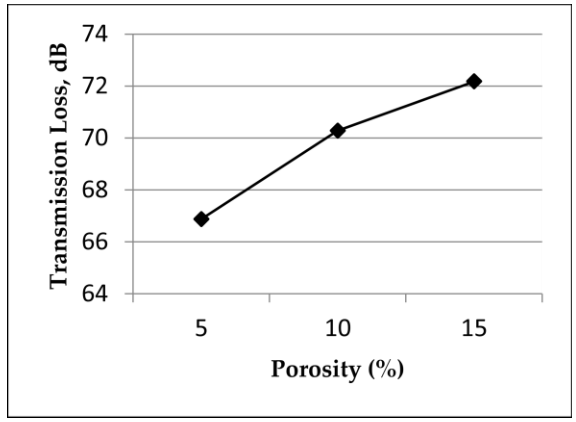
Porosity %	Length mm	Relative porosity %
15	70	43.39
15	80	37.97
15	90	33.75
15	100	30.38
15	110	27.61
15	120	25.31
15	130	23.37
15	140	21.70
15	150	20.25
15	160	18.98
15	170	17.87
15	180	16.88
15	190	15.99
15	200	15.19

3.2 Factor level for Taguchi Analysis

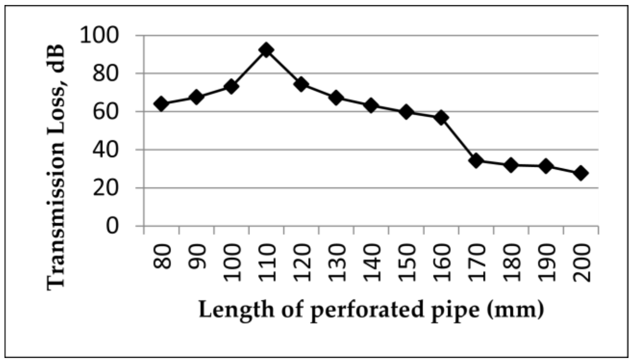
Once the range for factors is fixed the levels for Taguchi method [7][8] are found. For finding levels each factor is varied while keeping other two factors constant. With FEA simulation effect of each factor on acoustic performance is estimated.



(a)



(b)



(c)

Fig. 5. a) TL vs diameter, b) TL vs porosity, c) TL vs length at 800 Hz.

From figure 5, at diameter 3 mm the transmission loss is maximum, hence 3 mm is the chosen middle level for Taguchi analysis. Similarly, 15% and 110 mm are the middle levels of porosity and perforated pipe length for Taguchi optimization.

TABLE 2
FACTORS AND LEVELS

Factors	Level 1	Level 2	Level 3
Diameter (mm)	2	3	4
Porosity (%)	12.5	15	17.5
Perforated pipe length (mm)	105	110	115

4 TAGUCHI OPTIMIZATION

Taguchi method is used for design optimization. Data analysis is performed using commercial statistics software. For design optimization three factors with three levels is considered, hence L9 orthogonal array table is suitable in this case, which is shown in table no. 3.
Our objective is to get maximum noise reduction, i.e. transmission loss should be maximum. Hence larger the better is used for Taguchi method. The S/N ratio is defined as,

TABLE 3
ORTHOGONAL ARRAY – L9

Exp. No.	Diameter	Porosity	Length
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

$$\frac{S}{N} = -10 \, log \frac{\sum_{i=1}^{n} \frac{1}{{y_i}^2}}{n} \quad (6)$$

Where, yi = Experimental data, n = number of readings.

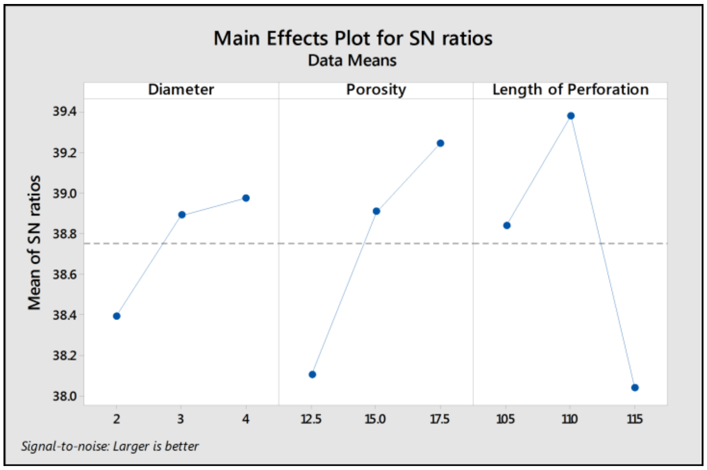


Fig. 6. S/N Ratios

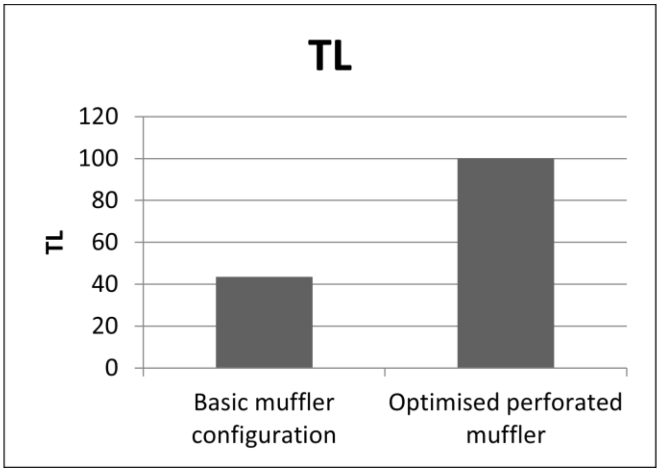


Fig. 7. Transmission loss at 800 Hz

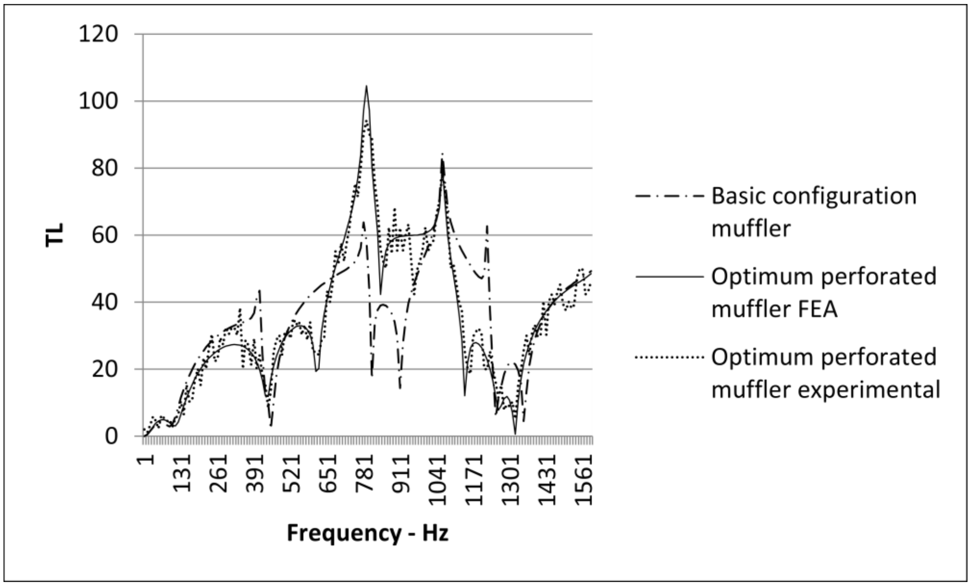


Fig. 8. Transmission loss comparison of basic muffler and optimized perforated muffler

From figure 6 optimum levels obtained for diameter, porosity and perforated pipe length are 4 mm, 17.5% and 110 mm respective.

5 Results and Discussions

Muffler configuration with optimized perforation design is analyzed and results are compared with acoustic performance of basic muffler configuration without perforations. Three factors, i.e. perforation diameter, porosity and perforated pipe length were considered for optimization of muffler. Using commercial FEA software acoustic analysis was performed. Using these results optimization was performed by using Taguchi method. From figure 7 and 8, we get maximum transmission loss at design frequency 800 Hz. The transmission loss is improved by 130%, i.e. it is increased from 43.479 dB to 100.13 dB.

6 Conclusion

Optimization of muffler with perforations for maximum transmission loss at 800 Hz design frequency is achieved by Taguchi method. Performance of mufflers are estimated with help of numerical analysis. Validation of results is done by experimentation. In experiments two load method is used. It is observed that results of numerical analysis and experimentation are in agreement.

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