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Design and Geometrical Optimization of Single Expansion Chamber Muffler and Interconnecting Tubes Using GMM

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***Abstract*: Engine exhaust noise can be controlled in the automobile using mufflers. Generally single expansion chamber muffler was used to eliminate the exhaust noise. Considering the exhaust noise and sound pollution there is an urge to develop an optimized design for this muffler for better acoustics performance. Transmission loss (TL) is the important performance parameter of the reactive mufflers. TL is influenced by the geometrical dimensions of the muffler and the frequency of the sound wave passing through the muffler. Plane wave theory is used to analyze the transmission loss of reactive mufflers at low-frequency range since plane wave theory results show close convergence with experimental results. Due to the complexity of analytical equations for complicated geometries using plane wave theory, a generalized matrix method (GMM) is used for analyzing the acoustical behavior of various geometries of mufflers. The objective of this paper is to optimize geometrical Parameters like length and diameter of a single expansion chamber with an interconnecting tube for maximum transmission loss.**

***Keywords*: GMM, Interconnecting tube, Muffler.**

1. Introduction

Exhaust noise of IC engine is the major pollutant of the environment and mufflers are fitted to IC engine to reduce the pressure pulses associated with the exhaust gas leaving from the engine. It acts as an element in the flow duct to reduce the sound transmitted along the duct while allowing free flow of the gas through the flow passage. Hindrances provided to counter the transmission of sound are commonly called mufflers or silencers, depending on the context generally; mufflers are classified as dissipative and reflective type. In reflective type, the acoustic energy is reflected back by area discontinuities since it consists of number of tubular elements of different transverse dimensions joint together. While in dissipative type, acoustic energy is dissipated as heat in the absorptive material. Transmission loss (TL) is the important performance parameter of the reactive mufflers. Transmission loss is influenced by the geometrical dimensions of the muffler and the frequency of the sound wave passing through the muffler.

Low frequency noise from the IC engine contributes major part of exhaust noise. Reflective mufflers are most effective in low frequency range and due to area discontinuities it reflects a substantial amount of incident power back to the source due to the mismatch of characteristic impedances When the wavelength λ of sound passing through a muffler is large compared to the transverse dimensions of the tube, the wave motion is nearly one dimensional, i.e. a plane wave. The performance of a reactive muffler is given by the transmission loss of acoustic energy within the muffler. Various methods are there to find out the transmission loss of mufflers having different geometries. Among these, plane wave theory based on analytical method is most commonly used to calculate the transmission loss of single expansion mufflers. This is due to the fact that at low frequency range, the plane.

The GMM is used to analyze the acoustical behaviour of different geometries. The geometric parameters are length of the chamber, diameter of the chamber, length and diameter of the interconnecting tube. Optimized dimensions of the single expansion chamber (Long chamber and short chamber) are to be found out. Dimension of the interconnecting tube is also found out and thus the optimized interconnecting tube is designed and is introduced to an optimized single expansion chamber and the transmission loss is found out.

Fig. 1. Muffler

2. Theory

A. *Plane wave theory*

In the physics of wave propagation, a plane wave (also spelled plane wave) is a constant-frequency wave whose wave fronts (surfaces of constant phase) are infinite parallel planes of constant peak-to-peak amplitude normal to the phase vector. It is not possible in practice to have a true plane wave; only a plane wave of infinite extent will propagate as a plane wave.

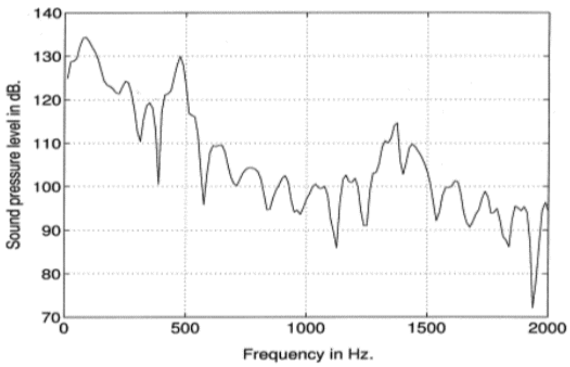

Fig. 2. Noise spectrum of an IC engine exhaust

Low-frequency noise from the IC engines contributes to major exhaust noise. From fig 3.6, it is seen that SPL is higher at low frequencies in an IC engine. Reactive mufflers are commonly used for attenuating noise at low frequencies. For this reason, plane wave theory is used for analyzing reactive mufflers.

B. Matrix approach for single expansion chamber mufflers

A schematic diagram of a single expansion chamber is shown in the fig. below,

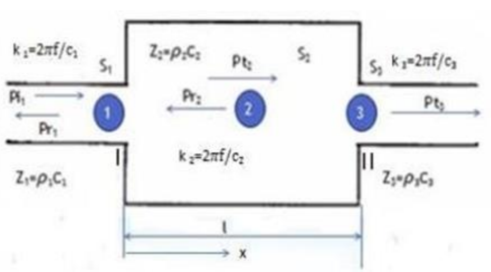

Fig. 3. Single expansion chamber

Let the cross section area of the inlet pipe and the outlet pipe of the expansion chamber are S1 and S3 respectively. Let the cross section area and length of the expansion chamber are S2 and l. The area discontinuities are I & II are as shown in fig 2. For the acoustical analysis used in plane wave assumption, the origin is fixed at section 1, and the positive x direction is shown in fig. 2.

At area discontinuities part of the acoustical energy is reflected back to the source due to the acoustical impedance mismatch, where other part transmitted into the downstream. The outlet pipe is assumed as infinite length or provided with anechoic termination. This assumption is to low reflective wave at the outlet pipe

Let the incident sound pressure wave be

$$(p_i)_1 = A_1 e^{J(\omega(-k_1 x)}$$

At the junction I, where this forward pressure wave is reflected is due to area discontinuity. The reflected pressure wave be,

$$(p_r)_1 = B_1 e^{J(\omega(+k_1 x)}$$

Let the forward pressure wave in the expansion chamber and the reflected wave at the junction II be

$$(p_r)_2 = B_2 e^{J(\omega(+k_2 x)}$$

$$(p_t)_2 = A_2 e^{J(\omega(-k_2 x)}$$

At the outlet S3, the forward wave be

$$(p_t)_3 = A_3 e^{J(\omega(-k_3(x-1))}$$

As the outlet is assumed as anechoic termination, there is no reflective wave.

Now at the junction I between S1 and S2, there is a continuity of a pressure and volume flow. These continuity conditions must also satisfy at the junction II. Using plane wave theory,

At junction I, x=0

$A_1 + B_1 = A_2 + B_2$

Continuity of volume leads to

$S_1(A_1 - B_1) = S_2(A_2 - B_2)$

At the junction II, x = l and since it is steady state, t = 0

$$A_2 e^{-jk_2 l} + B_2 e^{jk_2 l} = A_3$$

And volume equations become

$$\left(A_2 e^{-jk_2 l} - B_2 e^{jk_2 l}\right) S_2 = A_3$$

Transmission loss could be found out if A1 /A3 is known.

Assume the complex pressure amplitude at the anechoic cross section S3 be 1 i.e., A3=1

$$\begin{pmatrix} 1 & 1 & -1 & -1 & 0 \\ S_1 & -S_1 & -S_2 & S_2 & 0 \\ 0 & 0 & e^{-ikl_1} & e^{ikl_1} & -1 \\ 0 & 0 & S_2 e^{-ikl_1} & -S_2 e^{-ikl_1} & -1 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} A_1 \\ B_1 \\ A_2 \\ B_2 \\ A_3 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$$

Take this in simple form as

[M] 1 * [A] 1 = [R] 1

Where [M] 1 is the co-efficient matrix of single expansion type reactive muffler

[A] 1 is the complex pressure amplitude matrix of the single expansion type reactive muffler

[R] 1 is the right hand side matrix of the single expansion type reactive muffler.

Then the pressure amplitude matrix is given by $[A] = [M]^{-1} *$ [R] 1

And Transmission Loss,

$TL = 10\log 10\ (A_1^{\ 2} / A_3^{\ 2})\ 1$

C. GMM for single expansion mufflers with n chambers

Generalized matrix method (GMM) is a numerical approach

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based on plane wave theory and the matrix inverse technique is used for analysis. The analytical results will not allow having different cross-sectional areas at inlet and exhaust of the expansion chamber and the acoustical behaviour of the intermediate sections. But this matrix approach permits to have different areas at inlet and outlet. Main advantages of the GMM are that in GMM, mathematical complications are less and Transmission loss (TL) of complex geometries can be found out. Another major advantage is that, using GMM, acoustical behaviour of mufflers within the chambers can be analyzed without the complexity of the equations.

In general, the governing equation in matrix form for a reactive mufflers having n Expansion chamber is given by

[M]n is the coefficient matrices of the reactive mufflers with n expansion chambers.

[A]n is the complex pressure amplitude of the reactive mufflers with n expansion chambers.

[R]n is the right hand side matrix of the reactive mufflers with n expansion chambers.

By looking the above equations we can generalize this for n chamber as

For [M]n it is of the order (4n+1) x (4n+1)

And [A]n & [R]n as (4n+1) x1

$$\begin{pmatrix} 1 & 1 & -1 & -1 & 0 & - & - & - & 0 \\ S_1 & -S_1 & -S_2 & S_2 & 0 & - & - & - & 0 \\ 0 & 0 & e^{-ikl_1} & e^{ikl_1} & -1 & -1 & 0 & - & 0 \\ 0 & 0 & S_2 e^{-ikl_1} & -S_2 e^{ikl_1} & -S_3 & S_3 & 0 & - & 0 \\ - & - & - & - & - & - & - & - & - \\ - & - & - & - & - & - & - & - & - \\ 0 & 0 & 0 & 0 & - & - & e^{-ikl_{2n-1}} & e^{ikl_{2n-1}} & -1 \\ 0 & 0 & 0 & 0 & - & - & S_{2n} e^{-ikl_{2n-1}} & S_{2n} e^{ikl_{2n-1}} & -S_{2n+1} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

$$\{A\}_n^T = [A_1 B_1 A_2 B_2 A_3 B_3 \text{.......... ....} A_{2n+1}]$$

$$\{R\}_n^T = [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad \text{.......... ....} \quad 1]$$

Then the pressure angle amplitude matrix is given by

$$[A]_n^T = [M]_n^{-1} * [R]_n^T$$

$$\text{Transmission loss, } TL = 10\log_{10}\left({A_1}^2 \big/ {A_{2n+1}}^2 \right)$$

D. Design analysis of single expansion chamber with interconnecting tube

The schematic diagram of a single expansion chamber with interconnecting tube is shown in the figure 4.

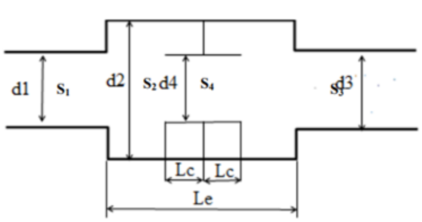

Fig. 4. Single expansion chamber with interconnecting tube

A GMM is developed for a single expansion chamber with interconnecting tube having varying diameters d1, d2, d3 and d4 for analyzing the acoustical behavior.

$$\begin{bmatrix} 1 & 1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & -m1 & m1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & e^{-ik(l_e-l_c)} & e^{ik(l_e-l_c)} & -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & m_2 e^{-ik(l_e-l_c)} & -m_2 e^{ik(l_e-l_c)} & 1-m_2 & m_2-1 & -1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & -1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -e^{2ikl_c} & e^{2ikl_c} & -1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -e^{2ikl_c} & -e^{2ikl_c} & m_2-1 & 1-m_2 & -m_2 & m_2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & -1 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & e^{-ik(l_e-l_c)} & e^{ik(l_e-l_c)} & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_3 e^{-ik(l_e-l_c)} & -m_3 e^{ik(l_e-l_c)} & -1 \\ 0 & 0 & 0 & 0 & -e^{-2ikl_c} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -e^{2ikl_c} & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[A]_1 = [A_1 \quad B_1 \quad A_2 \quad B_2 \quad A_3 \quad B_3 \quad A_4 \quad B_4 \quad A_5 \quad B_5 \quad A_6 \quad B_6 \quad A_7]^T$$

$$[R]_1 = [0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 1]^T$$

$$\text{Here, } m_1 = \frac{S_2}{S_1}, m_2 = \frac{S_2}{S_4}, m_3 = \frac{S_2}{S_3}$$

$$\text{Transmission loss} \quad TL = 10\log 10 \left| \frac{A_1^2}{A_7^2} \right|$$

3. Methodology

From the various studies conducted, it is clear that the wavelength λ of sound passing through a muffler is large compared to the transverse dimensions of the tube, therefore the wave motion is nearly one dimensional, i.e. a plane wave. Therefore, plane wave theory is used for find the attenuating effect of a muffler. Plane wave theory results are also close to the experimental results in low frequency range. Due to the complexity of analytical equations for complicated geometries, a generalized matrix method (GMM) should be used for analyzing the acoustical behavior of various geometries of mufflers.

Two types of single expansion chamber muffler (Long chamber and short chamber) have to be selected for analyzing the effect of TL and sound attenuating capacity. For increasing the transmission loss of the muffler, the geometric parameters should be optimized. The relation of geometry of muffler and transmission loss have to be found out and its sound attenuation capabilities have to analyzed for various dimensions

The optimized single expansion chamber muffler has to be selected for analyzing the effect of TL and sound attenuating capacity using an interconnecting tube in a single expansion chamber both long chamber and short chamber. The relations of geometry of interconnecting tube with transmission loss have to be found out and its sound attenuating capabilities have to be analyzed for various lengths and diameters

After getting these combination values the length and diameter of the interconnecting tube have to be optimized for the maximum possible transmission loss and sound attenuation capabilities using Taguchi method. After optimizing the TL of the muffler with the optimized interconnecting tube have to be found out using GMM and the results should be compared with the TL of the existing single expansion chamber muffler (Long chamber and short chamber) without interconnecting tube.

A. Design

The influence of geometrical parameters such as length and diameter on TL and sound attenuation for a single expansion chamber muffler (Long chamber and short chamber) and interconnecting tube is analyzed.

1) Long chamber

The existing long chamber muffler of 350 cc internal combustion four stroke engine with following specifications is selected.

Inlet pipe diameter (di) =0.05m
Outlet pipe diameter (do) =0.05m
Length is taken =0.7 m
Diameter of the chamber =0.1m

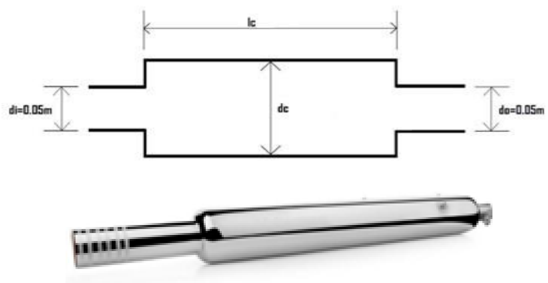

Fig. 5. Long chamber muffler

The GMM results obtained by considering all the parameters are given below,

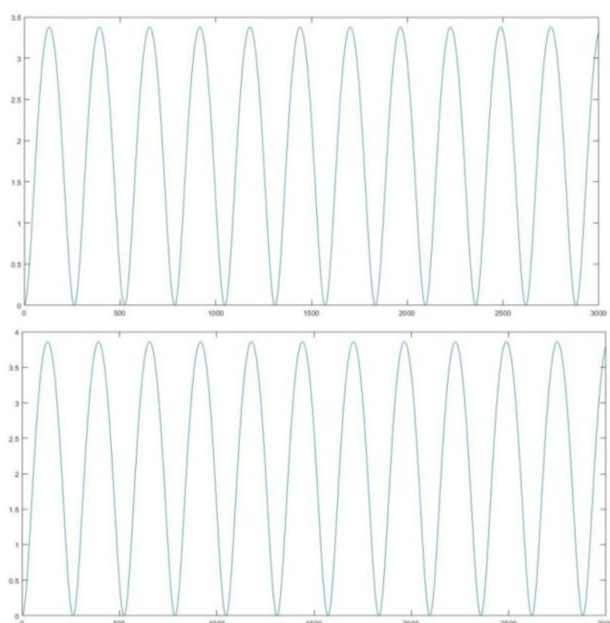

Fig. 6. TL v/s Frequency for long chamber muffler (x axis -frequency (Hz); y axis -TL (dB))

From the obtained results it is found that the increase in the diameter of the expansion chamber also increases the transmission loss. The above graph shows the result analytically

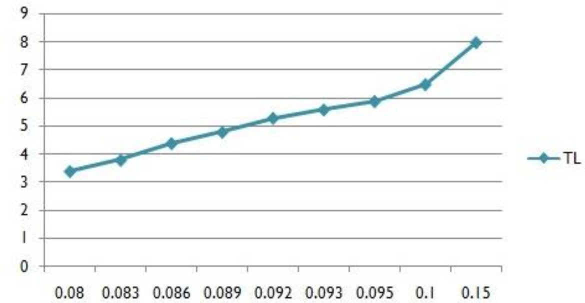

Fig. 7. Transmission loss v/s Diameter graph

From the obtained results it is found that the increase in the length of the expansion chamber also increases the sound attenuation.

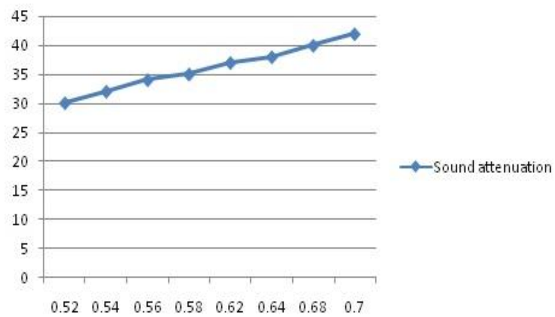

Fig. 8. Sound attenuation v/s length of the long chamber

2) Short chamber

The existing short chamber muffler of 350 cc internal combustion four stroke engine with following specifications is selected.

Inlet pipe diameter (di) =0.05m
Outlet pipe diameter (do) =0.05m
Length is taken =0.4 m

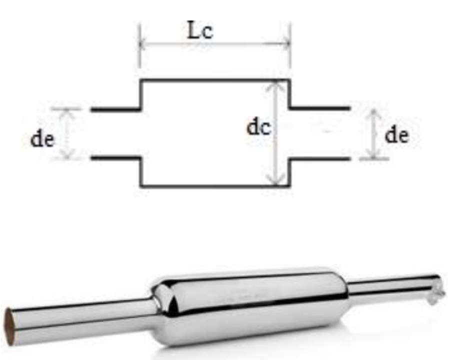

Fig. 9. Short chamber muffler

The GMM results obtained by considering all the parameters are given below,

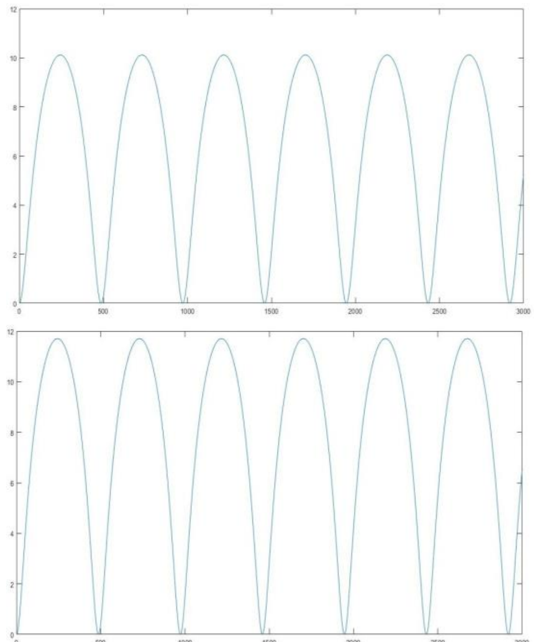

Fig. 10. TL v/s Frequency for short chamber muffler (x axis -frequency (Hz); y axis -TL (dB))

From the obtained results it is found that the increase in the diameter of the expansion chamber also increases the transmission loss

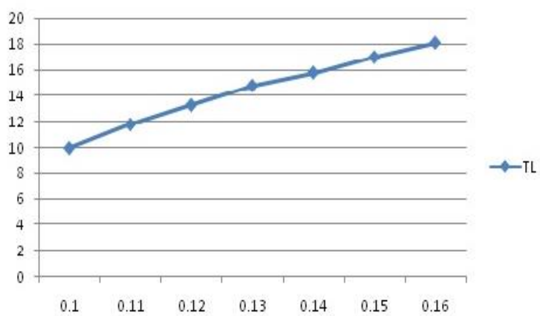

Fig. 11. Variation of transmission loss with diameter

From the obtained results it is found that the increase in the length of the expansion chamber also increases the sound attenuation.

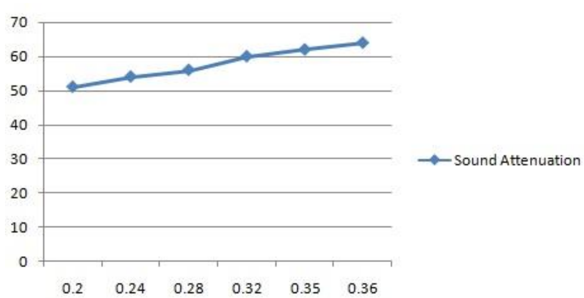

Fig. 12. Sound attenuation V/S length of short chamber

3) Interconnecting tube for long chamber

Fig. 13. Perforated and non-perforated interconnecting tubes

In long chamber muffler the interconnecting tube is designed in such a way that the diameter of the interconnecting tube ranges between 0.02m - 0.07m, that is the diameter of the interconnecting tube should be within these limits and it should not exceed the limit given. Similarly, the limit for the length of the interconnecting tube is taken as 0.1m – 0.6m. The boundary conditions are so given that the interconnecting tube must be designed within the specified limits. Otherwise the interconnecting tube will interfere with the dimensions of the muffler which in turn affects the performance of the muffler and decreases the sound attenuation. The GMM results obtained by considering all these parameters are given below

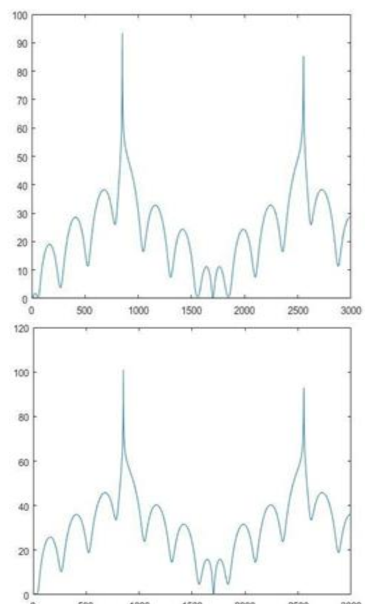

Fig. 14. TL v/s Frequency for long chamber muffler with an interconnecting tube

The GMM results obtained by considering all these parameters are given. The results obtained from the GMM are tabulated to better understand the change in TL and sound attenuation as the length of the interconnecting tube.

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Table 1
TL and sound attenuation capacity for various lengths of the interconnecting tube

S. no.	Diameter of interconnecting tube de(m)	Length of interconnecting tube Le(m)	Transmission loss dB	Sound attenuation (%)
1	0.02	.1	98	15
2	0.03	.2	89	27
3	0.04	.3	97	58
4	0.05	.4	90	69
5	0.06	.5	93	72

From the table 1 the TL decreases with increase in diameter of the interconnecting tube for a long chamber muffler with interconnecting tube. Sound attenuation capacity will increase if the length of the interconnecting tube in a long chamber muffler is increased.

4) Interconnecting tube for short chamber

In the case of short chamber muffler, the dimensions of the chamber should also be taken in account while designing the interconnecting tube. The diameter should be in between 0.02m – 0.1m. Similarly, the limit given for the length is 0.1m – 0.3m. The limits are given in order to make the sound attenuation optimum.

The GMM results obtained by considering all these parameters are given below,

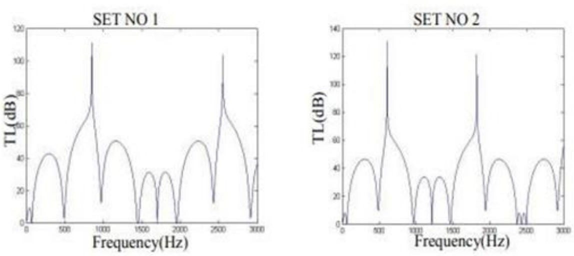

Fig. 15. TL v/s Frequency for short chamber muffler with an interconnecting tube

The results obtained from the GMM are tabulated to better understand the change in TL and sound attenuation

Table 2
TL and sound attenuation capacity for various lengths of the interconnecting tube

S. no.	Diameter of interconnecting tube de(m)	Length of interconnecting tube Le(m)	Transmission loss dB	Sound attenuation (%)
1	0.01	0.1	103	20
2	0.02	0.14	125	25
3	0.08	0.16	116	33
4	0.1	0.17	77	44

The sound attenuation capacity will increase if the length of the interconnecting tube in a short chamber muffler is increased. The TL decreases with increase in diameter of the interconnecting tube for a short chamber muffler.

B. Geometric optimization of long chamber

Different range of values of length and diameter of the long chamber is put into the Taguchi solver and combination values are obtained. The parametric combinations and their transmission losses and sound attenuation capacities are entered to the Taguchi solver for obtaining the most optimized parametric configuration.

Table 3
Combination values of parameters of a long chamber

S. no	Length of the chamber(m)	Diameter of the chamber (m)	Transmission loss (db)	Sound attenuation (%)
1	0.40	0.08	3.4	70
2	0.40	0.085	4.2	72
3	0.40	0.092	5.2	75
4	0.55	0.08	3.4	85
5	0.55	0.085	4.3	87
6	0.55	0.092	5.3	89
7	0.65	0.08	3.45	9
8	0.65	0.085	4.3	93
9	0.65	0.092	5.2	95

When the combination values of geometrical parameters are given in to the Taguchi solver it will give the optimized geometrical parameters.

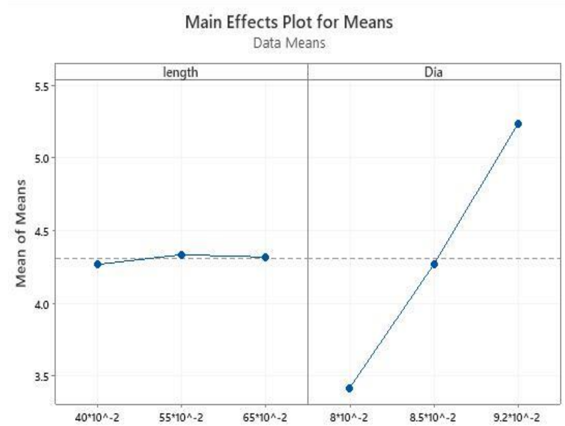

Fig. 16. Transmission loss v/s length and diameter by Taguchi solver

It is clear from the results (fig. 2) obtained from the Taguchi solver that the TL always increase with increase in diameter and thus the optimal diameter to attain max TL is 0.092 and in the case of length there is a fluctuating result and to optimize the length it is need to consider the results on sound attenuation capacity.

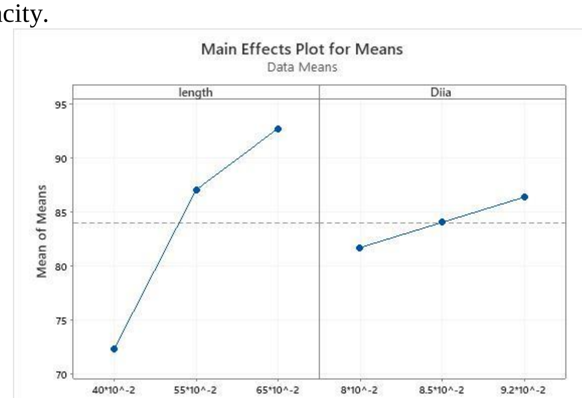

Fig. 17. Sound attenuation v/s length and diameter by Taguchi solver

From Fig. 3 it is clear that the optimal length of the long chamber is found out to be 0.65 m.

From both the graphs (Fig. 2 & Fig. 3) for a long chamber muffler the optimized length of expansion chamber = 0.65m and the optimized diameter of the expansion chamber =0.092 with inlet and outlet diameter = 0.05m.

C. *Geometric optimization of short chamber*

Different range of values of length and diameter of the short chamber is put into the Taguchi solver and combination values are obtained. The parametric combinations and their transmission losses and sound attenuation capacities are entered to the Taguchi solver for obtaining the most optimized parametric configuration.

Table 4
Combination values of parameters of a short chamber

S. no.	Length of the chamber(m)	Diameter of the chamber (m)	Transmission loss dB	Sound attenuation (%)
1	0.20	0.12	9.7	55
2	0.20	0.13	11	48
3	0.20	0.15	13.2	46
4	0.28	0.12	9.7	32
5	0.28	0.13	1.9	53
6	0.28	0.15	13.2	60
7	0.36	0.12	9.5	70
8	0.36	0.13	11	73
9	0.36	0.15	13.5	76

When the combination values of geometrical parameters are given in to the Taguchi solver it will give the optimized geometrical parameters.

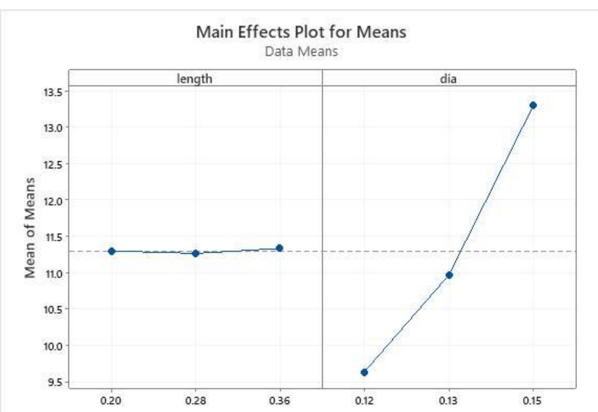

Fig. 18. Transmission loss v/s length and diameter by Taguchi solver

It is clear from the results (Fig. 4) obtained from the Taguchi solver that the TL always increase with increase in diameter and thus the optimal diameter to attain max TL is 0.15m and in the case of length there is a fluctuating result and to optimize the length it is need to consider the results on sound attenuation capacity.

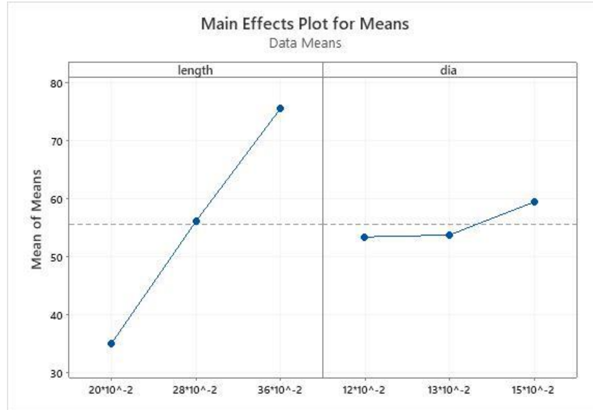

Fig. 19. Sound attenuation v/s length and diameter by Taguchi

From fig 5. it is clear that, the optimal length of the long chamber is found out to be 0.36 m.

From both the graphs (fig. 4 & fig.5) for a short chamber muffler the optimized length of expansion chamber = 0.36m and diameter of the expansion chamber =0.15m.

D. *Geometric optimization of interconnecting tube for long chamber*

Different range of values of length and diameter of the interconnecting tube is put into the Taguchi solver and combination values are obtained. The parametric combinations and their transmission losses and sound attenuation capacities are entered to the Taguchi solver for obtaining the most optimized parametric configuration that helps the existing single expansion chamber muffler without interconnecting tube to attain max TL and sound attenuation without altering its geometrical parameters like inlet, outlet or chamber diameters or their lengths.

In long chamber muffler the interconnecting tube is designed in such a way that the diameter of the interconnecting tube ranges between 0.02m - 0.07m, that is the diameter of the interconnecting tube should be within these limits and it should not exceed the limit given. Similarly, the limit for the length of the interconnecting tube is taken as 0.1m – 0.6m. The boundary conditions are so given that the interconnecting tube must be designed within the specified limits. Otherwise the interconnecting tube will interfere with the dimensions of the muffler which in turn affects the performance of the muffler and decreases the sound attenuation.

Table5
Combination values of parameters

S.no.	Length of interconnecting tube le(m)	Diameter of interconnecting tube de(m)	Transmission loss dB	Sound attenuation (%)
1	0.45	0.018	75	60
2	0.45	0.02	75	65
3	0.45	0.025	76	60
4	0.55	0.018	69	70
5	0.55	0.02	63	72
6	0.55	0.025	62	70
7	0.65	0.018	64	76
8	0.65	0.02	63	74
9	0.65	0.025	621	73

When the combination values of geometrical parameters are given in to the Taguchi solver it will give the optimized geometrical parameters.

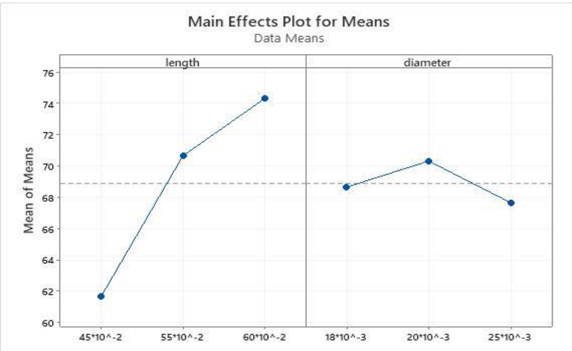

Fig. 20. TL v/s length and diameter by Taguchi solver

It is clear from the results (fig. 6) obtained from the Taguchi solver that the TL always increase with decrease in diameter and thus the optimal diameter to attain max TL is 0.02 m and in the case of length there is a fluctuating result and to optimize the length it is need to consider the results on sound attenuation capacity.

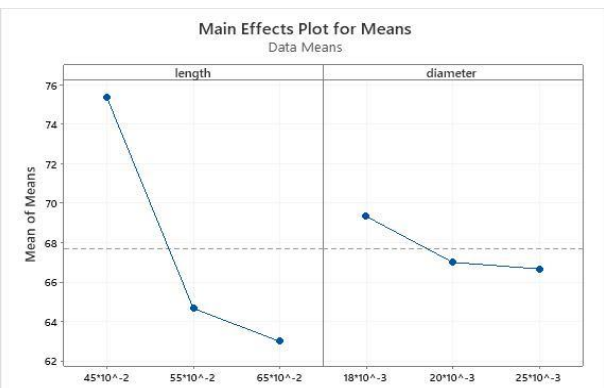

Fig. 21. Sound attenuation v/s length and diameter by Taguchi

From fig. 7 it is clear that, optimal length of the interconnecting tube is found out to be 0.45_m. From both the graphs (fig. 6 & fig. 7) for a single expansion chamber muffler with inlet and outlet diameter = 0.05m, length of expansion chamber = 0.65m and Diameter of expansion chamber = 0.0932m, The Optimal length of the interconnecting tube (lt) = 0.45m and Optimal diameter of the interconnecting tube (dt) = 0.02m.

E. Geometric optimization of interconnecting tube for short chamber

Different range of values of length and diameter of the interconnecting tube is put into the Taguchi solver and combination values are obtained. The parametric combinations and their transmission losses and sound attenuation capacities are entered to the Taguchi solver for obtaining the most optimized parametric configuration that helps the existing single expansion chamber muffler without interconnecting tube to attain max TL and sound attenuation without altering its geometrical parameters like inlet, outlet or chamber diameters or their lengths. In the case of short chamber muffler, the dimensions of the chamber should also be taken in account while designing the interconnecting tube. The diameter should be in between 0.02m – 0.1m. Similarly, the limit given for the length is 0.1m – 0.3m. The limits are given in order to make the sound attenuation optimum. It is observed that as the length of the interconnecting tube is increased within the specified limits the attenuation also increases `desirably which ultimately decreases the sound intensity at the outlet of the chamber.

Table 6
Combination values of parameters of an interconnecting tube

S.no.	Length of interconnecting tube le(m)	Diameter of interconnecting tube de(m)	Transmission loss dB	Sound attenuation (%)
1	0.1	0.018	74	70
2	0.1	0.020	74	72
3	0.1	0.025	73	75
4	0.25	0.018	77	78
5	0.25	0.020	77	78
6	0.25	0.025	78	77
7	0.30	0.018	70	80
8	0.30	0.020	69	82
9	0.30	0.025	69	90

When the combination values of geometrical parameters are given in to the Taguchi solver it will give the optimized geometrical parameters.

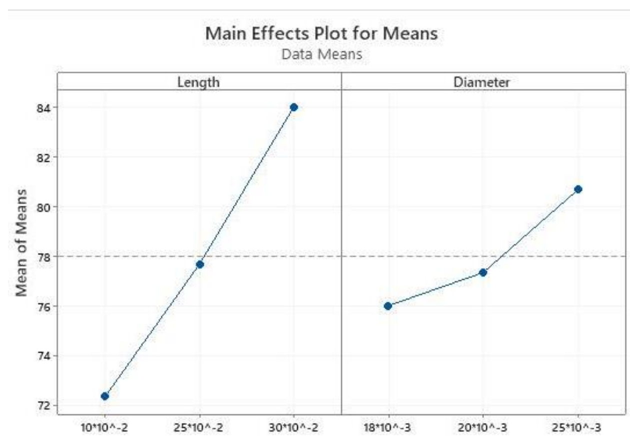

Fig. 22. Transmission loss v/s length and diameter by Taguchi solver

It is clear from the results fig. 8 obtained from the Taguchi solver that the TL always increase with decrease in diameter and thus the optimal diameter to attain max TL is 0.025m and in the case of length there is a fluctuating result and to optimize the length it is need to consider the results on sound attenuation capacity.

From fig. 9 it is clear that optimal length of the interconnecting tube is found out to be 0.25 m. From both the graphs (fig.8 & fig.9) for a single expansion chamber muffler with inlet and outlet diameter = 0.04m, length of expansion chamber=0.35m and Diameter of expansion chamber = 0.16m, The Optimal length of the interconnecting tube (lt) = 0.25m and Optimal diameter of the interconnecting tube (dt) =0.025m.

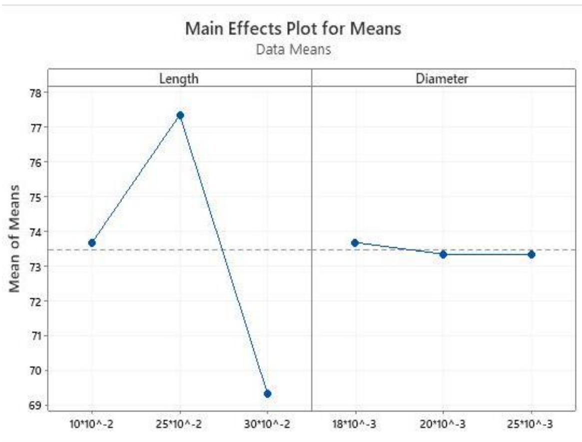

Fig. 23. Sound attenuation v/s length and diameter by Taguchi solver

4. Result and Discussion

The optimized design of single expansion chambers (Long chamber and short chamber) and the optimized interconnecting tube shows a tremendous increase in transmission loss when compared with the existing single expansion chamber mufflers with and without interconnecting tube.

A. Comparison of TL of optimized Long chamber with existing design

The analysis is mainly done on the existing muffler by varying the geometric parameters such as length of the expansion chamber, diameter of the expansion chamber. The transmission loss of the optimized muffler increases as compared to the transmission loss of the existing muffler. The specifications of the optimized design are, the length of the expansion chamber is 0.65m, diameter of the expansion chamber is 0.092 and the diameter of the outlet and inlet pipe is 0.05

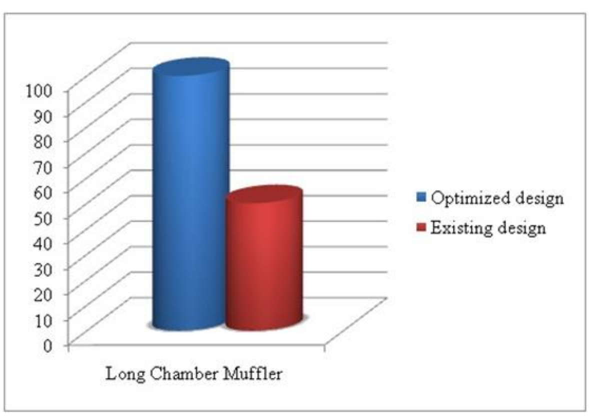

Fig. 24. Comparison of TL of existing with optimized design

The above graph shows the comparison of transmission loss of existing muffler and optimized muffler. High transmission loss is obtained from optimized design. After the analysis is done the transmission loss increase in the optimized model shows that the changes in geometric parameters such as chamber diameter and chamber length will results in increase in transmission loss.

B. Comparison of TL of optimized short chamber with existing design

The analysis is mainly done on the existing muffler by varying the geometric parameters such as length of the expansion chamber and diameter of the expansion chamber. The transmission loss of the optimized muffler increases as compared to the transmission loss of the existing muffler. The specifications of the optimized design are as, the length of the expansion chamber is 0.36m, diameter of the expansion chamber is 0.15m and the diameter of the outlet and inlet pipe is 0.05

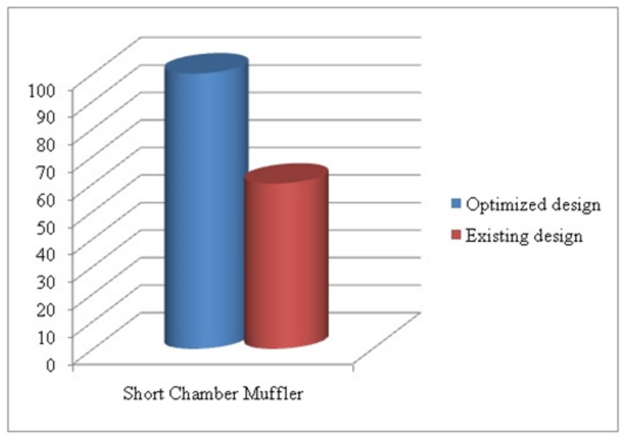

Fig. 25. Comparison of TL of existing with optimized design

The above graph shows the comparison of transmission loss of existing muffler and optimized muffler. High transmission loss is obtained from optimized design. After the analysis is done the transmission loss increase in the optimized *model* shows that the changes in geometric parameters such as chamber diameter and chamber length will results in increase in transmission loss.

C. Comparison of TL of a long chamber muffler with and without interconnecting tube

From the GMM results that the optimized mufflers with interconnecting tube have more transmission loss as well as sound attenuating capabilities than the muffler without interconnecting tube.

The analysis shows that by optimizing the muffler design by the addition of an interconnecting tube, transmission loss increases. i.e., approximately 20 times more TL than an existing long chamber muffler.

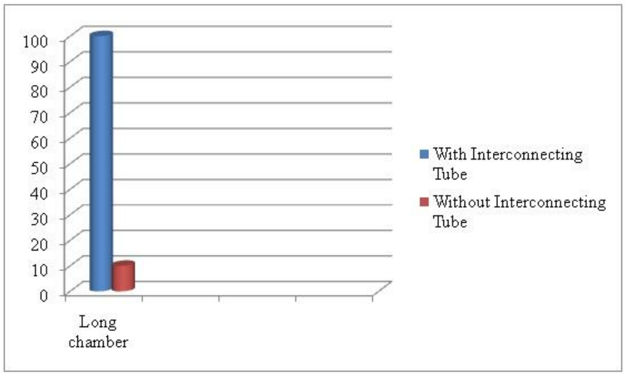

Fig. 26. Comparison of TL of long chamber with and without the interconnecting tube

D. Comparison of TL of a short chamber muffler with and without interconnecting tube

From the GMM results that the optimized mufflers with interconnecting tube have more transmission loss as well as sound attenuating capabilities than the muffler without interconnecting tube.

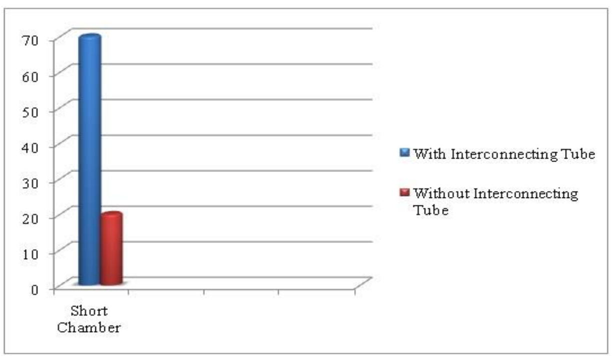

Fig. 27. Comparison of TL of long chamber with and without the interconnecting tube

The analysis results shows that by optimizing the muffler design by the addition of an interconnecting tube, transmission loss increases i.e., approximately 3 times more TL than an existing short chamber muffler. The significant increase of TL in the long chamber muffler must be due to the greater length of the interconnecting Tube when compared with the short chamber muffler. in the case of short chamber muffler the maximum allowable length of The interconnecting tube was 0.3m since the length of expansion chamber was only.0.36mwhereas in the case of the long chamber muffler it was .6m since the length of the Interconnecting tube has a greater effect on the sound attenuation capacity of the muffler, it is Predictable that the long chamber muffler should show a significant increase in transmission loss than the short chamber muffler.

5. Conclusion

The analysis shows that the GMM has a superior role in analyzing the transmission loss of single expansion chamber mufflers using plane wave theory.

The influence of geometrical parameter on mufflers was analyzed. The geometrical parameters such as length of the chamber, diameter of the chamber, length of the interconnecting tube and diameter of interconnecting tube have greater persuade on transmission loss and sound attenuation.

The influence on transmission loss using an interconnecting tube in simple expansion chamber muffler (Long chamber and Short chamber) was analyzed. The geometrical optimization of simple expansion chamber (Long and short chamber) and interconnecting tubes can be effectively done using Taguchi method

From the analysis the optimum diameter of the interconnecting tube has influence in transmission loss and the length favors sound attenuation.

This study confirms that an optimized interconnecting tube have a greater affinity in transmission loss and sound attenuation. It is found that the addition of the optimized interconnecting tube in long chamber muffler increases the transmission loss about 100 dB and in the short chamber muffler about 70db.

The putting in of perforated interconnecting will increase the transmission loss and sound attenuation than a normal interconnecting tube. The optimization of the perforated resonator holes again uplifts the transmission loss and sound attenuation.

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