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Muffler Transmission Loss optimization for a Vehicle using Genetic Algorithm

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Abstract
Automotive reactive muffler attenuate sound using interference which is produced by engine exhaust sound waves are partially or fully cancelled. to reduce the complexity of design this process is carried, which involves CAE modelling and analysis followed by optimization technique for maximization TL.TL constitutes a spectrum it has a function of frequency, to obtained single global measure RMS is calculated known as RMSTL. For optimization Genetic algorithm provide variation. for experimental validation of data, the Experimental is carried on Impedance tube, Conical adapters are designed to accommodate different diameter openings of Impedance tube and muffler. optimization done, by taking design variable as length and diameter of inlet outlet and muffler chamber varied in range of -15% - +15% of original dimensions. Later simulation results of this variable muffler are compared with base muffler results. In the optimized solution we obtain 10.24% maximization in TL suggested by this optimized solution.

Keywords: Transmission Loss, Muffler, Genetic Algorithm

1. Introduction

There are so many unwanted sounds that are coming from automotive vehicles, machines, and industrial applications mainly in automotive application. The unwanted noise level can lead to very dangerous diseases and permanent hearing loss on the person's body, conservative hearing. Therefore, there is a necessary to reduce this unwanted emitted noise using some devices structures. Mufflers are devices which optimize the radiated noise from some structures like engines by attenuating of sound.[1]

Sound can be affected by some external influences like pressure, temperature, and the density of the medium. there are Four types of vehicle noise sources in vehicle. they are engine noise, wind noise, road noise and exhaust noise. To keep up with government legislation muffler needs to satisfy the compatibility of appropriate dB level means accepted minimal transmission loss, also its robustness and structural integrity. To address this issue previously designed muffler is analysed and optimised as per geometry concern. [2-4]

The most important issue for the design process of mufflers is to develop efficient geometries which can optimize the noise TL of mufflers. In this way, it is necessary to understand the influence of geometrical properties of muffler parts on noise TL optimization. Here the shape optimization of multi chamber muffler is done. The experimental validation for finding out TL of multi chamber muffler is done using modified four microphone impedance tube setup which is equipped with power analyser and DAQ system. we are limiting Validation in frequency range of 60Hz to 2000 Hz, due to microphone constrain. [3-5] after this the finite element method simulation is done in the solid works the 3D model of multi chamber muffler is created and simulation to find out Transmission loss is done in COMSOL.

For the shape optimisation efficient way is to get variables for change in dimensions of components so, in my project I have created various geometries by keeping all quantities as constant and

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one as variable. Changes for inlet pipe length and diameter, Outlet pipe length and diameter, Muffler pipe length and diameter, also when we vary muffler pipe length the third chamber length also varies as per that. After creating all the changes all the dimensions will be vary for ±5%, ±10%, ±15%.[7] after obtaining all TL we can convert those entities inti RMSTL (root mean square transmission loss) as we see in simulation results there is maximum TL in particular frequency range so, the peak TL frequency is different in every case, but we can get its common range.so, there will not be any conflicts in results. [8-9]

After getting all the data it is collected in excel file which is imported in generic algorithm code for optimization is done in MATLAB. By using this we can optimise all the above parameters
The targets in the project to be achieved are as follow.

1. Optimise the Multi chamber muffler lengths and diameters.
2. Obtain above 5% maximisation of transmission loss compared to base muffler design.
3. Suggest design modification for muffler.
4. Check the effectiveness of use of impedance tube for experimental calculation of transmission loss for low cost.

2. Literature review

Mostafa Ranjbar and Milad kermani have done muffler design by Transmission loss maximization for wide range of frequency and A Comparative Study on Design Optimization of Mufflers by Genetic Algorithm and Random Search Method this is similar work with more elaborative details is given, in which they have investigated the effect of variation of dimension od component individual on overall performance, in this project they are working on single chamber or regular muffler proper. The experimentation is done for changes in between 5%-30% which is carried out by method of three-point method which is carried in MAP software.[5] later all the results are compared, analysed, and optimised using generic algorithm. from this work we can get that inlet diameter is critical parameter than other variables the results show rise in TL by 9dB. The methodology of this project is applied in this project. [1-3,5]

M. Ranjbar, M. kermani further extended above project as Muffler Design by Noise Transmission Loss Maximization Over a Narrow Band Frequency Range. Here they have used multi chamber muffler rather than simple expansion muffler outputs obtained are, TL can be maximised using By increasing the inlet radius ,By decreasing the radius of Ex-tube 1 and inner radius of in-flange, By decreasing the radius of Ex-tube 2 and inner radius of out-flange, By decreasing the inlet radius, Ex-tube 1 and inner radius of in-flange ,By decreasing the outlet radius, Extube 2 and inner radius of out-flange, By decreasing the outer radius of inflange, By increasing the outer radius of out flange.[7-8]

Mehmet ORAK, M Ranjbar et.al worked on sound transmission loss maximation of a multi-chamber exhaust system, which is similar work with more than four chamber muffler is studied M Ranjbar et.al have experimented On Muffler Design for Transmitted Noise Reduction where the validation and procedure of impedance tube testing to finding out transmission loss is given. The aim of project the was to investigate the passive noise reduction methods in mufflers. [9-13] Also, another aim of this study is to examine and design mufflers with various geometries like circular and rectangular. Gives the effect of geometry on noise transmission loss maximisation performance of mufflers. Four-poles method is used to determine the noise transmission loss. After experimentation they found the theoretical and experimental result are coincident with each other. Like for the rectangular muffler, the randomly increases and decreases or fluctuated waves are reason of external effects which the theoretical way does not include. [14-18]

3. Theory

3.1.Acoustic filter Design parameters [4]

1. Adequate insertion loss (attenuation)
2. Backpressure
3. Structural

3.2.Acoustic filter performance parameters

1. Transmission loss
2. Insertion loss
3. Noise reduction

3.2.1.Transmission Loss (TL)

It is defined as defined as power incident on muffler and that transmitted to downstream into exhaust outlet.

$$TL = Lw1 - Lw2 \text{ (dB)} \qquad \text{Eq.(1)}$$

$$TL = 10 * \log \left| \frac{S2\,(A2)^2}{2} \frac{2}{S1(A1)^2} \right| \text{ (dB)} \qquad \text{Eq.(2)}$$

$$TL = 20 * \log\left({}^{A2}/_{A1}\right) \text{ (dB)} \qquad \text{Eq.(3)}$$

Where, S1, S2 are areas of exhaust pipe, A1, A2 associated with incident and transmitted acoustic power. [2] [4]

3.3. Government legislation

As we see this case study is done in 2015 from that time noise regulations are changed this is 2020 **Government regulation** motor vehicle act regulationsLast amended September 20, 2020, by B.C. Reg. 240/2020, Section 7.03 [6]

3.4. Calculation of Noise Transmission Loss by Impedance tube

Another way to find out Transmission loss at low cost as well without full laboratory setup at high cost we can use impedance tube method to calculate TL.

According to standards ISO10534-2, ASTM E1050 & ASTM E2611 Transmission loss of a muffler can be calculated by using impedance tube setup.To measure the transmission loss, they use Four microphone transfer function method.[12]

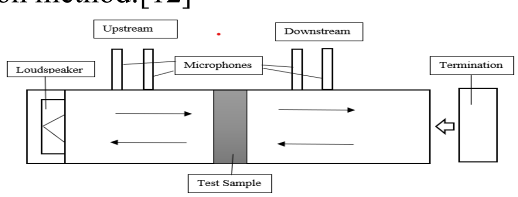


Figure 1: Diagram of Transmission loss measurement using Impedance tube

In impedance tube we can find out sound absorption coefficient, transmission loss of any material, frequency response at four mics is calculated and imported into transfer matrix method. Using Impedance tube, we can find TL at lower as well as higher frequency.

3.5. Genetic Algorithm (GA)

Its ideas are taken on principle of survival of the fittest. It is usually able to find the global minimum and can avoid local minima. They can handle all types of discontinuities.

This is an optimization method, this algorithm reflects the process of natural selection where the fittest individuals are selected for reproduction to produce offspring of the next generation, simply law of survival of the fittest.

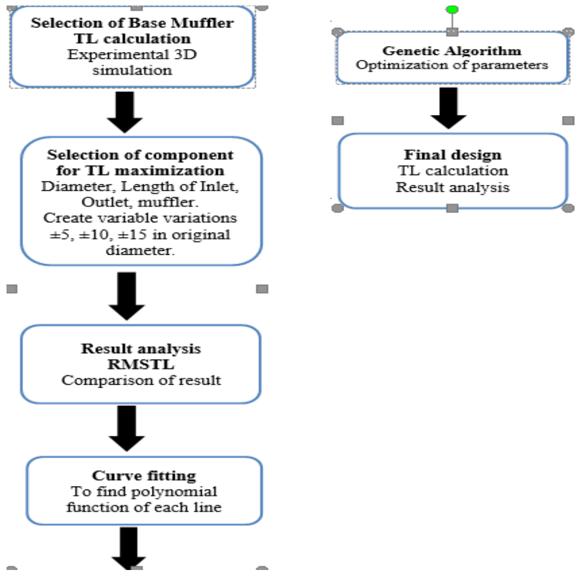
This method is considered to find the best optimum value of a simple muffler which generates a maximum RMSTL (root mean square of transmission loss). crossover, also called recombination, is a genetic operator used to mix the genetic information of two parental chromosomes to generate new offspring with new properties. Mutation is manipulation as per other data. [13]

Discrete variable optimizations used for engineering problems where design variable is fixed from a set of discreet values. Solving discreet problems have prone and cone to as we know we have limited range of value, but the combinational explosion can occur lead to take much longer time to solve the equation is simple type of optimisation where any function can be used as fitness function and specified as per objective maximization or minimization, Both methods have its advantages and disadvantages so, the combination of function based, and discreet variable optimization can give us fast and less complex solution.

Curve fitting is method used to find possible best fit curve on basis of discreet data. After creating a fit, for curve, you can apply a different types of post-processing methods for plotting, interpolation, and extrapolation methods to estimate confidence in intervals; and calculating integrals and derivatives.

TL constitutes a spectrum, i.e., it is a function of frequency f. So, to obtain some single global measure of the noise TL behaviour of a muffler in each frequency range of interest, the root means square level of noise transmission loss over that frequency band, known hereafter as RMSTL is calculated Based on software simulation is used in this project. By computing data of TL at each frequency obtained in numerical software MATLAB. [13,15]

4. Methodology



5. Simulation and experimentation

Muffler model taken for study is Mahindra 575 Diesel Direct Injection engine.
DI, 4 strokes, 4-cylinder, Diesel Engine, 2730 cc, 45 Hp, Engine Rated RPM: 1900

Table 1: Dimensions of Muffler

Component	Dimensions(mm)
Inlet diameter	48
Outlet diameter	42
Muffler diameter	93
Inlet pipe length	400
Outlet pipe length	272
Muffler length	503
Distance from 1st point to upstream baffle plate	25
Distance bet two baffle plates	75
1 Baffle plate hole no.	6
2nd baffle plate hole no.	3

5.1. CAE simulation

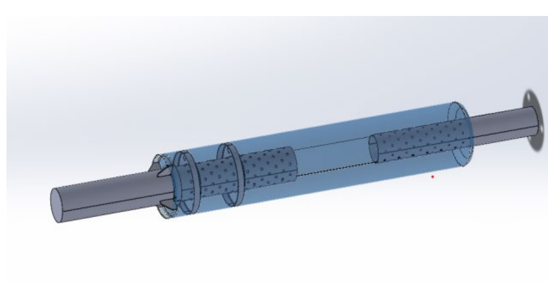


Figure 2: 3D model of Muffler

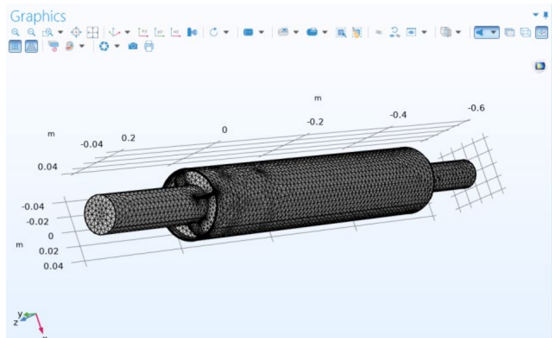


Figure 3: Meshed model in COMSOL

Variables

Name	Expression	Unit	Description
P_in	intop_in(p0^2/(2*acp...	W	incoming power
P_out	intop_out(p*conj(p)/(...	W	Outgoing power
TL	10*log10(P_in/P_out)		Transmission loss

Figure 4: Variable used for calculation

5.2. Experimental testing

In impedance tube we can find out sound absorption coefficient, transmission loss of any material, for practical validation Experimental results are necessary.

5.2.1. Experimental setup

To calculate transmission loss of muffler, frequency response at four mics is calculated and imported into transfer matrix method which will conducted automatically by LAB view software the DAQ system gives us the plot of transmission loss.

The experiment is conducted using white noise and with lid open and close alternatively. A random white noise signal is provided from the speaker at the inlet end of muffler because generally white noise predicts the good result to evaluate transmission loss performance. At outlet sound pressure level is measured with the use of microphones. First three readings are taken keeping the end of impedance tube open and next three readings are taken with the end of impedance tube closed. Further Muffler Transmission loss is computed with the use of transfer function method.

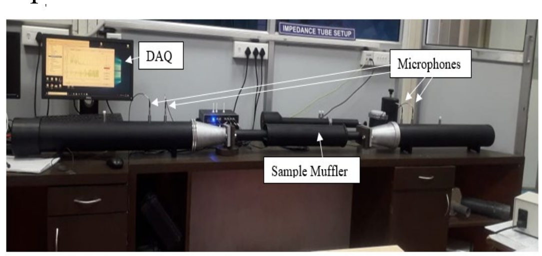


Figure 5: Actual Experimental Setup

Above image actual experimental setup on which experiments are conducted. From the above image we can see the changes in actual setup is made. The tube used to place the samples in impedance tube is replaced with muffler tube with modified conical ends so, it can be easily held into impedance tube and remaining setup remains same.

6. Result and discussion

6.1. Transmission Loss Experimental results for Base Muffler

From the below table we can see that the dominant frequencies are lies in range of 800Hz -1600Hz in this range we obtain highest Transmission loss.

Table 2: Transmission Loss from Experimental results for Base Muffler

Frequency (Hz)	TL (dB)
63	7.8
80	6.9
100	7.3
125	7.5
160	11
200	9.6
250	13.3
315	0.5
400	11.5
500	9.7
630	0.3
800	15.1
1000	17.1
1250	18.3
1600	22.2

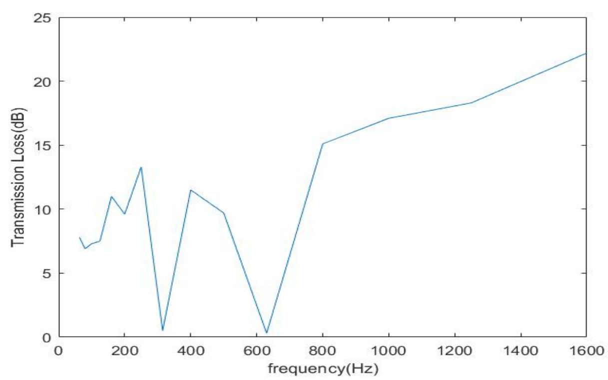


Figure 6: Transmission Loss from Experimental result

6.2. Transmission Loss CAE simulation results for Base Muffler

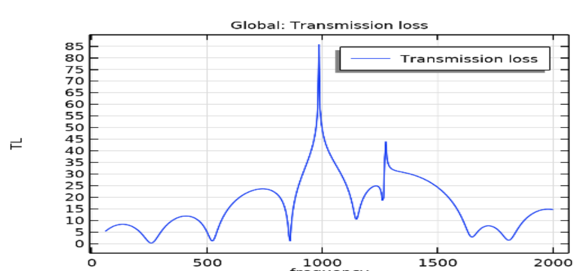


Figure 7: Transmission Loss from simulation result

Using COMSOL tool the transmission loss at each point with the interval of 5Hz within range of 60 Hz to 2000 Hz, all 389 points data is imported in MATLAB where Root mean square transmission loss (RMSTL) is calculated is about 20.90 dB.

6.3. Modified Geometry

For input variables we are taking length and diameter of each component length, muffler, outlet.

1. Effect of varying lengths of components

Table 3: Effect of length variation of components on TL

Per of change	**Inlet pipe length**	**Outlet pipe length**	**Muffler length**	**RMSTL**
0	400	272	503	20.90
+5%	420			19.43
		285.6		20.68
			528.15	19.84
+10%	440			18.71
		299.2		20.42
			553.3	20.02
+15%	460			18.62
		312.8		20.12
			578.45	19.93
-5%	380			20.06
		258.4		19.36
			477.85	18.97
-10%	360			19.38
		272.8		19.81
			452.7	18.92
-15%	340			16.74
		231.2		21.04
			427.55	18.89

2. Effect of varying Diameters of components

Table 4: Effect of diameter variation of components on TL

Per of change	**Inlet pipe Día**	**Outlet pipe Día**	**Muffler Día**	**RMSTL**
0	48	42	93	20.90
+5%	50.4			19.56
		44.1		19.46
			97.65	19.39
+10%	52.8			19.68
		46.2		19.52
			102.3	19.19
+15%	55.2			19.99
		48.3		19.77

			106.95	19.13
-5%	45.6			18.98
		39.9		19.49
			88.35	19.50
-10%	43.5			19.47
		37.5		18.99
			83.7	19.55
-15%	40.8			18.77
		35.7		18.99
			79.05	18.89

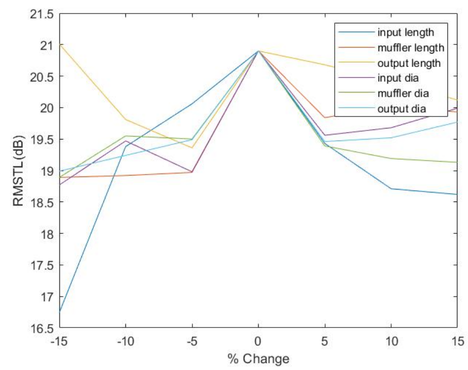


Figure 8: Combined graph of effect of variation of Length and diameter on RMSTL

From the graph we can see that base muffler have optimised values than other but when we reduce output length till the 5% reduction TL is decreasing but after that its rising, at the 15% we get maximum RMSTL 21 db. Change in diameter of the components does not show any significant effect on TL.

6.1. Curve fitting to obtain Polynomial equation from Varied RMSTL

All the data obtained till now is in discreet form by importing this data in MATLAB Curve fitting tool we can get polynomial function.

A(x) = a1*x^6 + a2*x^5 + a3*x^4 + a4*x^3 + a5*x^2 + a6*x + a7 Eq. (4)

Coefficient values are different for all 6 conditions.

Figure below displaying Curve fitting tool window of polynomial curve for input diameter.

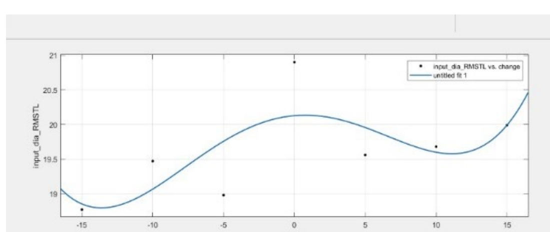


Figure 9: Polynomial curve for input diameter

In the MATLAB Optimtool is used to optimise the data. For which genetic algorithm solver is used with the population of 100 and other parameters are adjusted as per best for each equation separately.

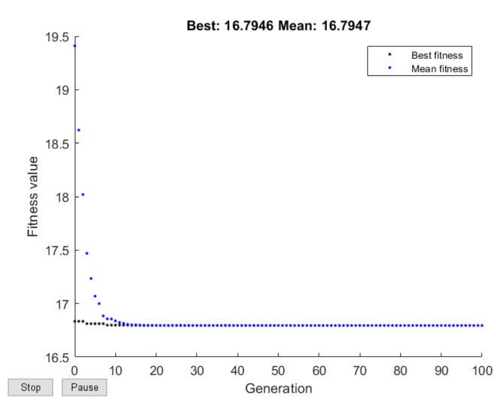


Figure 10: Optimized Inlet Length

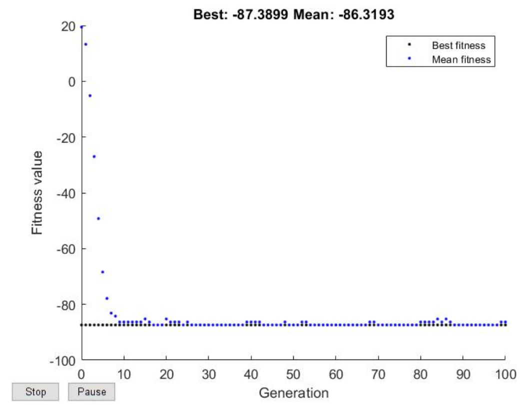


Figure 11: Optimized Inlet Diameter

Above plot shows optimised best fit for inlet length. Similar way other 6 optimization is done. now, result obtained is given below.

Table 5: Optimization result table

Part	Original dime(cm)	Optimization Percent	Optimized dimension
Inlet Diameter	48	-2.0260	**46.992**
Inlet length	400	-15	**340**
Muffler Diameter	93	7.3963	**99.882**
Muffler length	503	-0.1055	**502.497**
Outlet Diameter	42	-2.0938	**41.118**
Outlet length	272	15	**312.8**

From the above data we can see that most significant parameter is length Transmission loss. After getting all optimized values for each parameter using Genetic Algorithm, we reconstructed the 3D model to test it for transmission loss. now, the value of obtained RMSTL is 23.04 db.

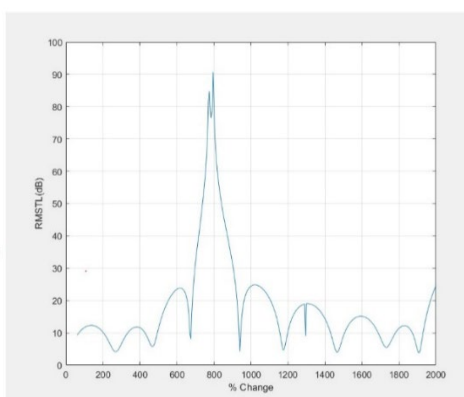


Figure 12: Transmission Loss of Optimised Muffler in COMSOL

If we observe the plot by comparing it with plot of TL of base muffler, we can see that its peak muffler TL is higher than base muffler which is 85dB and for optimised its 90.05dB. also, we compare the peak frequency in the base muffler it observed at 1000Hz but in optimised muffler it is at 800Hz.

7. Conclusion

Obtained RMSTL for optimised muffler is 23.04dB and for base muffler its 20.9 dB So, there is 10.24% increase in overall RMSTL.

Variation of diameter shows least effect on maximization of transmission Loss but length reduction of inlet and outlet pipe by -2.02%, -2.09% shows significant effect on RMSTL.

Increasing the length of expansion chamber will help to increase the T, also with the increase the increase of muffler pipe length area for perforation is also increased helps to flow enhancement.

Peak Transmission loss in base muffler is 85 dB and in optimised muffler its 90.05dB.

8. Future work

Optimisation of muffler with approach of the stress analysis using Modal analysis of muffler to check for dominant frequency. In result frequency at which peak occurred is 1000Hz in base muffler and in 800HZ in optimised muffler which is shifted to check its effect modal analysis must be done. and study of effect of changing of material on following geometry.

9. Conflicts of Interest

Riziyamaalisa Gavit declares that she does not have any conflicts of interest. Prof. Kiran Wani states that he has no conflict of interest.

10. Authors Contribution

This work is carried out by following authors, Conceptualization, Riziyamaalisa Gavit. and K. Wani; methodology, software simulations, validation, formal analysis, investigation, resources, data curation, writing—original draft preparation, writing—review and editing, visualization, Riziyamaalisa Gavit; Supervision, Project administration, Kiran Wani.

11. Acknowledgement

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