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Optimization of the Position of the Outlet of Side Outlet Muffler Using Genetic Algorithm

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Abstract

The shape and positions of the internal components of a reactive muffler play a vital role in the acoustic performance of the muffler. The optimization of the shapes and positions of the components becomes necessary for the design of the mufflers. In this paper, the GA technique has been used for the optimization of the position of the outlet of the side outlet muffler. The position of the outlet varies from 17 mm to 180 mm along the length of the enlarged portion of the side outlet muffler. For the accuracy check of the mathematical modelling of the side outlet muffle, the TL obtained from the analytical modelling is compared with the reference paper and an excellent agreement is obtained. The GA method concludes that the configuration of the side outlet muffler in which the outlet is at 137 mm from the end of the enlarged portion, shows remarkable acoustic performance. The maximum TL obtained from the analytical modelling for this configuration is 90.12 dB at 626 Hz, which is 27.41 dB greater than the reference paper. The result obtained from GA also validated through the finite element analysis of the same configured muffler. Also, the sound pressure level is presented in the forms of contours and isolines. The contours show the high and low sound pressure zones, and the isolines provide information about the transmission of sound waves inside the muffler. This study shows the effectiveness and the accuracy of the GA method in the finding of the positions of the internal components of the reactive muffler.

Keywords: Analytical modelling, Genetic algorithm, Optimization, Side outlet muffler.

1. Introduction

High noise levels may be harmful to individuals and cause both physiological and psychological problems[1]; consequently, the need for low-noise levels in many devices became critical and competitive[2]. Furthermore, users frequently express a need for a more compact muffler design as a requirement within a space-constrained environment. As a result, there is a rising requirement to improve the performance of mufflers while keeping size limits in mind. Sullivan and Crocker[3] began testing novel perforated-element mufflers to suppress the exhausting noise of a venting system. A number of conceptual and computational strategies for solving the acoustical difficulties have been proposed based on the study done by Sullivan and Crocker [4,5,6,7,8]. However, instability difficulties in the solution andthe restraints of non-flow remained the same. Peat[9] and Munjal[10], promulgate the numerical decoupling and decoupling methods, which were the solution for the shortcomings inearlier studies. Yet, the requirement to examine the optimum muffler design under space constraints is hardly tackled. Earlier research [11,12,13,14] adopted the use of optimum shape design to improve the efficacy of various non-perforated mufflers.

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To efficiently improve the performance of the noise control device, a new one-chamber perforated muffler design was developed employing a unique strategy of a genetic algorithm (GA) [15].

In the present study, position optimization of the outlet of a side outlet muffler (SOM) using GA has been proposed. The optimization of the position of the outlet of SOM is done in the desired frequency range. The optimized transmission loss (TL) in the desired frequency range has been presented for comparison. The optimized configurations of muffler are also analyzed through finite element analysis (FEA) and the FEA results are also compared with the analytical outcomes.

2. System Model

In this paper, a side outlet with one-chamber muffler is considered for the efficient suppression of the noise. To completely determine the design flexibility of SOM and its acoustical performance, a frequency range from 0 Hz to 3250 Hz has been chosen. Analytically, the TL expression for the SOM can be obtained with the help of transfer matrices. This has been explained in the following:

D_i and D_e are the diameters of the inlet/outlet and enlarged portion of SOM respectively. L is the total length of the enlarged portion, which can be seen as the sum of L_1 and L_2. From the 2 × 2 transfer matrix[16] $[T]$ for this configuration one can get the TL of SOM.

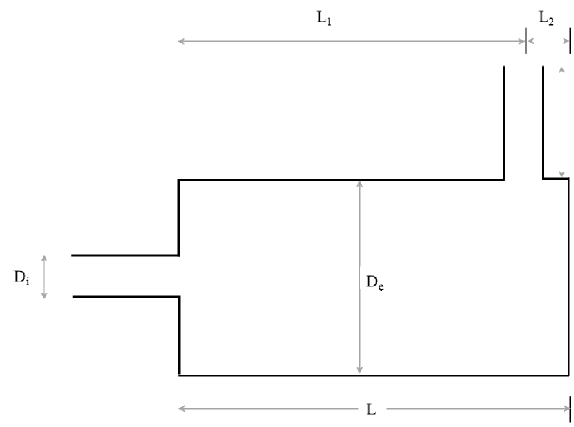

Fig.1 —Schematic diagram of a SOM[17].

$$[T] = \begin{bmatrix} \cos(kL_1) - \sin(kL_1) * \tan(kL_2) & i * Y' * sin(kL_1) \\ \frac{i}{Y'} * \{sin(kL_1) + \cos(kL_1) * \tan(kL_2)\} & cos\,(kL_1) \end{bmatrix} \quad (1)$$

$$TL = 20 * \log\left\{\cos(kL_1) - \frac{1}{2} * \sin(kL_1) * \tan(kL_2) + \frac{i}{2} * \sin(kL_1)\left(\frac{Y_1}{Y'} + \frac{Y'}{Y_1}\right) + i * \frac{Y_1}{Y'} * \frac{1}{2} * \cos(kL_1) * \tan(kL_2)\right\} \quad (2)$$

where, Y', Y_1, and k are the impedance (characteristic impedance) of the enlarged portion,impedanceof the inlet/outlet,and wave number, respectively.

3. Mathematical Model Check

An accuracy check of the mathematical model on the SOM is done using data from Zhang *et al.*[17] before running GAand is displayed in Fig. 2. The comparison between the analytical modelling and the reference paper[17] shows a fair agreement with each other.

3.1 Genetic algorithm (GA)

The use of optimization search techniques spotted after the Darwinian notions of natural selection and evolution is central to the idea of GAs, which was initially codified by Holland[18] and then continued by D. Jong[19] for functional optimization. In GA optimization, a single set of test solutions was chosen and developed into the perfect solution.

The design parameters (X_1, X_2, X_3, X_4,….,X_k) were selected for the optimization of objective function (OBJ). Initially, chromosome bit length (*bit_n*) is chosen. Thereafter, the parameter (X_k) with the lower and upper bound $[Lb, Ub]_k$ was plotted to the binary value band. The plotting mechanism between the variable bounds and the kth binary chromosome $\underbrace{0\,0\,0\,0 \ldots 0\,0\,0}\sim\underbrace{1\,1\,1\,1 \ldots 111}$ was then formed. Encodingx to B2D (binary to decimal) can be performed as follows:

$$B2D_k = \text{integer}\left\{\frac{x_k - Lb_k}{Ub_k - Lb_k}(2^{bit\_n} - 1)\right\} \quad (3)$$

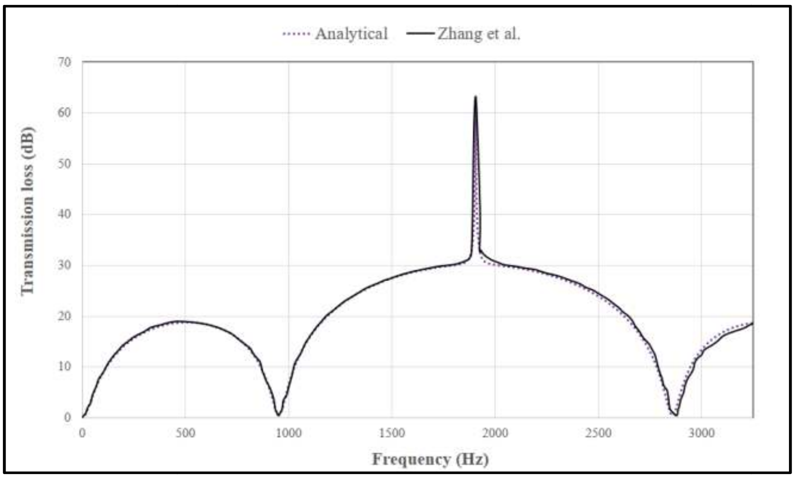

Fig. 2 —Mathematical model accuracy check on the SOM.

Randomization was used to create the initial population. The parameter set was programmed to create a string representing the chromosome. The full set of converted chromosome $[B2D_1, B2D_2, \ldots, B2D_k]$was then assigned a fitness by decoding the conversion system independently using the objective function (OBJ).

$$fitness = OBJ(X_1, X_2, X_3, X_4 \ldots, X_k) \quad (4)$$

$$\text{Parameters, } X_k = B2D_k(Ub_k - Lb_k)/\,(2^{bit\_n} - 1) + Lb_k \quad (5)$$

As shown in Fig. 3, tournament selection, a random assessment of the relative fitness from pairs of chromosomes, were used to develop the gene's elitism. During the GA optimization, one pair of offspring can be generated by using uniform crossover from the selected parent. Fig. 4 depicts the uniform crossover mechanism in GA optimization. As shown in Fig. 4, if the plotting gene is 1, then gene data among parents will be internally shared via the mask genes.

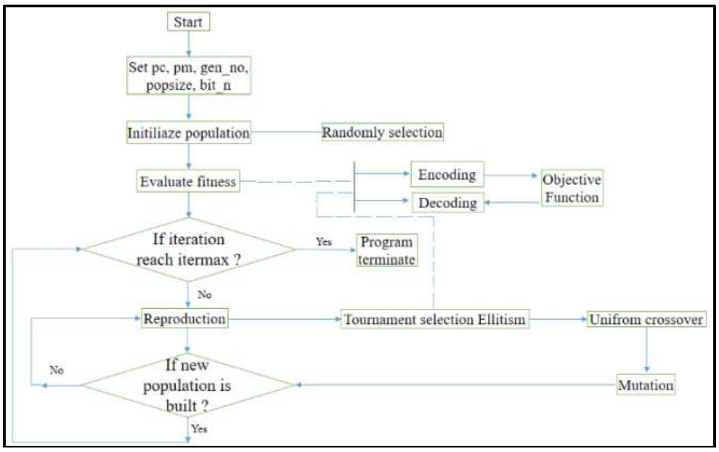

Fig. 3 —Flow chart of GA optimization.

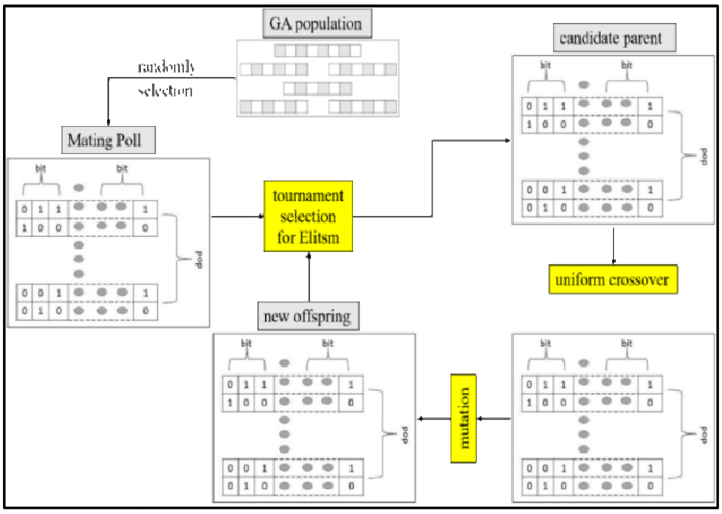

Fig. 4 — Uniform crossover mechanism in GA optimization.

4. Objective function for optimization

The objective function in this study is the TL of the SOM. It can be observed from equation 5 that TL is a function of diameters of the inlet (D_i), outlet (D_o), and enlarged portion (D_e), the length of enlarged portion (L), the position of the outlet (L_2), the wave number (k), and velocity of sound (c) in the medium. The position of the outlet (L_2) is the variable in the objective fitness function. The function can be written as:

$$Objective\ function = TL(D_i, D_e, L_2, k, c, L) \quad (6)$$

with design parameter constraint

$$0.017\ m \leq\ L_2 \leq 0.180\ m \qquad (7)$$

5. Finite Element Analysis (FEA)

The FEA for particular optimized cases has been carried out in the harmonic acoustic module of the ANSYS workbench. The computational domains for the optimized cases are shown in Figs. 5 (a), 5(b), and 5(c). The domains are discretized into acoustic elements (FLUID 221) to capture the acoustic effects. Surface velocity, radiation boundary, and rigid wall conditions are applied at inlet, inlet and outlet, and wall of SOM, respectively.

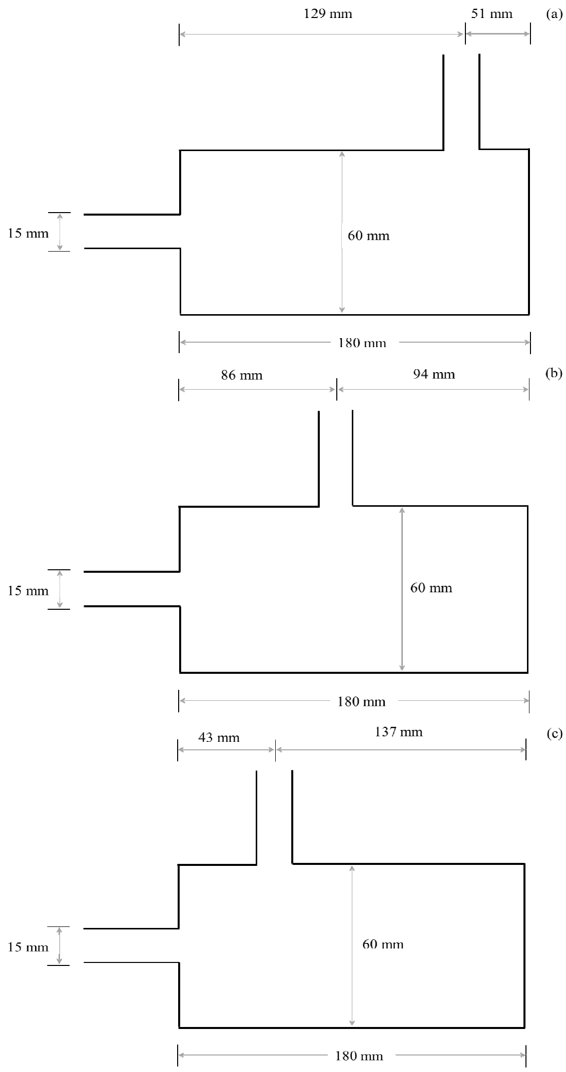

Fig.5 — Computational domains for (a) model_1, (b) model_2, and (c) model_3.

6. Results and Discussion

The TL of SOM without optimization of the location of the outlet is presented in Fig. 2. Initially, the position of the outlet of the SOM is at 0.045 m from the end of the enlarged portion. The position of the outlet is varied along the length of the enlarged portion by keeping other parameters constant. The GA provides 4 optimized positions for the outlet of SOM. The positions of the outlet from the end of the enlarged portion are 51 mm, 94 mm, 137 mm, and 180 mm, respectively. The last position of the outlet does not make sense in the design of the SOM. This is so because, at 180 mm position of the outlet, the surface of the outlet becomes outside the body of the SOM. The maximum TL values at the optimized positions and at original position of the outlet is listed in the Table 1. The comparison of the TL obtained from the analytical modelling for the different models of the SOM is shown in Fig. 5 along with the original muffler.

As the distance of the axis of the outlet is increasing, there is increase in the value of the TL. This is due to the effect of the extended portion between the axis of the outlet and the end of the enlarged portion. The TL is maximum for the model_3 of the SOM and has value 90.12 dB at 626 Hz. The TL from FEA for all the models of SOM are also presented in Fig. 5. There are three sudden peaks in the analytical TL curve of the model_3 and have values 90.12 dB at 626 Hz, 62.5 dB at 1878 Hz, and 75.10 dB at 3130 Hz, respectively. The peaks also show the better capability of the model_3 in the noise suppression as compared to the other models. The FEA curves for the respective models of the SOM show excellent match with the analytical curves. The matching of FEA and analytical curves for the respective models also shows the accuracy of the GA in the optimization of the position of the outlet of the SOM.

Table 1—Maximum transmission loss of SOM at optimized position of outlet

Models	Location of outlet (L_2) (mm)	Length of enlarged portion (L) (mm)	Diameter of enlarged portion (D_e) (mm)	Diameter of inlet (D_i)/outlet (D_o) (mm)	TL (dB)
model_1	51	180	60	15	83.82
model_2	94	180	60	15	75.46
model_3	137	180	60	15	90.12
Original	45	180	60	15	62.07

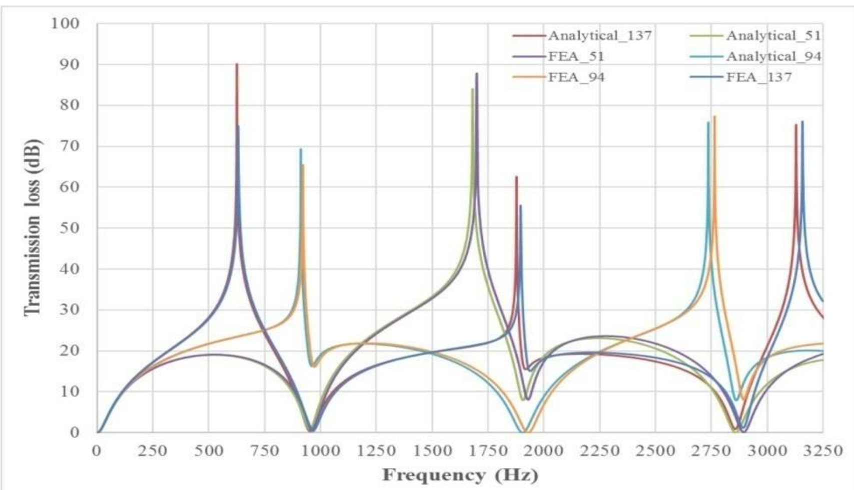

Fig.6 —TL for SOM at different positions of the outlet.

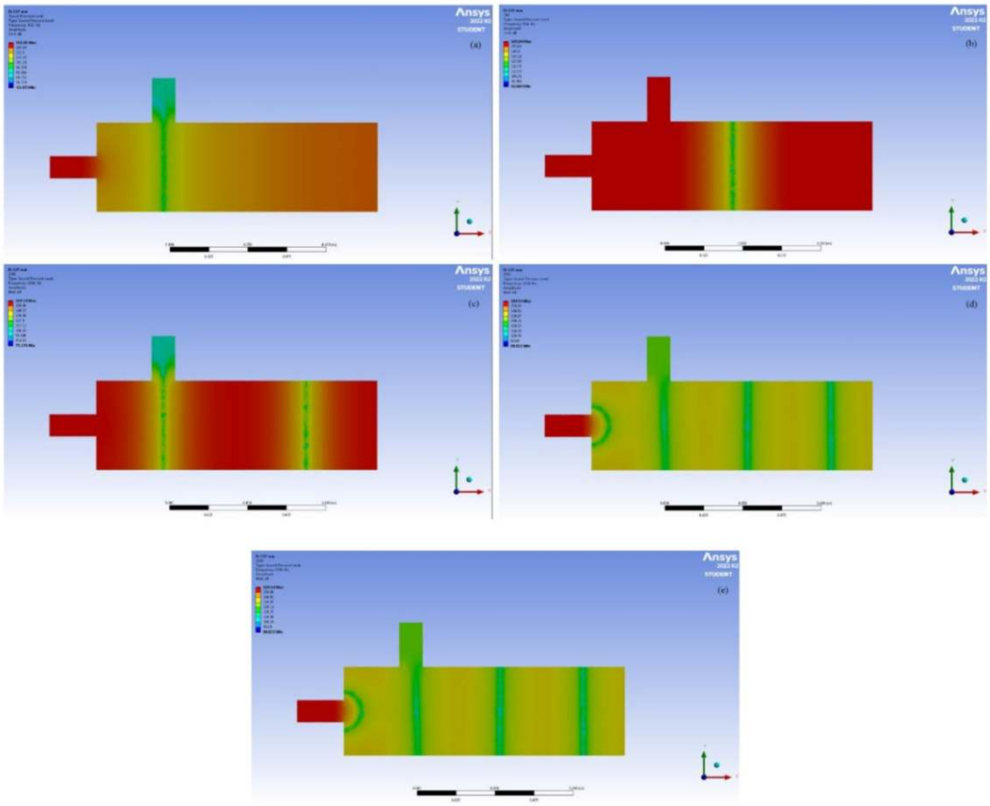

Fig. 7 —.Sound pressure level contours at (a) 622 Hz, (b) 966 Hz, (c) 1878 Hz, (d) 2892 Hz, and (e) 3158 Hz.

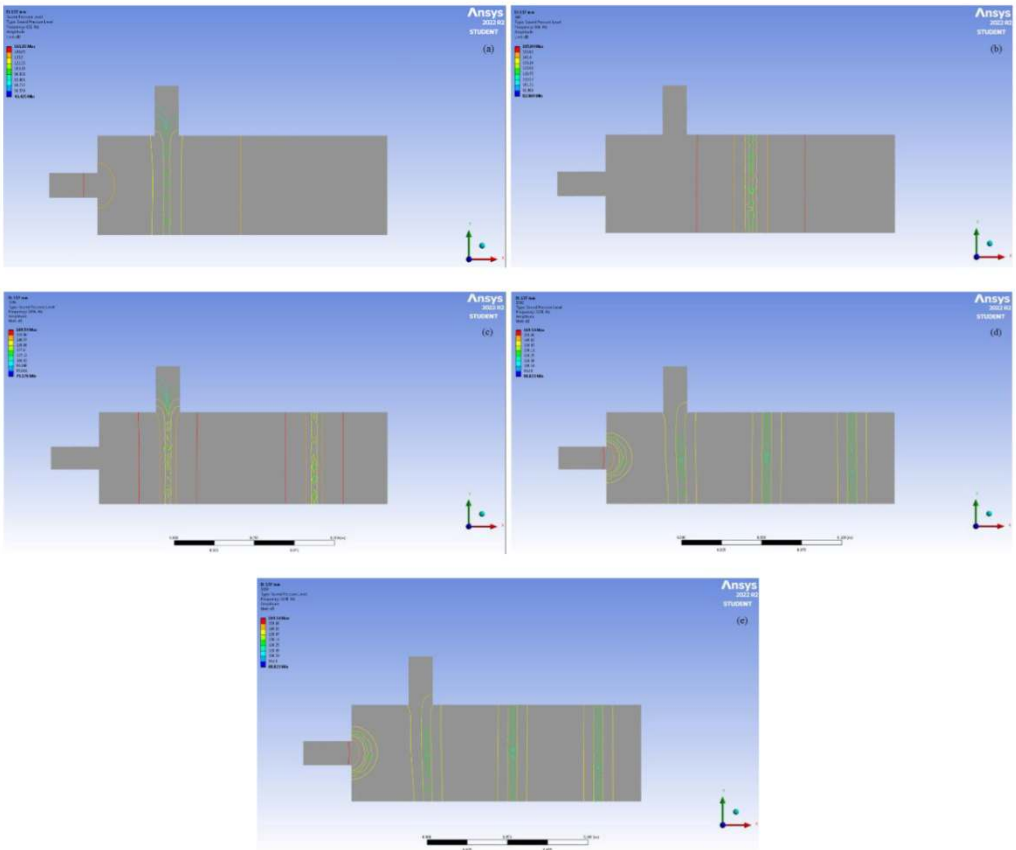

Fig. 8 —.Sound pressure level isoline at (a) 622 Hz, (b) 966 Hz, (c) 1878 Hz, (d) 2892 Hz, and (e) 3158 Hz.

Sound pressure level for the model_3 in contour from and isoline from at different frequencies are shown in Fig. 6 and Fig. 7. The selection of the frequencies is based on the values of the TL in the FEA curve of mdoel_3. The frequencies such as 632, 966, 1896, 2892, and 3158 Hz are for the first peak, first trough, second peak, second trough, and third peak, respectively. Among all the contours, the sound pressure level at 626 Hz shows best attenuation which also supports the TL value at this frequency.

7. Conclusions

The mathematical modelling for a SOM has been successfully done. The GA has been applied on the mathematical model of the SOM taking TL as the objective function. This optimization technique provides 4 optimized positions of the outlet among which position of the outlet at 137 mm gives the better performance. The FEA for all the optimized cases has also been performed which confirms the accuracy of the GA. This study also helps in the selection of working frequency range for the different models. The model_1 shows effectiveness in 1183-1824 Hz. The model_2 shows excellent performance in 0-1188 Hz and 2406-2861 Hz, model_3 shows better response in 0-742 Hz, 1840-2010 Hz, and 2861-3250 Hz.

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