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Muffler Design for Noise Reduction and Pressure Loss Optimization Using Multiobjective Genetic Algorithm

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Abstract. The muffler plays a crucial role in reducing the noise generated by the internal combustion engine exhaust gases. Therefore, an effective muffler design should be capable of significantly reducing noise levels. However, we must also consider backpressure, which can negatively impact engine performance. Backpressure is the additional pressure exerted by the muffler towards the engine, and it can have adverse effects on engine performance, thus requiring minimization. These two objectives often conflict with each other. Hence, in this research, we utilize multiobjective genetic algorithms as a tool to optimize muffler design. Inspired by the natural selection process, genetic algorithms aim to find a muffler design that is not only effective in reducing noise but also produces minimal backpressure. Thus, this study aims to achieve a balance between noise reduction and backpressure minimization in muffler design. The multiobjective genetic algorithm proposes 105 muffler design solutions. These solutions are not dominated by each other against both TL and PL objectives. The design that has the best value in the TL objective is solution 1 with TL and PL values of 26.06 dBA and 2.27 kPa. The design that has the best value in the PL objective is solution 3 with TL and PL values of 8.36 dBA and 1.87 kPa. The muffler compromise design chosen was a solution 41 with TL and PL values of 17.78 dBA and 2.07 kPa.

Introduction

Vehicle mufflers have a major role in dampening the noise generated by internal combustion engines[1]–[3]. Excessive noise can be annoying and needs to be reduced, because the adverse effects can be felt by the surrounding environment and human health, as well as cause discomfort[4], [5]. Therefore, an effective muffler design is one that is able to significantly reduce noise levels. However, in the muffler design process, we must also consider the back pressure. Back pressure is the additional pressure generated by the muffler that can negatively impact engine performance[6], [7]. This back pressure can reduce engine power and increase specific fuel consumption[8]. The challenge is that these two parameters, i.e. noise dampening and minimizing back pressure, often contradict each other. When muffler designs are optimized to suppress noise, the resulting backpressure tends to increase, and vice versa. In situations like this, where a good muffler design is needed for both aspects, namely reducing noise and minimizing back pressure, a multi-objective optimization approach is the right choice.

Until now, there have been many multi-objective optimization studies that use evolutionary algorithms, such as multiobjective genetic algorithm (MOGA), to obtain optimal muffler designs[8]–[14]. They used this method on different types of mufflers in various studies. The achievements of the study show that computational intelligence such as genetic algorithms are superior in terms of finding optimal designs. So that in this research researchers will also carry out the same goal where optimizing the design of a muffler by considering both objectives using the help of MOGA to achieve an optimal design both in reducing noise and minimizing back pressure. The result of this study is an optimal muffler design that excels at dampening noise and minimizing back pressure. By obtaining an optimal design for a muffler, it can help reduce noise pollution and produce a low reverse pressure muffler design, which in turn will improve engine performance and reduce specific fuel consumption.

Research Method

The parameters of the noise reduction ability of a muffler consist of 3 indicators, namely transmission loss (TL), insertion loss (IL), and level difference (LD)[3]. Generally, TL and IL are often used in many studies. TL is the difference in sound power inside the inlet and the transmitted sound wave. IL is the difference in sound power at the same point by using and not using a muffler. For back pressure, the parameter used is pressure loss (PL). PL is the pressure difference at the muffler inlet and outlet. PL represents the backpressure produced due to an increase or decrease in PL in line with the backpressure[1], [10], [15].

In this study noise reduction parameters use TL and minimizing backpressure use PL. The TL value can be approximated using the following equation, refer Eq. 1 $Sduct$ is the area of the inlet/outlet (x_1), $Sexp$ is the area of the expansion space (x_2), L is the length of the expansion space area (x_3), k is the number of waves, which can be calculated using Eq. 2, visual analyser software is used to measure the frequency of the muffler sound at idle engine speed [16].

$$\mathrm{TL} = 10\log_{10}\left[1 + \frac{1}{4}\left(\frac{S_{duct}}{S_{exp}} - \frac{S_{exp}}{S_{duct}}\right)^2 sin^2 kL\right] \tag{1}$$

$$k = 2\pi/\lambda \tag{2}$$

$$\lambda = f\ c \tag{3}$$

Where,

TL	= Transmission loss (dBA)
$Sduct$	= Cross-sectional area of duct (m^2)
$Sexp$	= Cross-sectional expansion chamber (m^2)
k	= Number of waves in a distance
L	= Expansion chamber length (m)
λ	= Wavelength (m)
f	= frequency (Hz)

Then, for PL it can be approached using the following equation, refer Eq. 4 and 5. Where, ΔP is PL (Pa), ρ is exhaust gas density (kg/m^3), U is the flow velocity (m/s), D is the inlet/outlet diameter (m), d is the muffler diameter, and L_{eff} is the length of the muffler expansion section (m) [16].

$$\Delta P = \frac{1}{2}\rho\ U^2\ \boldsymbol{K} \tag{4}$$

$$\boldsymbol{K} = 0.981 + \frac{0.0346L_{eff}}{(D-d)\left[\frac{D^2}{D^2-d^2}\right]^2} \tag{5}$$

The TL and PL equations above are used as an approach to evaluate the performance of the selected parameters, and are used as fit functions in the optimization process using a multiobjective genetic algorithm.

Optimization Formulation. In this study, the design objective is to maximize TL and minimize PL. The objective functions of TL and PL have been shown in Eq. 1 and 4. Then for design space consists of three design variable, namely inlet / outlet diameter (x_1), muffler diameter (x_2), muffler expansion section length (x_3). Description of design variables and their space are presented in Fig. 1 and Table 1.

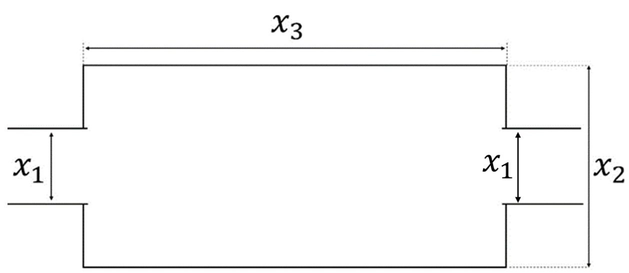

Fig. 1 Design Variable

Table 1 Desription of Design Variables & Spaces

Description	Code	Design Space
Diameter of inlet/outlet	x_1	$30 \text{ mm} \leq x_1 \leq 50 \text{ mm}$
Diameter of muffler	x_2	$110 \text{ mm} \leq x_2 \leq 190 \text{ mm}$
Length of expansion section	x_3	$300 \text{ mm} \leq x_3 \leq 420 \text{ mm}$

Result and Discussion

Optimization Procedure. The optimization process uses widely used optimization market software. The first step is to create an objective function which is then stored as a fitness function to be called upon in the optimization process, objective function using Eq. 1 and 4. The second stage is to determine the population size of 300 and the initial population number of 150, the number of generation 100, choose the mutation function adaptive feasible,choose the intermediate crossover function and choose plot functions pareto front, refer Fig. 2. After the optimization stage is set correctly, then finallys, the process runs.

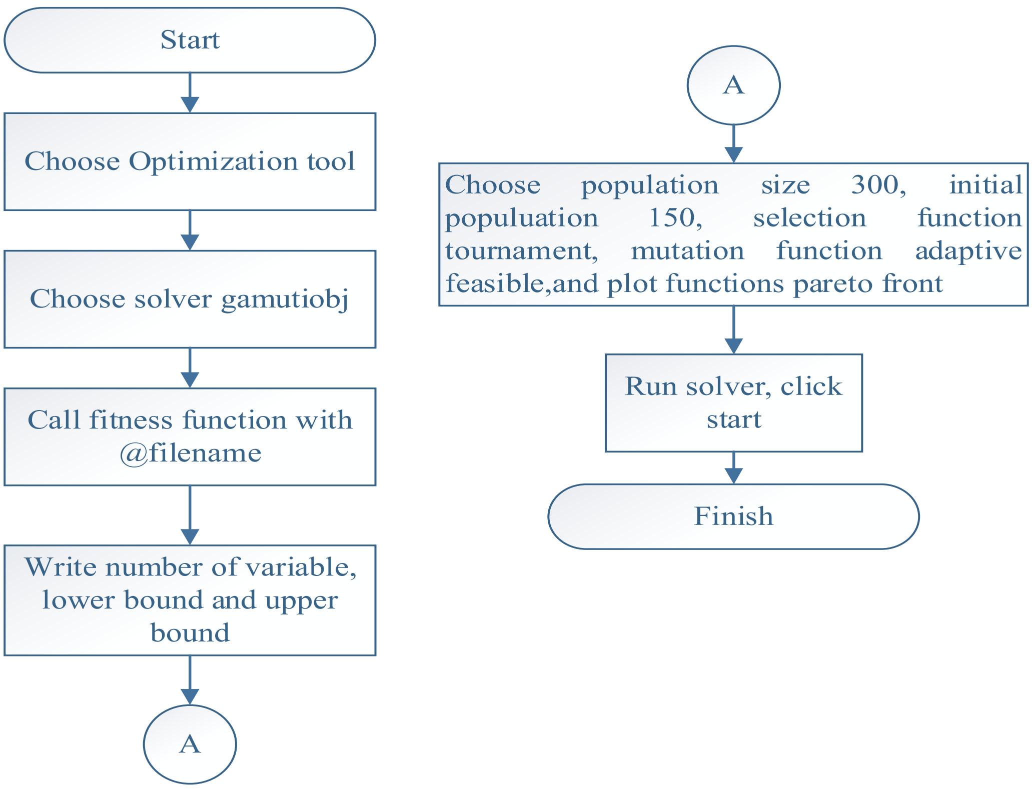

Fig. 2 Optimization Procedure.

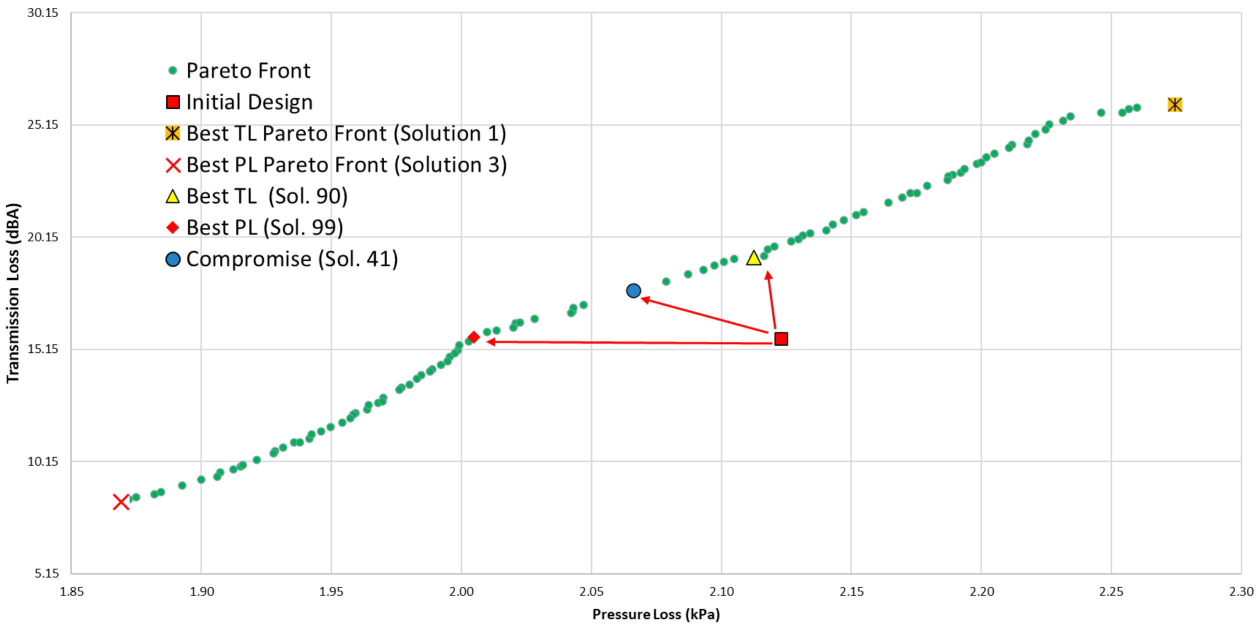

Fig. 3 Pareto Front Solutions

Figure 3 above is a pareto front solutions chart. The result of optimization using a multiobjective approach is the production of optimal design solutions that are not dominated by each other on both objectives called non-dominated solutions. These solutions, if graphed against two objectives, will form a graph of pareto solutions. Green dots are optimal muffler design solutions totaling 105 design solutions, where the design solutions are not dominated by each other on TL and PL performance. While the red dot, the initial design of the muffler, is not included in the row of pareto front solutions, meaning that the initial design of the muffler is not an optimal design. After getting pareto front solutions that contain optimal muffler designs, the second stage in optimization is to choose one of the design solutions according to user references. The options according to user reference are presented in Table 2.

Table 2 Description of Geometrical Data and Performances

Configuration	x1 (mm)	x2 (mm)	x3 (mm)	TL (dBA)	PL (kPa)
Best TL pareto front (solution 1)	30.00	190.00	345.34	26.06	2.27
Best PL pareto front (solution 3)	48.85	110.52	418.89	8.36	1.87
Initial design	40	140	390	15.63	2.12
Best TL (sol. 90)	30.58	134.01	416.67	19.24	2.11
Best PL (sol. 99)	30.92	110.21	418.51	15.70	2.00
Compromise (sol. 41)	30.26	121.84	418.25	**17.78**	**2.07**

From Table 2, it can be seen carefully that the TL and PL values of the initial design are surpassed by other designs. Solution 1 is a muffler design solution when referring to user references who have the highest TL muffler desire which means the best in noise reduction. While solution 3 is a muffler design solution when referring to user referrals who have the desire for a muffler with the lowest PL which means the best in minimizing back pressure. Solution 90 is the best muffler design solution in TL and slightly better in PL when compared to the initial design. Solution 99 is the best muffler design solution in PL and slightly better in TL than the initial design. The last is solution 41 as a compromise solution, where this solution is a muffler design solution that has a position in the middle if we look at the graph of pareto solutions, refer Fig. 3, the value of TL and PL in the compromise solution still has a better value than the initial design, so users can also choose this design as a muffler design solution that is good in TL and PL parameters.

Conclusions

Multiobjective genetic algorithms produce a set of solutions. The best muffler design solutions in terms of TL and PL that are not dominated by each other. Users can correctly select each muffler design solution at pareto solutions, and will not find the design is not optimal. MOGA can help in solving optimization cases where the desired performance parameters are found to conflict with each other like this simple muffler case. The multiobjective genetic algorithm proposes 105 muffler design solutions. These solutions are not dominated by each other against both TL and PL objectives. The design that has the best value in the TL objective is solution 1 with TL and PL values of 26.06 dBA and 2.27 kPa. The design that has the best value in the PL objective is solution 3 with TL and PL values of 8.36 dBA and 1.87 kPa. The muffler compromise design chosen was a solution 41 with TL and PL values of 17.78 dBA and 2.07 kPa.

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References

[1] M. A. Habib, A. U. Patwari, A. S. Anwar, S. Shadman, and O. H. Abir, “3D CFD Based Optimization Technique for Muffler Design of a Motorcycle,” *Appl. Mech. Mater.*, vol. 860, pp. 52–57, 2017, doi: 10.4028/www.scientific.net/AMM.860.52.

[2] R. Li, Y. Zhou, Y. Xue, and S. Han, “Local Structural Optimization Method Based on Orthogonal Analysis for a Resistant Muffler,” *IEEE Access*, vol. 9, pp. 40560–40569, 2021, doi: 10.1109/ACCESS.2021.3063768.

[3] J. K. Lee, K. S. Oh, and J. W. Lee, “Methods for evaluating in-duct noise attenuation performance in a muffler design problem,” *J. Sound Vib.*, vol. 464, p. 114982, 2020, doi: 10.1016/j.jsv.2019.114982.

[4] A. Jahanbakhshi, M. Yousefi, S. Karami-Boozhani, K. Heidarbeigi, and Y. Abbaspour-Gilandeh, “The effect of combined resistance muffler on noise pollution and the allowable driver exposure in Massey-Ferguson tractors (MF 285 and MF 299),” *J. Saudi Soc. Agric. Sci.*, vol. 19, no. 6, pp. 409–414, 2020, doi: 10.1016/j.jssas.2020.06.002.

[5] M. Mohammadi and S. E. Razavi, “Investigation of the Efficiency of Various Reactive Mufflers by Noise Reduction and Transmission Loss Analyses,” *J. Theor. Appl. Vib. Acoust.*, vol. 4, no. 2, pp. 1–8, 2018.

[6] A. Kashikar, R. Suryawanshi, N. Sonone, R. Thorat, and S. Savant, “Development of muffler design and its validation,” *Appl. Acoust.*, vol. 180, p. 108132, 2021, doi: 10.1016/j.apacoust.2021.108132.

[7] S. Thirumurugaveerakumar, “Design and optimization of muffler back pressure,” *AIP Conf. Proc.*, vol. 2270, no. November, 2020, doi: 10.1063/5.0019700.

[8] D. Siano, F. Bozza, and F. Auriemma, “Acoustic and fluid-dynamic optimization of an automotive muffler,” *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.*, vol. 227, no. 5, pp. 735–747, 2013, doi: 10.1177/0954407012465689.

[9] Y. C. Chang, M. C. Chiu, and M. R. Wu, “Acoustical assessment of automotive mufflers using FEM, neural networks, and a genetic algorithm,” *Arch. Acoust.*, vol. 43, no. 3, pp. 517–529, 2018, doi: 10.24425/123923.

[10] S. Chao and H. Liang, “Comparison of various algorithms for improving acoustic attenuation performance and flow characteristic of reactive mufflers,” *Appl. Acoust.*, vol. 116, pp. 291–296, 2017, doi: 10.1016/j.apacoust.2016.09.034.

[11] M. C. Chiu, “Genetic algorithm optimization on a venting system with three-chamber hybrid mufflers within a constrained back pressure and space,” *J. Vib. Acoust. Trans. ASME*, vol. 134, no. 2, pp. 1–11, 2012, doi: 10.1115/1.4005220.

[12] S. Zuo, K. Wei, and X. Wu, “Multi-objective optimization of a multi-chamber perforated muffler using an approximate model and genetic algorithm,” *Int. J. Acoust. Vib.*, vol. 21, no. 2, pp. 152–163, 2016, doi: 10.20855/ijav.2016.21.2405.

[13] C. Lu, W. Chen, Z. Liu, S. Du, and Y. Zhu, “Pilot study on compact wideband micro-perforated muffler with a serial-parallel coupling mode,” *Appl. Acoust.*, vol. 148, pp. 141–150, 2019, doi: 10.1016/j.apacoust.2018.12.001.

[14] Y. C. Chang, M. C. Chiu, and S. E. Huang, “Numerical analysis of circular straight mufflers equipped with three chambers at high-order-modes,” *Appl. Acoust.*, vol. 155, pp. 167–179, 2019, doi: 10.1016/j.apacoust.2019.05.021.

[15] A. Elsayed, C. Bastien, S. Jones, J. Christensen, H. Medina, and H. Kassem, “Investigation of baffle configuration effect on the performance of exhaust mufflers,” *Case Stud. Therm. Eng.*, vol. 10, pp. 86–94, 2017, doi: 10.1016/j.csite.2017.03.006.

[16] D. A. Bies, C. H. Hansen, and C. Q. Howard, *Engineering Noise Control*, Fifth edit. CRC Press Taylor & Francis Group, 2018. [Online]. Available: http://books.google.com.sg/books?id=LU8U3mka-DUC&pg=PA665&dq=loss+factor+for+materials+table&hl=en&sa=X&ei=dcSlT_mALJCurAfS6MTgAQ&redir_esc=y#v=onepage&q=loss factor for materials table&f=false%5Cnhttp://books.google.com.sg/books?id=LU8U3mka-DUC&pg=PA665&