Development of Shape of Helmholtz Resonator Cavity for Attenuation of Low Frequency Noise of Pure Reactive Muffler

Amit Kumar Gupta[1], Nirmal Gupta[2]

[1]Assistant Professor, [2]M.E. Scholar
Mechanical Engineering Department
IET-Devi Ahilya University, Indore

***ABSTRACT*: The cut off frequency and the transmission loss measurement with different shape of Helmholtz resonator is observed with muffler is thoroughly investigate in this research work to attenuate low frequency noise by using wave 1-D. A reactive muffler is important noise control element for reduction of exhaust noise. Mufflers are arranged along the exhaust pipe as the part of the exhaust system of an IC engine to reduce its noise. But the attenuation of low frequency noise in muffler is not effective; therefore a cavity called Helmholtz Resonator is attached at the inlet of muffler which is capable to attenuate particularly low frequency noise coming from exhaust. Helmholtz resonators are often used to have control steady, simple harmonic sound field that have tonal, narrow band spectrum. For the high tuned Helmholtz resonators, it is found frequency shifted to a lower resonance frequency in combination with reduced quality factor. Quantification results of transmission loss measurement by using 1-DOF Helmholtz resonator shows the good agreement with the numerical results. It can measure the performance of Muffler's Transmission loss. The resonator attenuates the noise level at low frequency zone and also increases average transmission loss. This study is concentrated on the modeling of Helmholtz type resonator with along with different cavity shape like cylindrical, conical and Spherical of a fixed volume for attenuation of first cut-off frequency found in muffler. This attempt gives the proper geometry selection approach for further study. Finite element analysis tools comsol multiphysics and wave 1-D and 3-D module used to validate the results. The results show interesting fact that resonator not only attenuate a particular low frequency noise on muffler and also increases transmission loss which is very effective.**

***Keywords:* Helmholtz resonator, FEA Acoustic Module- wave 1-D, Sound Transmission loss, Reactive Muffler**

1. INTRODUCTION

In recent past year the demand of automobile increases rapidly. A muffler for an automobile is specified by various measurement parameters like Insertion Loss, Transmission Loss. The best used parameter to evaluate the sound radiation characteristics of muffler is Transmission loss [1][2].Transmission Loss is defined as difference between power incident on muffler proper and that transmitted downstream into an anechoic termination. It is independent of source and presumes an anechoic termination at tail pipe. It describes the performance of a muffler. Reactive and dissipative type of muffler are mainly used for noise attenuation as dissipative muffler have absorbing material to take energy out of the acoustic motion in the wave, as it propagates through the muffler [2][12]. Noise levels of more than 80 dB are injurious for human beings. It described that the transmission losses can be determined reliably with the test rig setup. Many tools are available to simulate the transmission loss characteristics of a muffler [4][13]. A Helmholtz resonator exposed to grazing flow with a specific speed can produce strong flow fluctuations. These oscillations can generate desired or undesired pressure fluctuations within the flow over the resonator opening. Example of this process, such as gas fluctuation inside pipelines with closed side branches, the grazing flow over aircraft landing gear, and cabin pressure fluctuation inside a vehicle. A Helmholtz resonator is an alternative type of side branch resonator for suppressing pure tones of constant frequency, which consists of a short neck which is connected to large cavity with fixed volume of compressible fluid [5][10]. Resonator is having a significant effect on the transmission loss inside an air intake system and increases in transmission loss will reduce the overall sound pressure level. Also as observed resonator is playing a vital role in sound pressure reduction but it should be designed for the desired frequency only. Volume, neck length and neck diameter of resonator can be tuned for the optimized results [6]. There are different ways to reduce the sound pressure level of an air intake system but simple way is to provide a resonator for increasing the transmission loss in an air filter box [7].Experimentally Two-load method is commonly used to predict the transmission loss of an Acoustic muffler. Finite Element Method is also used to show the comparative study of Transmission Loss of Muffler [8],[9]. In this paper, muffler is simulated by Finite Element Analysis tool, wave 1-D which is used to predict muffler's transmission loss performances. Then, various shaped resonators have modeled and simulation has been carried out by wave 1-D module and comsol multiphysics. Quantification results of transmission loss measurement by using Helmholtz resonator shows the good agreement with the numerical results.

2. OBJECTIVES AND MODELLING

For the evaluation of low frequency noise, a resonator is attached to a reactive muffler. The Helmholtz resonator is behaving as cavity which attenuates low frequency noise by keeping the cavity and neck volume as constant. In this paper some of the cavity shape has been adopted for evaluating maximum transmission loss for the first cut-off frequency observed during flow of noise through pure muffler. A cylindrical, conical and spherical shape of resonator cavity has been developed for the 340 Hz frequency noise. Following design condition are adopted for modeling of Helmholtz resonator [3].

1. Test muffler: length of chamber as 500 mm with diameter 130 mm.
2. Keeping volume of muffler constant for a given length.
3. The volume of Helmholtz resonator calculated based on first cut-off frequency keeping other parameter constant.
4. Create geometry of resonator of different of shape like cylinder, conical and spherical with constant volume.
5. Validation of result with existing one for maximum transmission loss measurement.

3. Modeling and Simulation of Muffler by Using Comsol

A pure reactive muffler is modeled by using wave 1D module and also validated by Ansys and Comsol Multiphysics. Muffler consist of three main part namely Inlet section, Expansion chamber and Outlet section. The inlet and outlet section has same dimension as 35 mm diameter and length of section as 110 mm. The expansion chamber has a diameter of 130 mm and length as 500 mm. This geometry created by wave 1D module is further investigated by cavity view and whole work as a single part. This will help to mesh the geometry for considering gas volume. As the expansion chamber is large enough which required a fine meshing tool for meshing. There are two type tetrahedral and triangular meshing is always carried out for good result. After complete meshing of muffler, simulation has done by applying noise source like acoustic piston which is connected to inlet of muffler and the anionic termination is attached to outlet of muffler. Some of the boundary condition are taken as constant as they are not variant with the frequency source.

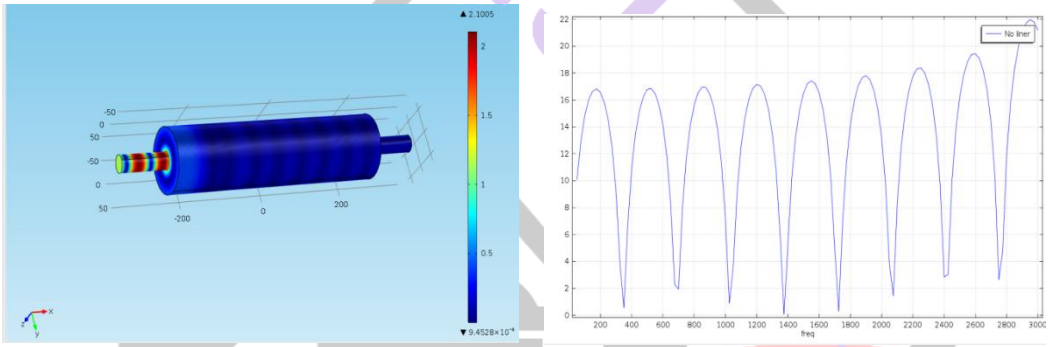

Fig. 1: Schematic of Basic Muffler Model and TL Curve by using Comsol [3].

4. POST PROCESSING BY USING WAVE 1-D AND COMSOL

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. A. F. Seybert model is used to compare the wave result. The working fluid was perfect air having following boundary conditions [3,5]:

1. Gas Volume approximately: 447613.6823 mm^3.
2. Exhaust gas Temperature: 300 K.
3. Exhaust Gas pressure: 1.0 bar.
4. Initial fluid composition: Fresh Air.
5. Upper frequency Limit: 1000 Hz.
6. Lower

Frequency Limit: 1 Hz.

Model is prepared on wave build 3D with inlet & outlet boundary condition shown in figure 2.

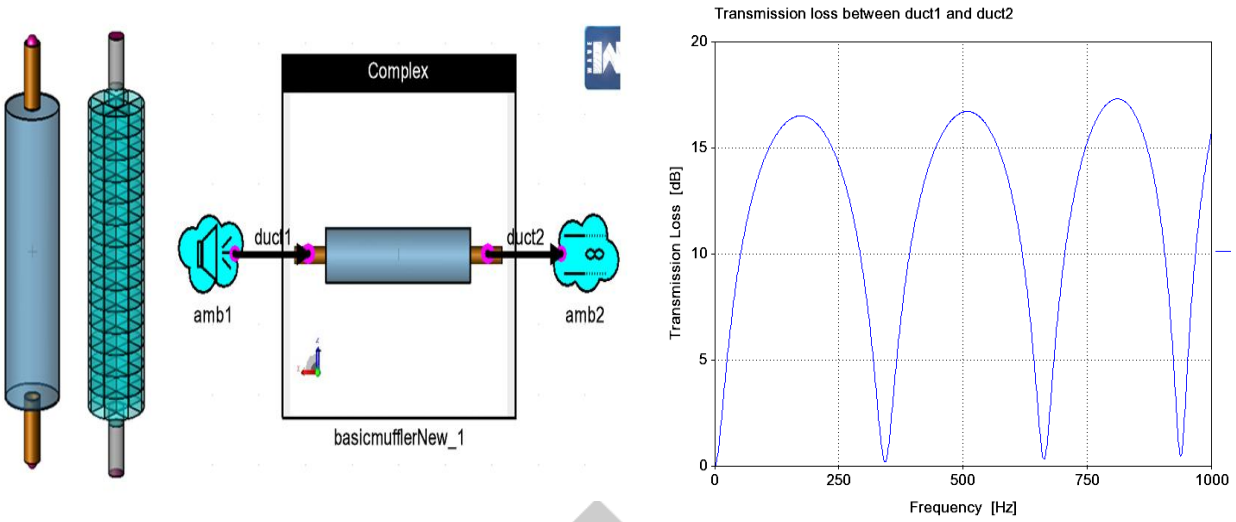

Fig. 2: Muffler Post Processing by Wave 1-D.

5. MODELLING AND CALCULATION OF HELMHOLTZ RESONATOR VOLUME

In the case of cylindrical (circular cross section) expansion chambers, the dimensions of chambers are taken in such a way to observe complete wave propagation phenomenon. The length to diameter ratio was also so chosen that one dimensional calculation becomes easier for a sufficiently frequency range in Table 1. The first cut off frequency is shown in transmission loss curve. The formula for cut off frequency is given by $f = \frac{C}{2L}$ [5].To obtains the volume of resonator put the cut off frequency which is observed as 340 Hz shown in figure 1. Formula used to calculated volume of Helmholtz resonator

$$f_r = \frac{C}{2\pi}\sqrt{\frac{S_b}{L*V}} \qquad \text{..... (eq. 1)}$$

C= Velocity of sound approx. 340m/s, S_b = Neck area, by taking neck diameter d = 45 mm.

L= Length of neck. Assume 90 mm, V= Volume of resonator = $V_{resonator} = \frac{\pi}{4} * D^2 * L$ ..... (eq. 2)

Where the D is the diameter of Helmholtz resonator,

From equation 1 and 2, we get

$$340 = \frac{340}{2\pi}\sqrt{\frac{\pi/_4 * (0.045)^2}{(0.090) * (\pi/_4 * D^2 * 0.125)}}$$

With the calculation, Diameter of cavity (D) = 67.523 mm

6. MODELING OF HELMHOLTZ RESONATOR OF FIXED CAVITY VOLUME

A. Cylindrical Resonator: Two concentric tube of different diameter is coupled, smaller one is called neck and bigger one is called cavity of the resonator. By keeping length of cavity constant as 125 mm, the volume of cavity has measured by measuring diameter as 67.523mm gives 447613.6832 mm^3. In this resonator L/D ratio of neck and cavity is taken as 2 and 1.85 respectively. By the simulation on wave 1D module the first cut-off frequency has attenuate in a very great amount gives the maximum transmission loss for a particularly 340 Hz frequency noise is around 53 dB which is almost negligible in muffler attenuation alone.

Dimensions
Length of cavity = 125 mm
Diameter of cavity = 67.523 mm
Length of neck = 90 mm
Diameter of neck = 45 mm
Diameter of duct = 35 mm

Volume of resonator=447613.6823 mm^3

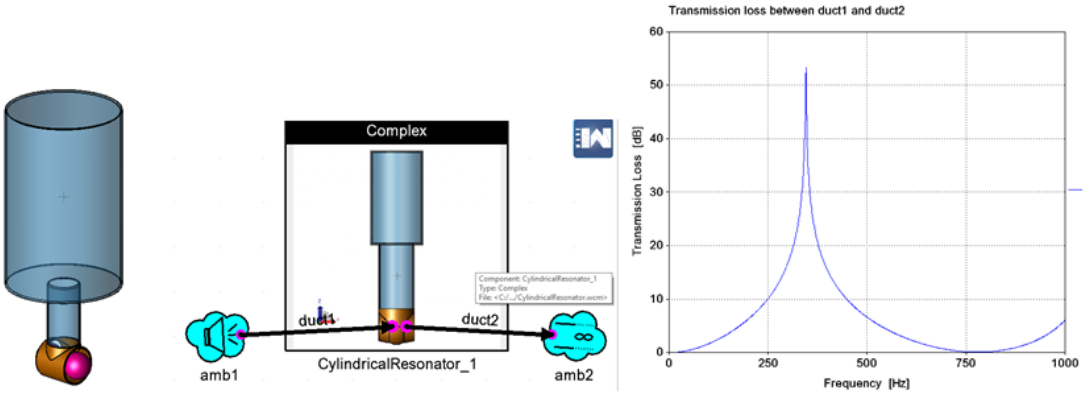

Fig. 3: Modeling and Transmission Loss of Cylindrical Type Helmholtz Resonator

B. Conical Resonator: A conical shape resonator is also called taper cylinder is model by using below dimension. By keeping volume of resonator cavity constant as 447612.19 mm^3, the top and bottom radius of cavity has changed and measured value give the attenuation of noise. In this resonator L/D ratio of neck is taken as 2. By the simulation on wave 1D module the first cut-off frequency is changed and also increases with the increase in transmission loss. As the transmission loss increases up to 57 dB but cut-off frequency is also increased as 400 Hz.

Dimensions
Length of cavity = 125 mm
Top radius = 20.4191 mm
Bottom radius = 45.4730 mm
Length of neck = 90 mm
Diameter of neck = 45 mm
Diameter of duct = 35 mm
Volume of resonator =447612.19 mm^3

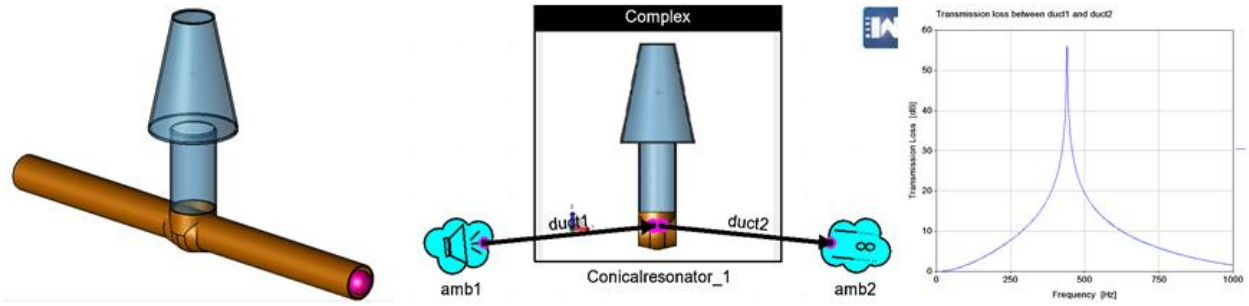

Fig. 4Modeling and Transmission Loss of Conical Type Helmholtz Resonator

C. Spherical Resonator: Attenuation of spherical resonator is purely in a linear way and result shows that the increse in frequency increases transmission loss and give the varient sound transmission.

Dimensions
Radius of cavity = 47.61545 mm
Bottom cut face radius = 22.5 mm
Length of neck = 90 mm

Diameter of neck = 45 mm

Diameter of duct = 35 mm
Volume of resonator =447613.24 mm^3

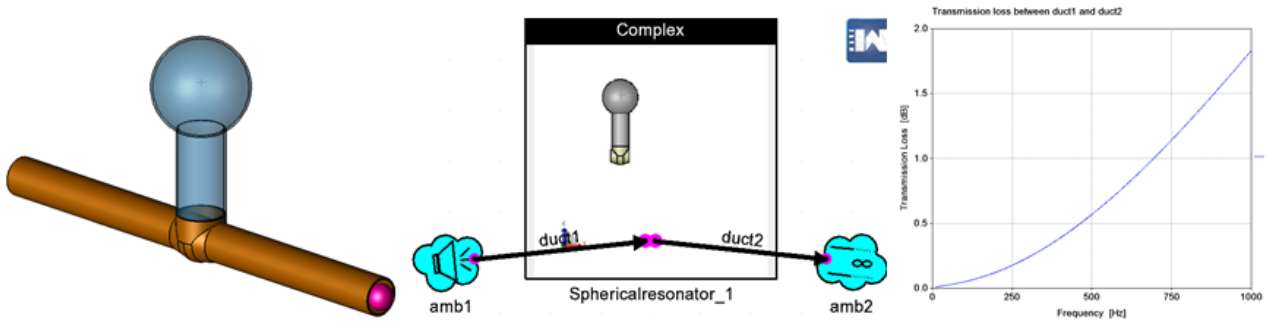

Fig. 5: Modeling and Transmission Loss of Spherical Type Helmholtz Resonator

7. RESULTS AND DISCUSSION

This research work shows that the results of Transmission loss of various resonators which are verified by experimental method as well with simulation CFD tool. The experimental results show good agreement with the numerical results. From this result it can be concluded that the development of cylindrical resonator is best suited for the attenuation of first cut-off frequency as it increase the transmission loss at very much extent so there is no need of modification of expansion chamber. This can also measure the performance of Muffler's Transmission loss. The transmission loss is evaluated in the two cases with simple reactive muffler without resonator and with resonator, muffler having same gas volume in both the cases. The result shows that the Transmission Loss attenuated with first cut off frequency of 340 Hz as shown in figure 7 by using Helmholtz resonator. It attenuates the TL up to 53 dBfor cylindrical resonator at first cut off frequency. For conical resonator the transmission loss measured 58 dB but it changes the first cut-off frequency. Also figure 6 shows that the resonator attenuates the noise level at low frequency zone. The avg. transmission loss is increased up to 4.47 dB by applying cylindrical type Helmholtz resonator. Spherical resonator is not capable to attenuate noise with same volume.

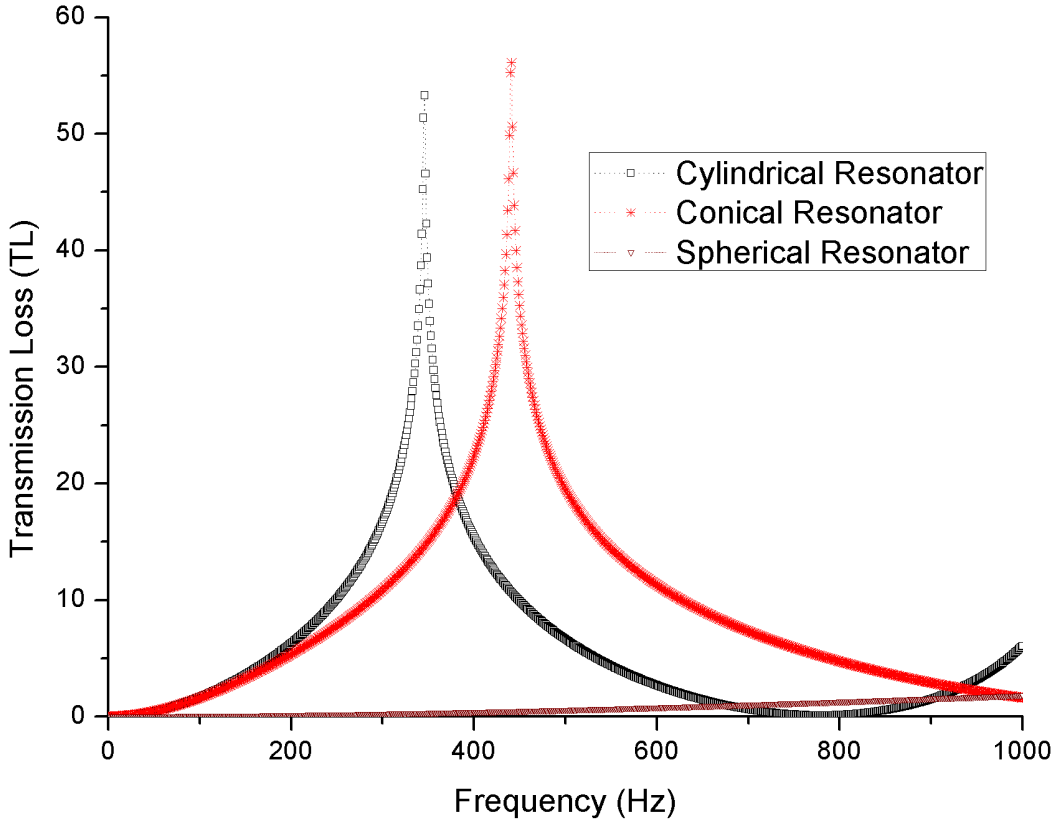

Fig. 6: Comparison of Transmission Loss for Various Shape of Helmholtz Resonator

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