PREDICTION OF TRANSMISSION LOSS ON A SIMPLE EXPANSION CHAMBER MUFFLER

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Abstract: Over a few decades it is observed that the number of vehicles has increased because of which the level of noise emitted by vehicles is getting worse. Exhaust noise is preferred to be highest than the other structural noise. So, acoustic filters are used for reducing this noise coming from the exhaust system. Simple expansion chamber muffler is one such filters. Transmission loss is the main performance parameter for evaluating the noise reduced by this muffler. In this study a new design of muffler is proposed by optimization, where length and diameter of chamber are considered as the main parameter for optimization. This design is created in CAD software and the acoustic analysis for the muffler is performed through simulation method in ANSYS software. The results obtained from analysis are compared with the work performed by two other authors. From this it is found that the optimized single expansion chamber muffler gives us better acoustic performance value.

Keywords: Simple Expansion chamber, Muffler, Transmission loss, Noise reduction.

1. Introduction

Over the last two decades number of vehicles has increased, due to which the level of noise emitted by vehicles is getting worse. In this exhaust system produces noise almost ten times than that of structural noise. So special attention has been paid on exhaust system by using acoustic filters. Muffler is one such type of acoustic filter which plays an important role in reducing exhaust noise. That's why many researchers have selected muffler as their prime area of interest for research. In general, the inlet pressure and outlet pressure of muffler are taken into consideration because the mufflers performance parameters entirely depend on it. A vast number of simulation methods are available to design and check its performance virtually. In earlier years due to the lack of advancement in computer use and functions there has been limitations for predicting mufflers performance and its properties cannot be aligned with practical results sometimes. But with the invention of more sophisticated simulation software and solvers like Finite Element Method (FEM) and Computational Fluid Dynamics (CFD), it has become easy for predicting this muffler performance with great accuracy [1].

A muffler or silencer is an acoustic filter applied at exhaust system for reducing the emitted noise of an IC engine. In most internal combustion engines, compressors, air conditioning system etc. mufflers are installed within the exhaust system. The muffler is used as an acoustic soundproofing device for the reduction of the noise emitted by the exhaust system by way the way of acoustic quieting. In most internal combustion engines, compressors, air conditioning system etc. mufflers are installed within the exhaust system. The muffler is used as an acoustic soundproofing instrument for the noise reduction at the exhaust system by the way of acoustic quieting [7]. In automotive industry, reactive muffler or dissipative mufflers are normally used and they work at certain frequency spectrum. Reactive mufflers are favorable at low frequency ranges whereas dissipative are favorable for high frequency ranges about 1500-2000 Hz [9]. The science of acoustics of muffler and ducts is over 150 years old. Davis et.al in 1954 had done the first comprehensive experiment on the design and analysis of muffler. Davis et al. used the acoustic transfer matrix method and studied the noise reduction principle of muffler. Experimental verification is also performed and with respect to it muffler research theory is established [2]. In their report they had done experiment on 77 different single chamber and multiple chamber mufflers. From the experiment they have plotted the attenuation to frequency curve and this result were compared to the theoretical results. Later Fukuda et al. had developed the transfer matrix method (TMM) which is ideally suited for acoustical modelling of cascaded element in automotive mufflers [3]. This strategy made the standing wave factors to move starting with one component then onto the next in course. The investigation of this work is performed through transfer matrix method. This method made the standing wave variables to move from one element to the next in cascade. It led to innovation of algebraic algorithm which help in rational synthesis of 1D acoustical filter and vibration isolator [4]. Different researchers have developed different filters with time and one such is the Helmholtz resonator. Munjal studied the Helmholtz resonator and in his work and it was found that Helmholtz resonator introduce a spark peak at its resonance frequency [5]. Sullivan and Crocker modelled a concentric tube resonator and use a 1D control volume approach and later he used a segmentation approach and configured a three interacting ducts [12]. A large research was carried out over the decade and acoustical analysis of complex perforated element and open-end flow reversal element was done. Automobile engine is a variable speed engine and a muffler should act as a low pass filter. Lee worked on hybrid silencers which consists of both dissipative and reactive components. Initially, study is performed on a single expansion chamber. He used the mean flow effect and investigated the acoustic behaviour analytically, computationally and experimentally [9]. A simple expansion chamber consists of a chamber, an inlet and outlet tube. According to Potente (2005), larger expansion ratio gives larger value of transmission loss. According to his study length of chamber should be 1.5 times the diameter of chamber. He also said that size and weight of muffler are also main factors that should be considered while designing the muffler [6].

This study aims in developing an optimized single expansion chamber muffler by comparing it with the work performed by Milad et al. and Lee et al. Length of chamber, diameter of chamber and the inlet/outlet diameter of chamber are considered as the main parameter for study. Initially the work performed by Milad et al. is considered and its acoustic performance parameter are evaluated through simulation method. These results are again compared with the work performed by Lee et al. for simple expansion chamber. Here for both the cases the relation between length of chamber(L) and diameter of chamber(D) i.e L/D ratio is varied from 1.2 to 1.6 and the acoustic performance parameter is evaluated for all the cases. Whereas the relation between diameter of chamber and diameter of inlet tube is kept constant. The results obtained are then considered for proposing a new optimized design of single expansion muffler.

2. Performance Evaluation Parameter: Transmission Loss (TL)

It is used to characterize the acoustic behaviour of a silencer, since it is representative of the silencer itself, neither source or termination impedance is considered[8]. TL is also defined as the ratio of incident and transmitted power (L_{wi} and L_{wout}) of a silencer and it is an assumption of anechoic termination and plane-wave propagation inside upstream and downstream tubes by

$$TL = L_{wi} - L_{wout} = 10log\left|\frac{S_{in}{A_{in}}^2}{2}\frac{2}{S_{out}{A_{out}}^2}\right| \quad (1)$$

Where Sin and Sout are the cross-sectional areas of the inlet and outlet ducts respectively and Ain and Aout are the magnitude of incident and transmitted planer waves. When the inlet and outlet pipe ducts are same then the equation reduce to

$$TL = 20log\left|\frac{A_{in}}{A_{out}}\right| \quad (2)$$

The magnitude of incident and transmitted waves needed can be expressed in terms of reflection coefficients in terms of inlet and outlet surface of the silencer (Ra and Rb) as

$$A_{in} = \frac{p_{m2}}{1+Ra} \quad (3)$$

$$A_{out} = \frac{p_{m2}}{1+Rb} \quad (4)$$

TL is used to access the acoustic performance since it is independent of the input and termination impedance, i.e. representative of the silencer itself.

In case of Simple Expansion Chamber, the transmission loss is calculated as

$$\text{Transmission Loss (TL)} = 10\ \text{Log}_{10}\left[1 + \frac{1}{4}\left(m - \frac{1}{m}\right)^2 sin^2 kL_c\right] \tag{5}$$

L_c is chamber length, D is chamber diameter, d is inlet tube diameter

wave number of sound (k) =2πf/c,

where f is frequency, and c is sonic speed

$$m = \frac{\frac{\pi}{4}D^2}{\frac{\pi}{4}d^2} = \frac{D^2}{d^2} \tag{6}$$

3. Research Methodology

In this study the work performed by Milad et. Al. and Lee et.al. are studied by simulation method and its performance results are compared with a new proposed simple expansion chamber design. The results obtained by simulation method for the new proposed design are validated by mathematical calculation.

4. Results and Discussion

4.1 Simple expansion chamber

Case 1: For proposing the relations, consider the model of Milad et al.as shown on figure 1.

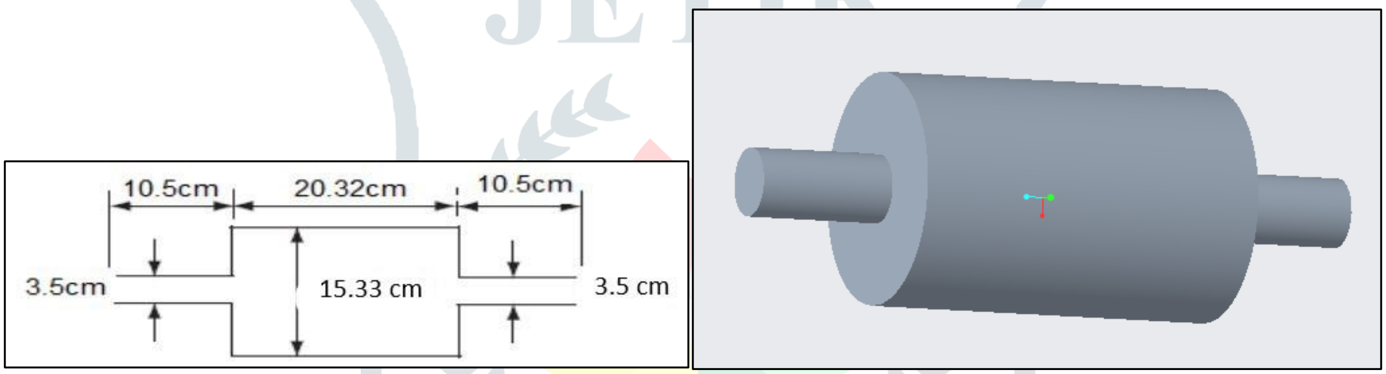

Figure 1 : Simple expansion chamber model of Milad et al.(2017)

From the figure we can say that

Length of expansion chamber = 1.33 x Diameter of expansion chamber

Diameter of expansion chamber = 4.38 x Diameter of inlet/ outlet tube

The experimental work performed by Seybert and Tao [7] for the figure 1 is shown in figure 2.

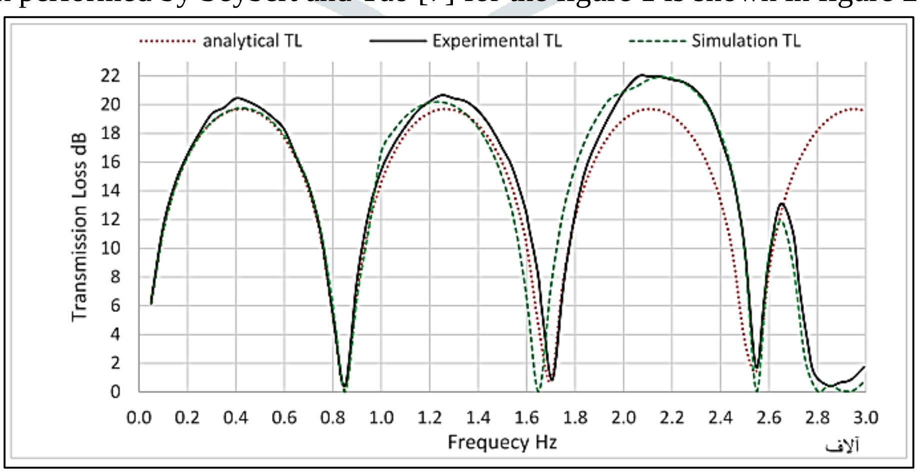

Figure 2: Work performed by Milad et al.

The transmission loss values for the figure 2 is shown in table 1 and the maximum TL is around 22 dB between frequency 2000 Hz – 2150 Hz.

Table 1: Measured experimental data by Seybert and Tao

Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL	Hz	TL
50.0	6.3	450.0	20.2	850.0	0.4	1250.0	20.7	1613.3	11.1	1953.3	19.6	2360.0	19.6	2700.0	11.1
100.0	11.5	500.0	19.6	900.0	7.8	1300.0	20.4	1646.7	8.3	2000.0	20.9	2406.7	17.4	2726.7	7.2
150.0	14.6	550.0	19.1	950.0	12.6	1350.0	20.2	1666.7	5.2	2060.0	22.0	2453.3	14.8	2760.0	3.5
200.0	16.5	600.0	18.3	1000.0	15.4	1400.0	19.6	1706.7	0.9	2106.7	22.0	2500.0	10.0	2786.7	1.3
250.0	18.0	650.0	16.3	1050.0	17.2	1450.0	18.5	1753.3	7.6	2146.7	22.0	2546.7	1.7	2846.7	0.4
300.0	19.3	700.0	14.3	1100.0	18.5	1500.0	17.0	1800.0	12.4	2200.0	21.7	2580.0	6.3	2893.3	0.7
350.0	19.8	750.0	11.1	1150.0	19.6	1540.0	15.7	1846.7	15.7	2253.3	21.5	2600.0	9.1	2940.0	0.9
400.0	20.4	800.0	5.4	1200.0	20.2	1593.3	12.8	1906.7	18.0	2306.7	20.9	2646.7	13.0	2993.3	1.7

The work performed by Milad et al. is now performed in simulation software and the results found are shown in table 2 and figure 3.

Table 2: Transmission loss values from simulation software

Tabular Data

	Frequency [Hz]	Transmission Loss [dB]		Frequency [Hz]	Transmission Loss [dB]		Frequency [Hz]	Transmission Loss [dB]
1	50.	6.133	21	1050.	16.639	41	2050.	21.114
2	100.	11.141	22	1100.	18.1	42	2100.	21.583
3	150.	14.233	23	1150.	19.107	43	2150.	21.781
4	200.	16.314	24	1200.	19.75	44	2200.	21.714
5	250.	17.76	25	1250.	20.077	45	2250.	21.363
6	300.	18.747	26	1300.	20.108	46	2300.	20.685
7	350.	19.369	27	1350.	19.843	47	2350.	19.584
8	400.	19.673	28	1400.	19.259	48	2400.	17.86
9	450.	19.68	29	1450.	18.309	49	2450.	15.042
10	500.	19.389	30	1500.	16.894	50	2500.	9.7298
11	550.	18.78	31	1550.	14.83	51	2550.	0.
12	600.	17.803	32	1600.	11.712	52	2600.	9.3676
13	650.	16.365	33	1650.	6.5014	53	2650.	11.761
14	700.	14.285	34	1700.	7.8078e-003	54	2700.	8.7167
15	750.	11.175	35	1750.	7.2231	55	2750.	2.192
16	800.	6.0921	36	1800.	12.35	56	2800.	1.0074e-002
17	850.	2.8958e-003	37	1850.	15.519	57	2850.	0.38481
18	900.	6.455	38	1900.	17.689	58	2900.	1.3721e-002
19	950.	11.454	39	1950.	19.24	59	2950.	5.3264e-002
20	1000.	14.548	40	2000.	20.35	60	3000.	0.7307

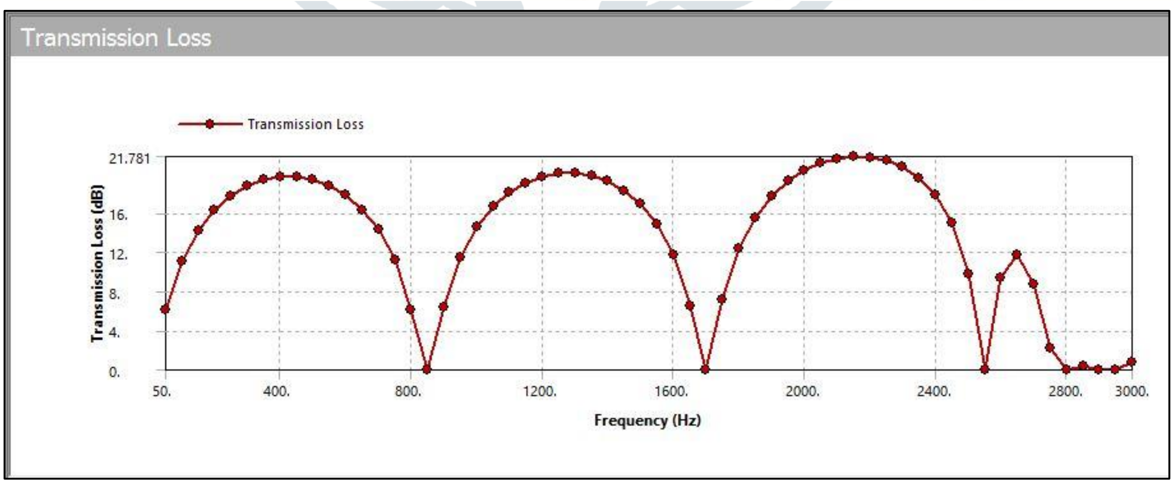

Figure 3 : Transmission loss curve from simulation software for the model of Milad et al.

From the experimental and simulated result, it is found that the TL is almost same at all frequencies and the maximum transmission loss value is about 21.78 dB.

4.2 Dimension Modification: The length and diameter of the chamber are now modified for this model i.e. the work of Milad et al.

Different assumed conditions

Case I: Length of expansion chamber (Lc) = 1.2 x Diameter of expansion chamber (Dc)

Case II: Length of expansion chamber (Lc) = 1.3 x Diameter of expansion chamber (Dc)

Case III: Length of expansion chamber (Lc) = 1.4 x Diameter of expansion chamber (Dc)

Case IV: Length of expansion chamber (Lc)= 1.5 x Diameter of expansion chamber (Dc)

Case V: Length of expansion chamber (Lc)= 1.6 x Diameter of expansion chamber (Dc)

Diameter of inlet or outlet tube (Di) = Diameter of expansion chamber (Dc) / 4.38

The Transmission Loss is now evaluated for all the different cases shown in table 3 and the results obtained are shown in table 4.

Table 3 : Dimension of different models

S. No.			CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
	Dc (cm)	Di(cm)	Lc (cm)	Lc (cm)	Lc (cm)	Lc (cm)	Lc (cm)
1	15	3.42	18	19.5	21	22.5	24
2	15.25	3.48	18.3	19.825	21.35	22.875	24.4
3	15.5	3.54	18.6	20.15	21.7	23.25	24.8
4	15.75	3.60	18.9	20.475	22.05	23.625	25.2
5	16	3.65	19.2	20.8	22.4	24	25.6
6	16.25	3.71	19.5	21.125	22.75	24.375	26
7	16.5	3.77	19.8	21.45	23.1	24.75	26.4
8	16.75	3.82	20.1	21.775	23.45	25.125	26.8
9	17	3.88	20.4	22.1	23.8	25.5	27.2

The transmission loss performance parameter is evaluated for these conditions by using ANSYS.

Table 4 : Transmission Loss for different dimension mufflers evaluated by simulation software

S. No.			CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
	Dc (cm)	Di(cm)	Transmission Loss				
1	15	3.42	47.944	22.051	21.282	21.357	22.584
2	15.25	3.48	58.44	22.029	21.289	21.356	22.562
3	15.5	3.54	41.811	22.055	21.287	21.358	22.439
4	15.75	3.60	37.106	22.046	21.278	21.317	22.457
5	16	3.65	35.185	22.041	21.317	21.261	22.601
6	16.25	3.71	42.483	22.051	21.286	21.35	22.545
7	16.5	3.77	46.474	22.045	21.29	21.353	22.604
8	16.75	3.82	37.55	22.034	21.323	21.311	22.632
9	17	3.88	36.92	22.067	21.288	21.322	22.522

From table 4 it is found that decreasing the L/D ratio to 1.3 gives us high transmission loss value. But further decreasing it will give us drastic change in the acoustic performance value which will affect the efficiency of muffler.

Case 2: Consider the work performed by Lee. The figure 4 is taken from work of Lee.

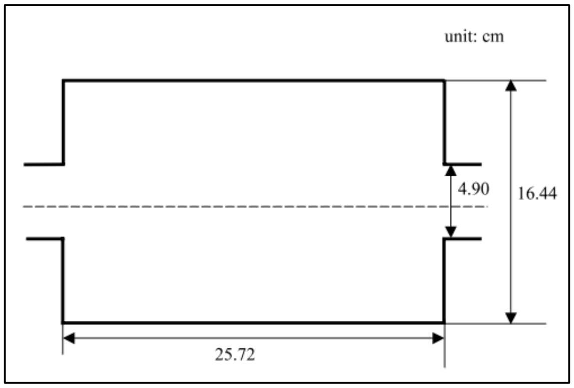

Figure 4: Simple expansion chamber from work done by Lee (2005)

From the figure we can say that
Length of expansion chamber = 1.56 x Diameter of expansion chamber
Diameter of expansion chamber = 3.36 x Diameter of inlet/ outlet tube

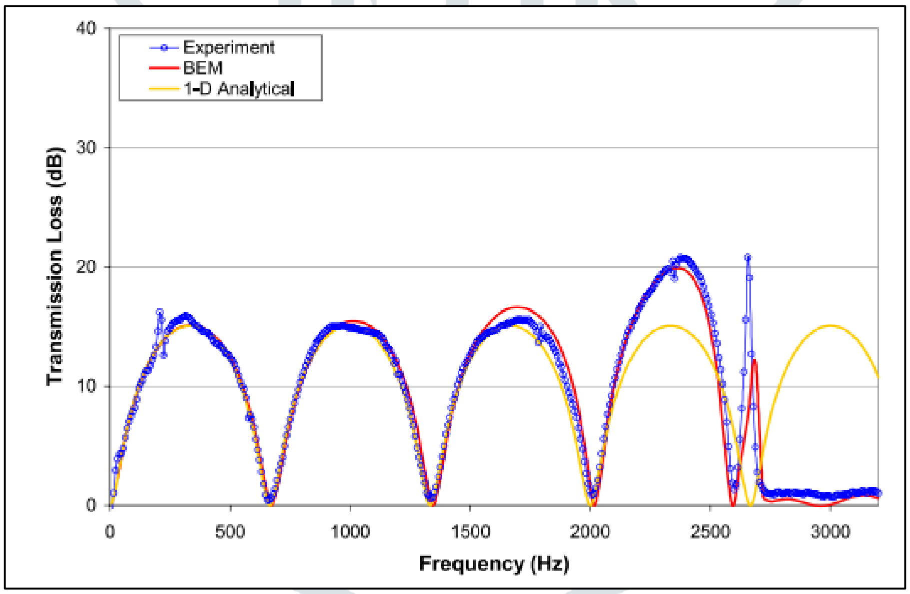

Figure 5 : TL of simple expansion chamber from work done by Lee et. al.

The experimental and analytical work performed by Lee in shown in figure 5.

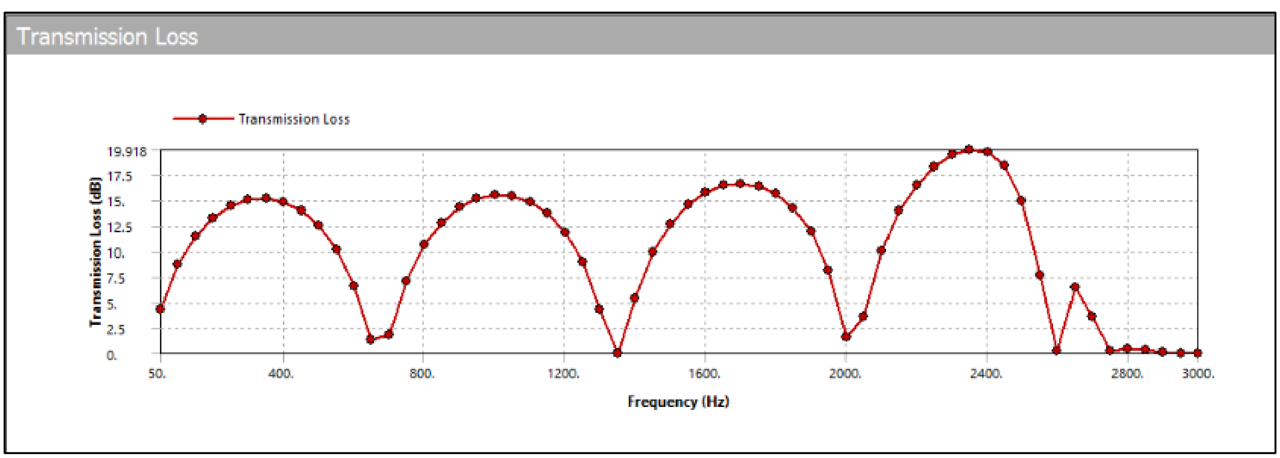

Figure 6 : TL for simple expansion chamber found by simulation software

The work performed by Lee is now performed in ANSYS and result obtained is shown in figure 6. Both the figure shows an equal amount of TL for each frequency and maximum transmission loss value is around 19.92 dB.

Now, Considering the different modified cases of dimension, the transmission loss value is evaluated. Here the relation between diameter of chamber and diameter of inlet tube is changed.

Different assumed conditions

Case I: Length of expansion chamber (Lc) = 1.2 x Diameter of expansion chamber (Dc)

Case II: Length of expansion chamber (Lc) = 1.3 x Diameter of expansion chamber (Dc)

Case III: Length of expansion chamber (Lc) = 1.4 x Diameter of expansion chamber (Dc)

Case IV: Length of expansion chamber (Lc)= 1.5 x Diameter of expansion chamber (Dc)

Case V: Length of expansion chamber (Lc)= 1.6 x Diameter of expansion chamber (Dc)

Diameter of inlet or outlet tube (Di) = Diameter of expansion chamber (Dc) / 3.36

Table 5: New dimension considered variation in inlet tube dimension

S. No.			CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
	Dc (cm)	Di(cm)	Lc (cm)	Lc (cm)	Lc (cm)	Lc (cm)	Lc (cm)
1	15	4.46	18	19.5	21	22.5	24
2	15.5	4.61	18.6	20.15	21.7	23.25	24.8
3	16	4.76	19.2	20.8	22.4	24	25.6
4	16.5	4.91	19.8	21.45	23.1	24.75	26.4
5	17	5.06	20.4	22.1	23.8	25.5	27.2

Table 6 : Transmission Loss for new dimension mufflers evaluated by simulation software.

S. No.			CASE 1	CASE 2	CASE 3	CASE 4	CASE 5
	Dc (cm)	Di(cm)	Transmission Loss				
1	15	4.46	37.7	18.409	17.37	19.058	26.285
2	15.5	4.61	32.372	18.378	17.347	19.073	19.836
3	16	4.76	67.508	18.409	17.391	19.131	19.938
4	16.5	4.91	33.285	18.427	17.403	19.07	19.874
5	17	5.06	61.836	18.412	17.409	19.146	19.954

The above table 6 shows the evaluated result of the cases taken in table 5. It is found that decreasing the L/D ratio to 1.2 gives us drastic change in the acoustic performance value which will affect the efficiency of muffler.

From the two tables i.e. table 4 and table 6 we have observed the transmission loss value for the model considered in Case 1 is higher than that for Case 2 model. Thus, it can be concluded that by varying the L/D ratio the acoustic performance characteristics for Case 1 model is better than case 2 model.

Consider the acoustic performance parameter i.e. transmission loss (TL) for the different designs taken in table 4. It is observed that the variation in TL value is not much by using the relation between length of chamber and diameter of chamber as in case 2 and case 5. Case 1 gives us a high value of TL i.e. the TL values drastically increases in the high frequency range. If we consider a case where the length of chamber is more than that considered in case 5, there the TL value will increase. But we not considering the case above Case 5 as size and weight of muffler is also a factor that should be considered which designing a muffler as said by Polente. Considering the different factors for designing we come a conclusion that Case 2 would be the most appropriate for designing a muffler.

4.3 New Expression

From the different analysis and results shown in table 4 and table 6, below mentioned relations could be considered as the standard relation for designing a simple expansion muffler.

Length of chamber = 1.3 x Diameter of chamber (5)

Diameter of inlet or outlet tube (Di) = Diameter of expansion chamber (Dc) / 4.38 (6)

Equation 5 and equation 6 are considered as the standard relation for designing a muffler.

4.4 New Proposed design for Simple Expansion Chamber

In this study equation 5 and equation 6 is used for designing a simple expansion chamber muffler. The dimension taken are shown in figure 7. The diameter of the chamber, length of chamber and the diameter of the inlet / outlet tube are 15.5 cm, 20.15 cm and 3.54 cm respectively.

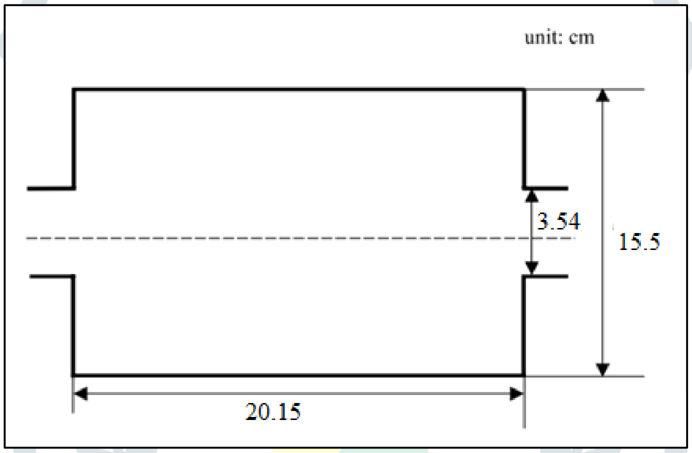

Figure 7: Simple Expansion Chamber

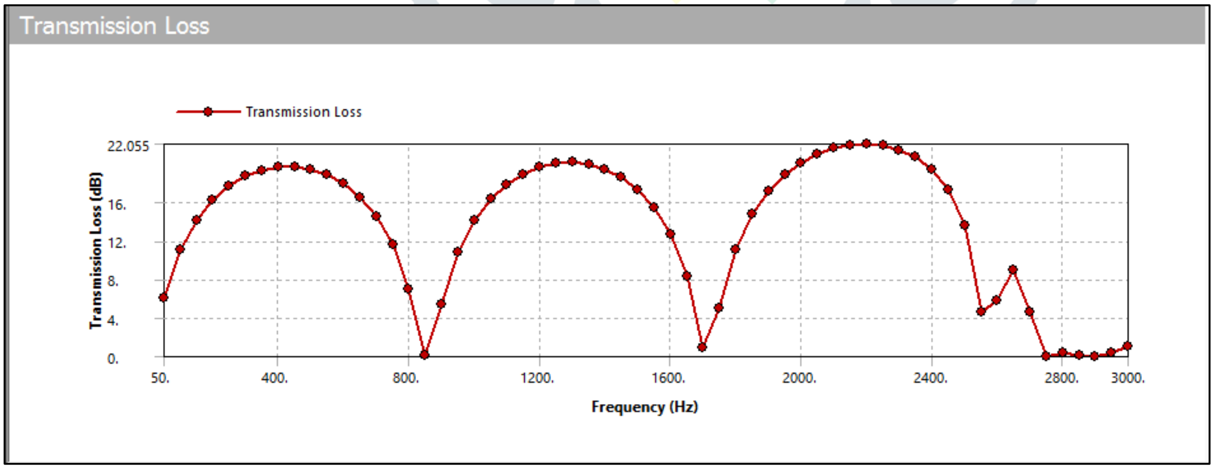

Figure 8: Transmission loss curve for Simple expansion chamber

The predicted transmission loss from the 1D-plane wave simulation approach is shown in figure 8. It shows the maximum transmission loss in the high frequency range and it about 22.06 dB.

Mathematical Calculation

Considering the new proposed design, the performance parameter is evaluated through mathematical formula of muffler. The performance parameter i.e. transmission loss is calculated at two frequencies 400 Hz and 1200 Hz respectively.

$$m = \frac{\frac{\pi}{4}D^2}{\frac{\pi}{4}d^2} = \frac{D^2}{d^2} = \frac{15.5^2}{3.54^2} = 19.17$$

- *At f = 400 Hz,* $k = \frac{2\,\pi\,f}{c} = \frac{2\,\pi\,400}{343} = 7.327$

$$TL = 10\,Log_{10}\left[1 + \frac{1}{4}\left(19.17 - \frac{1}{19.17}\right)^2 sin^2(7.327\ \times 0.2015)\right] = 19.617\,dB$$

- *At f = 1200 Hz,* $k = \frac{2\,\pi\,f}{c} = \frac{2\,\pi\,1200}{343} = 21.982$

$$TL = 10\,Log_{10}\left[1 + \frac{1}{4}\left(19.17 - \frac{1}{19.17}\right)^2 sin^2(21.982 \times 0.2015)\right] = 19.31\,dB$$

From the simulation method and mathematical method, it is found that for the proposed design the transmission loss (TL) value is almost same with respect to the frequencies.

Frequency (Hz)	TL from simulation method (dB)	TL from mathematical method (dB)
400	19.658	19.617
1200	19.657	19.31

5. Conclusion

Considering the transmission loss as the main acoustic performance parameter, acoustic analysis is performed for different cases and it is found that case 1 model performs better than case 2 model. The transmission loss increased by about 8% in case 1. Considering case 1 as the base design the ratio of length and diameter of the chamber is now varied from 1.2 to 1.6. From the study made by different researchers it is found that size and weight are also a factor to be considered while designing and it should be according to the space available for placing the muffler. Thus, the new optimized simple expansion chamber muffler is constructed with L/D ratio of 1.3. This optimized design results in 1.27% and 10% increase in transmission loss as compared to the case 1 and case 2 model respectively. It can be concluded that the optimized simple expansion chamber muffler could also be used as in vehicle for reducing exhaust noise.

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