Research Paper Engineering

Acoustic Characterization of Reactive Mufflers by Different Cross Sections Using One-Dimensional Analysis

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ABSTRACT

Mufflers are device which are installed within the exhaust system. It is basically used for noise reduction. Reactive muffler plays an important role as noise control element for reduction of automotive exhaust noise, fan noise, and other noise sources involving the flow of gases. Mufflers are typically arranged along the exhaust pipe as the part of the exhaust system of an internal combustion engine to reduce its noise. The expansion chambers with various cross section like Circular, Elliptical, Square & Rectangular are commonly use for noise attenuation. The degree of attenuation can also be improved with design optimization of inlet pipes, outlet pipes & baffle plates. The present paper aims to concentrate to study the acoustic performance of reactive mufflers with various cross sections by one-dimensional wave approach. Here the result shows to identify the transmission loss characteristics by taking different cross sections of simple expansion chambers by taking consideration of constant volume of expansion chamber.

Keywords: Acoustics, Transmission loss (TL), Reactive Muffler, Wave one-dimensional Analysis.

INTRODUCTION

Reactive Mufflers are commonly used to reduce noise related with internal combustion engine exhausts, high pressure gas or steam vents, compressors and fans. At present the expansion of automobile industries in India are in increasing trend and also the presence of automobiles in on road has been increasing day-by-day. So that noise pollution has become one of the major environmental concerns & human concern in present situation. With increasingly stringent regulations for controlling noise pollution of automotive vehicles, mufflers are important part of engine system and commonly used in exhaust system to minimize noise caused by exhaust gases. Design of muffler is a complex function that affects the noise characteristics and fuel efficiency of the vehicle. Basically a muffler for an automobile is characterized by numerous parameters like Insertion Loss (IL), Transmission Loss (TL). The best used parameter to evaluate the sound radiation characteristics of muffler is transmission loss (TL). This is the one of the most frequently used criteria of muffler performance because it can be predicted very easily from the known physical parameters of the muffler. Many tools are available to simulate the transmission loss characteristics of a muffler. In this paper, a series of various cross section like Circular, Elliptical, Square & Rectangular has been designed according to muffler configurations and all mufflers are simulated by Wave one-dimensional Analysis to predict transmission loss performances.

Mufflers can also be used where it is directly access to the interior of a noise containing enclosure is required, but through which no steady flow of gas is necessarily to be maintained. For example, an acoustically treated entry way between a noisy and a quiet area in a building or factory might be considered as a muffling device. Muffler may function in any one or any combination of three ways: they may suppress the generation of noise; they may attenuate noise already generated; and they may carry or redirect noise away from sensitive areas.

TYPES OF MUFFLERS

Acoustic Mufflers are basically of Reactive muffler and Absorptive muffler, Reactive mufflers & Combination of both the muffler.

- **Reactive Muffler**

It is the arrangement of various pipe segments that is interconnect with a number of larger chambers. The noise reduction mechanism of reactive Muffler is that the area discontinuity provides an impedance mismatch for the sound wave traveling along the pipe. The reflective effect of the Muffler chambers and piping essentially prevents some sound wave elements from being transmitted past the Muffler. The reactive Mufflers are more effective at lower frequencies than at high frequencies, and are most widely used to attenuate the exhaust noise of internal combustion engines. A generic reactive engine Muffler comprised of two proportionally sized chambers with a pair of interconnecting tubes is shown below. [1]

- **Absorptive Muffler**

Absorptive Mufflers contain fibrous or porous sound-absorbing materials like glass wool and attenuate noise by converting the sound energy propagating in the passages into heat caused by friction in the voids between the oscillating gas particles and the fibrous or porous sound-absorbing material.

- **Combination Muffler**

Some of the Mufflers combine with both reactive and absorptive elements to extend the noise attenuation performance over a broader noise spectrum. Combination Mufflers are also widely used to reduce engine exhaust noise.

METHOD OF TL MEASUREMENT

- **Empirical Relation**

The transmission loss increases with the increasing of the ratio of the cross-sectional area of expansion chamber to

both inlet and outlet pipe cross-sectional areas of expansion chamber. The transmission loss of a muffle is given by the following equation (1). [2]

$$TL = 10\,log_{10}[1+\tfrac{1}{4}\left(m-\tfrac{1}{m}\right)^2 sin^2\,kl] \qquad 10\ldots\ldots (1)$$

Equation (1) derived using 1-D wave analysis rather than lumped analysis, so it takes into account the effect of axial modes but it is not valid if cross modes exist in the chamber.

Where;

m: Expansion ratio; cross-sectional area of expansion chamber to cross-sectional area of inlet & outlet pipe.
k: Wave number; 2πf/c
c: velocity of sound
l: Length of expansion chamber; m
TL: Transmission Loss; dB

- **One-Dimensional WAVE Approach**

WAVE is a 1-dimensional gas dynamics code which is based on finite volume method for simulating engine cycle performance. Tools using this one-dimensional approach accurately predict all engine breathing characteristics. This enables engineers to Consider air system and combustion effects during analysis. One-dimensional tools such as WAVE are also predictive in nature in contrast to the representative nature of mean-value engine models. Since WAVE is an engine specific package, it is very likely to be applied in a co-simulation application where correct representation of the engine dynamics can affect the overall representation of the controller or vehicle dynamics. [3]

TYPES OF MUFFLER CROSS SECTION USED FOR 1-D ANALYSIS

Generally four basic types of mufflers are used which is shown in Figure 1. Also one-dimensional Simulation Setup of WAVE is shown in Figure 2.

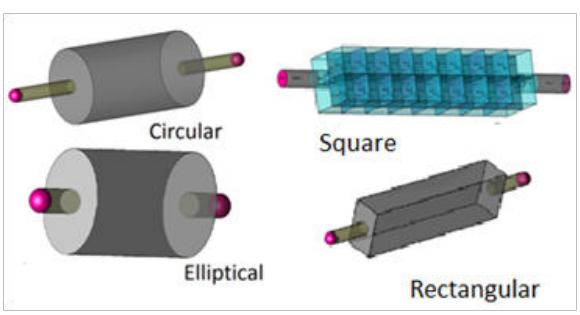


Figure 1: Types of muffler cross section with inlet & outlet point

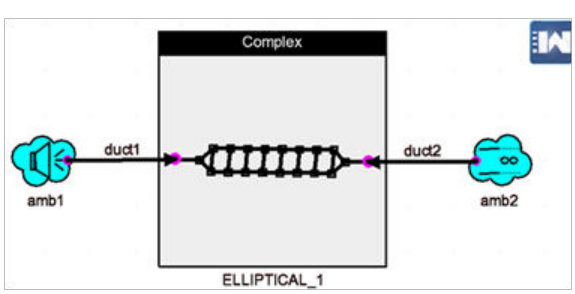


Figure 2: one-dimensional Simulation Setup of WAVE Mufflers dimension with constant volume is shown in Table-1

TABLE – 1 Different Mufflers Dimensions

Types of Muffler Shape having length 400mm	Geometrical Parameter	Approximately same gas volume in mm^3
Circular	Radius= 51 mm	8171
Elliptical	Major & Minor Radius: 65 mm X 40 mm	8168
Square	90 mm X 90 mm	8100
Rectangular	116mm X 70 mm	8120

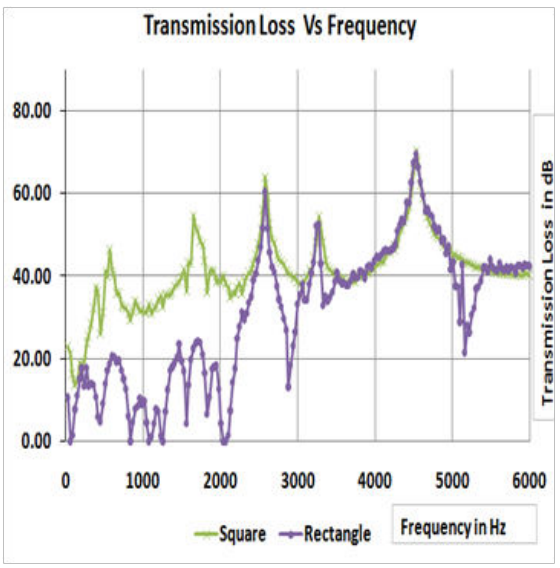


Figure 3: Simulation result for Circular & Elliptical cross section

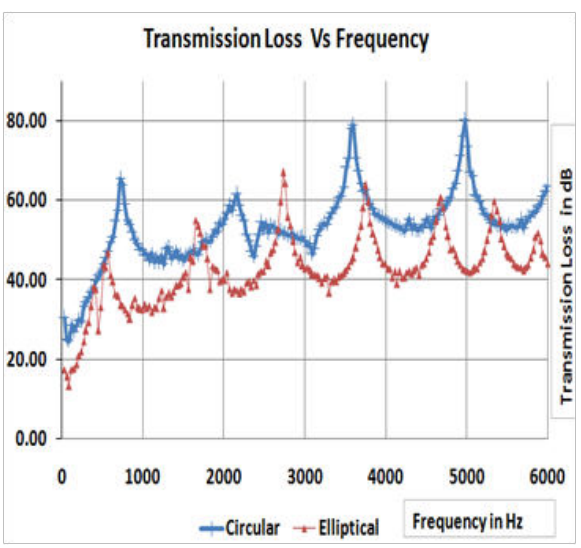


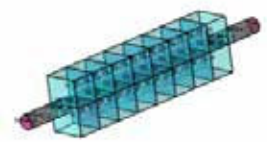
Figure 4: Simulation result for Square & Rectangular cross section

The working fluid was perfect air having following boundary conditions:

1. Gas Volume approximately: 8100 mm^3.
2. Exhaust gas Temperature: 600 K.
3. Exhaust Gas pressure: 1.05 bar.
4. Initial fluid composition: Fresh Air.
5. Upper frequency Limit: 6000 Hz.
6. Lower Frequency Limit: 30 Hz.

Model is prepared on wave build 3D with inlet & outlet boundary condition. Results are shown in table-2.

TABLE – 2 Comparisons of different mufflers

Shape of expansion chamber with same Gas volume	Meshed One-Dimensional Wave Model	Average TL up to frequency 6000 Hz
Circular		53 dB
Elliptical		42 dB
Square		41 dB
Rectangular		31 dB

CONCLUSION

Conclusions by One-dimensional WAVE simulation:

1. The Circular cross section shape of muffler is capable of attenuating the noise up to the range of 25 dB as compare to rectangular cross section shape.
2. Attenuation curve represent clearly that the high transmission loss can achieve by Circular & Elliptical cross section which is good.
3. By comparison the result obtained from the Circular & Elliptical Cross section of muffler noise attenuation is more in case of circular muffler but elliptical one is more in use due to space limitation. This difference however increases uniformly with the ovality parameter of elliptical cross section muffler.

REFERENCES

[1] Barbieri R. & Barbieri N., "Finite element acoustic simulation based shape optimization of a muffler", Applied Acoustics Vol. 67 pp 346-357, (2006). | [2] David A., "Engineering Noise Control Theory and practice Fourth edition" spon press (2009). | [3] Joseph G. and Scott R. Anderson "Creating the virtual vehicle model today", Ricardo, Inc.