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Parametric Analysis of Transmission Loss in Expansion Chamber Muffler using Simulation

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Abstract

Transmission loss in a muffler is independent of the source and ideally requires an anechoic termination at one end of the muffler. Hence, measuring the same in a lab setup may not always be feasible. Parameters, designated as handles, are employed to optimize designs of lab-grade expansion chamber mufflers. Parameters such as length and ratio of diameters with extended ports are presented for a set of expansion chamber muffler models.

Keywords: *Analysis, Expansion chamber muffler, Noise attenuation, Simulation, Transmission loss in mufflers*

I. INTRODUCTION

Acoustic muffler is an essential part incorporated in a vehicle to reduce noise pollution due to exhaust. Although coming up with a complete solution is a tedious task, the muffler is one of the devices that serves the purpose of vehicle exhaust noise reduction to a significant extent [*1*, *2*]. A Muffler is a special duct or pipe that impedes the transmission of sound while permitting the free flow of air. Ideally a muffler is expected to have no back pressure, high durability and no maintenance cost [*3*, *4*]. Wu et. al showed that simple expansion chamber muffler without absorbent linings, but with appropriate expansion ratio performs better at lower frequency [*5*]. The importance of optimal volume for certain exhaust duct diameters to minimize the total exhaust time is underlined by Zhao et. al [*6*]. It is already reported that the circular or elliptical cross section gives better noise attenuation [*7*] and so, a parametric study of the effect of change in length, and change in ratio of cross section, over a variety of combinations thereof, is discussed in this paper.

II. II. MUFFLER

One of the passive noise control devices is the reactive muffler [*1*, *2*, *5*, *6*]. It works on the principle of destructive interference. The phase of the reflected wave changes whenever there is either contraction or expansion. Acoustical performance of the reactive muffler is not affected significantly by the presence of flow resistive elements. It must also be noted that the reactive muffler is prone to generate backpressure, decreasing efficiency at times, and increasing fuel consumption [*8*]. Muffler performance or attenuating capability is evaluated mainly by determining transmission loss. Transmission loss (TL) is the acoustic power level difference between the incident and transmitted wave through a muffler [*9*].

A. Expansion Chamber Muffler

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Expansion chamber muffler is the basic muffler in which two tubes of different cross sections are joined together creating an expansion chamber. Expansion of acoustic wave at inlet of expansion chamber and contraction at outlet leads to Transmission Loss [*4*]. Sudden expansion and contraction in the expansion chamber causes sound waves to reflect and interfere destructively with each other. The result of this destructive interference is studied here with the help of three mufflers M-1, M-2 and M-3.

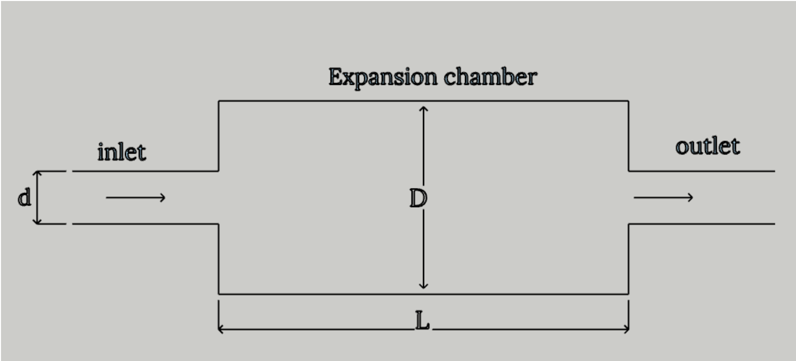

Fig. 1: Simple Expansion Chamber Muffler

Transmission Loss calculations in dB is made using standard formula [*4*]

$$TL = 10\log_{10}\left\{1 + \frac{1}{4}\left(m - \frac{1}{m}\right)^2 \sin^2 kl\right\} \quad (1)$$

where,

TL is Transmission Loss due to the muffler
m = $\frac{D^2}{d^2}$
D^2 = Diameter central chamber
d^2 = Diameter of inlet or outlet pipe
L= length of central chamber, (parameters are as shown in fig.1)
and k is wave number that can be given by $\frac{2\pi f}{c_0}$

The predictable transmission loss curve has a maximum at sin kL=1 hence, frequency corresponding to maximum value of TL is given by

$$f = \frac{(2n+1)c}{4L} \quad (2)$$

where, n=1,3,5,..., c is speed of sound and L is length of the chamber.

Hence,

$$TL = 10*\log_{10}\{1 + \frac{1}{4}(m - \frac{1}{m})^2\} \quad (3)$$

Which, after ignoring exceedingly small terms, gives

$$TL \approx 20*\log_{10}(\frac{m}{2})$$

(4)

III. B. Simulation

The three mufflers available in lab, having fixed cross section and a provision for changing length viz. mufflers M-1 with m= 4.84, M-2 with m=7.248 and M-3 with m=12.52 were studied (tabulated in Table 1). Transmission Loss is calculated and plotted for each muffler using MATLAB (Eqn.1)

Table1. Muffler parameters

Muffler Description	Inlet / outlet Diameter (d) in m	Chamber Diameter(D) in m	$m = \frac{D^2}{d^2}$
M-1	0.050	0.110	4.84
M-2	0.052	0.140	7.248
M-3	0.052	0.184	12.52

The ratio of diameters squared of the chamber to inlet (outlet) *'m'* is changed (maintaining the length *'L'* at 0.6m)

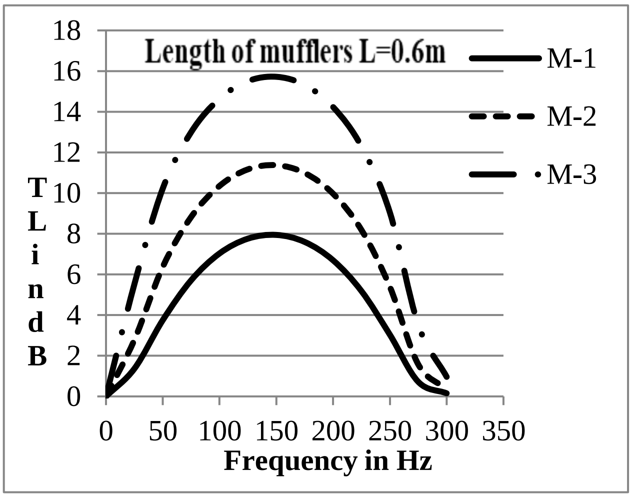

Fig 2. Transmission Loss curves for Mufflers M-1, M-2 and M-3 for a chamber length L=0.6 m.

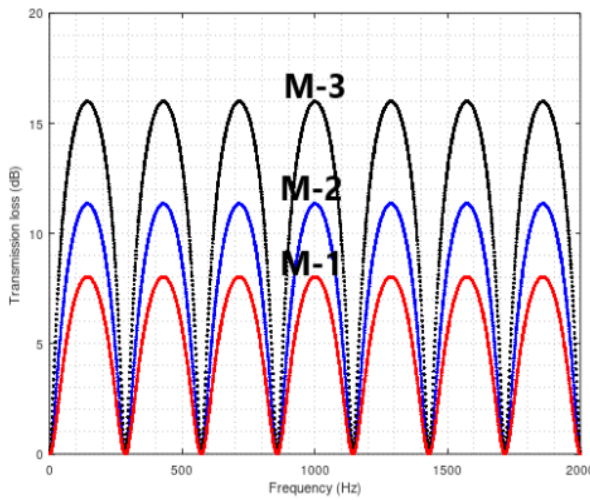

Fig. 3. Transmission Loss curves for Mufflers M-1, M-2 and M-3 for overtones for a chamber length L=0.6m

The Transmission Loss value increases with increase in *'m'* [9] as seen in Fig.2A and Fig 2B. The frequency value corresponding to the maximum values of TL is found to be 150 Hz for first

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harmonics (Fig.2A). Fig.2B shows the overtones of the same waves. The maximum values of TL for each muffler calculated theoretically and by simulation are given in Table 2.

Table2. TL_{max} by calculation and by simulation

Muffler	TL_{max} by simulation dB	TL_{max} using Eqn. 4 dB
M-1 (m= 4.84)	7.94	7.67
M-2 (m=7.248)	11.37	11.18
M-3 (m=12.52)	15.71	15.93

Both the TL values by simulation and by calculation are comparable.

The minima in Fig.2 (B) i.e., TL=0 is at sin kL=0 (ref. Eqn.1) and hence, kL=nπ i.e.,

$$\frac{2\pi f}{c_0}L = n\pi \quad (5)$$

$$f = \frac{nc_0}{2L} \quad (6)$$

Hence, at the frequency values $\frac{c_0}{2L}$, $\frac{c_0}{L}$, $\frac{3c_0}{2L}$, ………. troughs will occur[*4*], and for these frequencies, the muffler will not be of use. To improve the performance of a muffler, troughs are to be uplifted. This is achieved by protruding the inlet and outlet ports within the chamber i.e., using an "extended inlet – extended outlet expansion chamber muffler".

C. Extended inlet – extended outlet expansion chamber muffler

If the inlet and outlet pipes are inserted inside the chamber, then it is called as "extended inlet – extended outlet expansion chamber muffler" where the inlet and outlet tubes are extended into the expansion chamber [*4*], (Fig. 3). The lengths of inlet and outlet ports inside the chamber are so chosen that $l_1=L/2$ *and* $l_2=L/4$. The predicted advantage of this design - part of the chamber between extended pipe and the side wall acts as a "side branch resonator" thereby improving Transmission Loss[*2, 4, 10*].

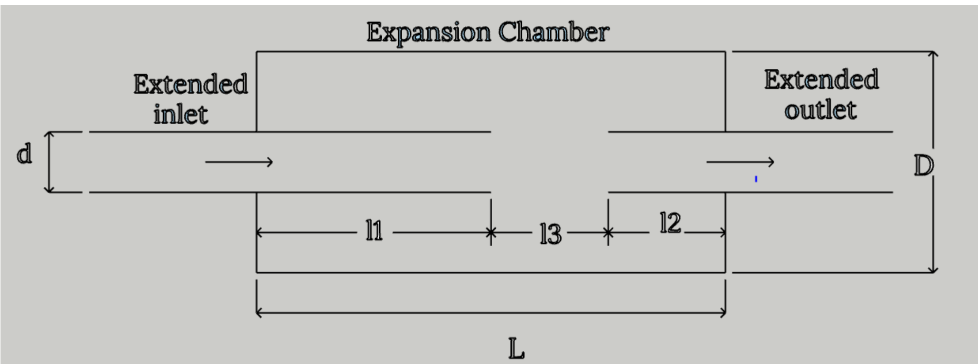

Figure 4. Extended inlet-Extended outlet Expansion Chamber Muffler

Mufflers M-1, M-2 and M-3 are considered separately for different lengths by maintaining the ratio of cross section *'m'* constant. TL curves for different lengths are compared for dependence on length of chamber.

D. Simulation Method/Algorithm:

Step 1. Lab grade muffler M-1 is considered for parametric study of Transmission Loss using MATLAB programming.

Step 2. Length of chamber is chosen *L=0.3m* (ranging from 0.3m to 0.7m in steps of 0.1m)

Step 3. Evaluation of Transmission Loss using transfer matrix method [*10*, *11*]

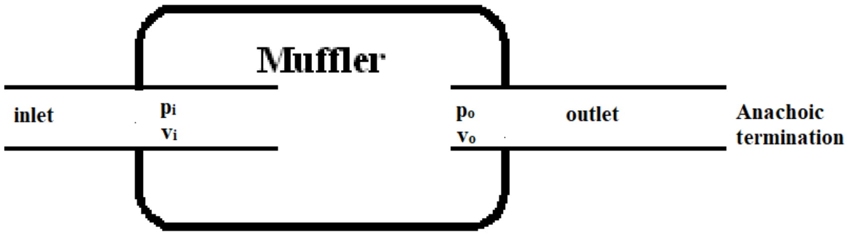

Figure 5. Extended inlet-Extended outlet Expansion Chamber Muffler with points where pressure and velocity is considered

$$\{p_i\ v_i\} = [T_{11}\ T_{12}\ T_{21}\ T_{22}]\{p_o\ v_o\} \quad (7)$$

where,

p_i and v_i are acoustic pressure and mass velocity at entry point of muffler chamber and,

p_o and v_o are acoustic pressure and mass velocity at exit point of muffler chamber as shown in figure 4.

T_{11}, T_{12}, T_{21}, T_{22} are four pole parameters of muffler which is valid only for planar wave propogation

Transmission Loss of muffler is calculated as

$$TL=20 \log_{10} \left[\frac{T_{11}+\left(\frac{S}{c}\right)T_{12}+\left(\frac{c}{S}\right)T_{21}+T_{22}}{2}\right] \quad (8)$$

Step 4. Graph analysis

Step 5. *L= L+ 0.1*; If the length *L* is within range, go to step 3 or else go to step 6.

Step 6. Choose next muffler and repeat from step 2.

The program is executed for M-1, M-2 and M-3 and the graphs are plotted which are given below.

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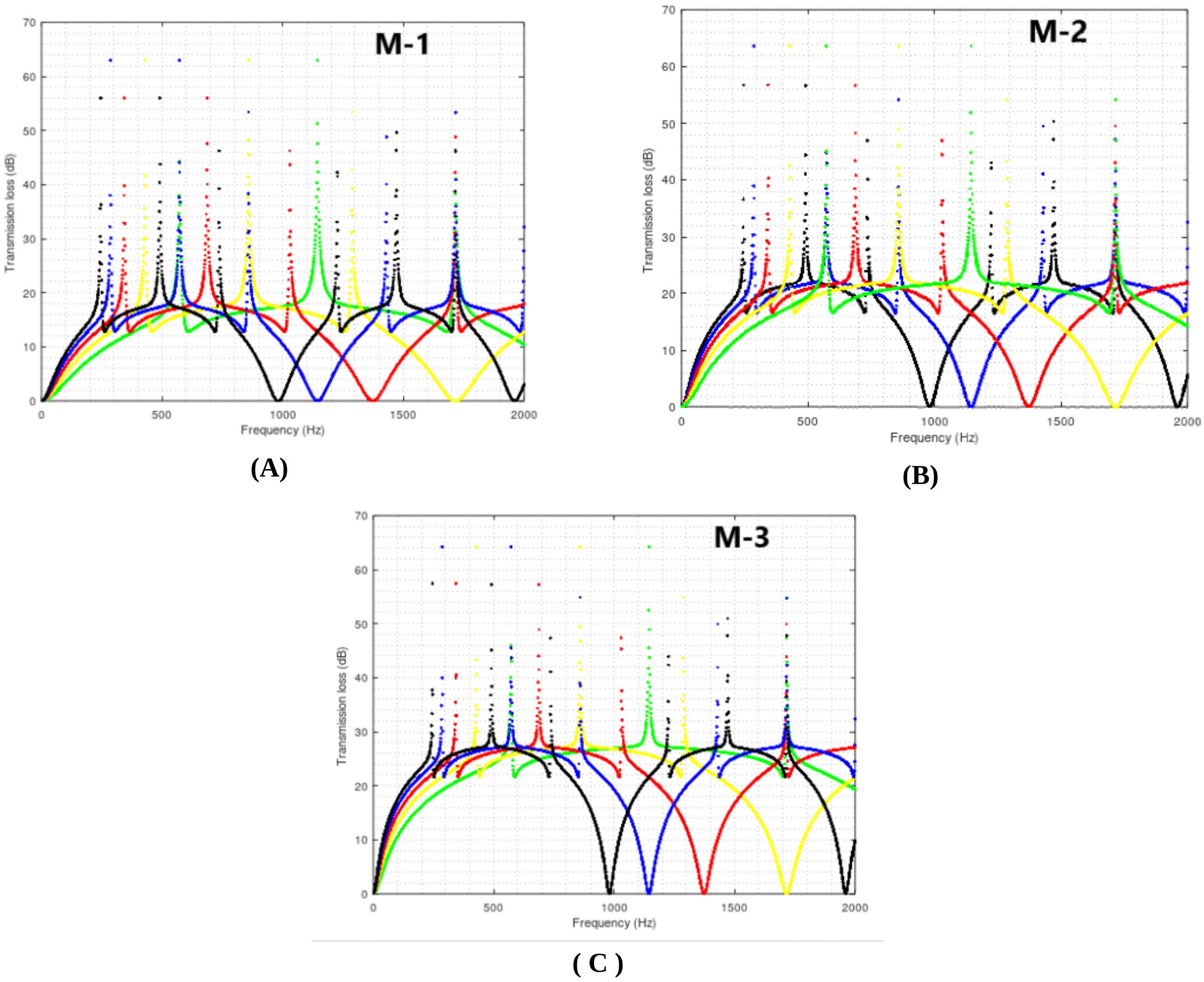

Figure 6. Graph of Transmission Loss versus Frequency for mufflers M-1(A), M-2(B) and M-3(C) for *L*=0.3m (green), 0.4m (yellow), 0.5m (red), 0.6m (blue) and 0.7m (black)

IV.

III. CONCLUSION

The following conclusions can be drawn from the nature of the curves:

1. First, second and third troughs that were observed in case of a regular Expansion Chamber muffler are not same as in extended inlet – extended outlet expansion chamber i.e. at $\frac{c_0}{2L}$, $\frac{c_0}{L}$ and $\frac{3c_0}{2L}$, the troughs are raised to 18.49 dB for M-1, 21.66 dB for M-2 and 27.65 dB for M-3. However, the fourth trough which is occurring at $\frac{2c_0}{L}$ is retained.
2. The nature of the curve repeats fifth trough onwards, and also for all mufflers which shows similarities with the results reported in 'Acoustics of Ducts and Mufflers' [*4*].
3. Value of Transmission Loss is independent of length of chamber, but depends on ratio of the diameters of chamber to the inlet/outlet ports.
4. Resonant frequency changes with change in length of chamber

5. The performance of "extended inlet- extended outlet expansion chamber muffler" is superior than a regular expansion chamber muffler

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