Enhancement of Low-Frequency Noise for Muffler by Optimizing the Space between Three 1-Degrees of Freedom Helmholtz Resonator

Ravi Jatola¹ and Amit Kumar Gupta²

¹Assistant Professor, Department of Mechanical Engineering, SGSITS, Indore (M.P., India)
²Assistant Professor, Department of Mechanical Engineering, IET-DAVV, Indore (M.P., India)

Abstract. The Helmholtz resonator is one of the basic elements to attenuate low-frequency noise and increase sound transmission loss in a muffler for particular low frequency zone. It can be enhancing the performance without any change in the geometry of the muffler. It can greatly reduce the high-intensity noise in low-frequency zones. A comparative study has been carried out by implementing the two and three resonators arranged in series arrangement at optimum spacing for increasing transmission loss. The model of Helmholtz resonator at wavelength 1000 mm at different spacing like \((<\lambda/4)\), 1st antinode: \((-\lambda/4)\) and 1st node: \((-\lambda/2)\) were prepared by using wave build 3-D and simulating above condition on wave 1-D module. This work is also validated by simulating the same geometry on Comsol tool for the mentioned spacing. This attempt gives a comparative study about perfect spacing during use of more than one resonator in a series. The neck and cavity ratio are taken as 2 and 1.85 respectively for the modelling of an identical resonator. The Conclusion shows that, at \((-\lambda/4)\) resonator gives the maximum attenuation at 340 Hz cut-off frequency in low-frequency zone.

1 Introduction

The demand for automobiles has been dramatically increasing in recent years. [1] A car's silencer is specified by a number of measuring characteristics, including insertion loss and gearbox loss.[2] Transmission loss is the parameter that is most frequently used to assess the sound radiation properties of a silencer.[3] The Transmission Loss computation is typically the most used technique for describing a system's acoustic performances.[4] This work provided an overview of sound transmission loss and discussed its substantial environmental effects. It investigates the fundamentals of sound transmission, the factors that influence it, and the environmental impacts of sound attenuation. The difference between the power incident on the silencer itself and the power transported downstream into an anechoic termination is known as transmission loss.[5][6] It assumes an anechoic tailpipe termination.
and is independent of the source. It describes how a silencer functions. As dissipative mufflers have absorbing material to take energy out of the acoustic motion in the wave as it propagates through the muffler, they are primarily utilized for noise attenuation. [7] For humans, noise levels more than 80 dB are harmful. It explained how the test rig arrangement can be used to accurately evaluate gearbox losses. There are numerous tools available to replicate a muffler's transmission loss characteristics.[8] Strong flow fluctuations can be produced by a Helmholtz resonator when it is subjected to grazing flow at a particular speed. These oscillations can cause pressure changes in the flow above the resonator opening that are either desired or undesirable.[9] Examples of this phenomenon include the fluctuation of gas inside closed-side pipelines, the grazing flow over airplane landing gear, and the fluctuation of cabin pressure inside of vehicles. [10] For suppressing pure tones of constant frequency, a Helmholtz resonator is a different sort of side branch resonator that consists of a short neck connected to a big cavity with a fixed volume of compressible fluid.[11] Increases in gearbox loss inside an air intake system will lower the total sound pressure level since the resonator has a strong impact on gearbox loss.[4] Resonators, as has been noted, are essential for reducing sound pressure, but they should only be made at the desired frequency. The resonator's volume, neck length, and neck diameter can be tweaked for the best results.[12] There are several ways to lower the sound pressure level of an air intake system, but one straightforward method is to add a resonator to the air filter box to increase gearbox loss.[13] Experimentally, the two-load method is frequently used to estimate an acoustic muffler's transmission loss.[14] The comparative analysis of the gearbox loss of a silencer is also demonstrated using the finite element method.[15] In order to anticipate the gearbox loss performances of the silencer, wave 1D, a finite element analysis tool, is employed in this work to simulate the silencer.[16] Then, using the wave 1D module and Comsol Multiphysics, simulations of variously shaped resonators were run.[17] The quantification of transmission loss using a Helmholtz resonator shows good agreement with the numerical results.[18] To reduce the narrow-band low-frequency noise, the Helmholtz resonator which consists of a chamber connected to the main duct through a neck was initially employed. After that, some researchers [19][20] used Helmholtz resonators as reactive-type attenuators to lessen hydraulic fluid pulsation.[21] The hydraulic flow pulsation, on the other hand, includes multiple higher harmonics in addition to the fundamental frequency, whereas the conventional single Helmholtz resonator only has one resonance frequency and can thus minimize one frequency flow pulsation harmonic. Three degrees of freedom (3-DOF) technology was created X.Yu. [22]

![Fig. 1. Structure of Three 1-DOF Helmholtz resonator](image)

Helmholtz resonator and pointed out that it can get good attenuation properties at three frequency harmonics of hydraulic flow pulsation.[23] Considering that the energy of hydraulic flow pulsation mainly distributes at the fundamental frequency and its first two harmonics. Fig.1 shows the equivalent analogy used for 3-DOF Helmholtz resonator which
is very suitable to increase the transmission loss at low frequency on muffler and has important research value to attenuate the low frequency by using 3-DOF Helmholtz resonator.[21]

2 Objectives

The primary objective is to find out low frequency noise of muffler dimensions shown in figure 2.

![Muffler Dimension](image1)
![3-D Model of Muffler and Meshed model by Comsol](image2)

**Fig. 2.** (a) Muffler Dimension (b) 3-D Model of Muffler and Meshed model by Comsol

The transmission loss of simple muffler of circular section without Helmholtz Resonator is shown in figure 3. Here it is found that here low frequency noise found at 340 Hz. So here main objective is to attenuate the low frequency noise by Helmholtz Resonator.

![Transmission Loss](image3)

**Fig. 3.** Transmission Loss for Circular Chamber Muffler
By applying Single Helmholtz resonator and calculate the dimension by using equation 1 shown below

\[ f_r = \frac{C}{2\pi} \sqrt{\frac{S_v}{L \times V}} \] ……..(1)

\( f_r \) - Helmholtz resonator frequency
\( C \) – Speed of the sound in the medium (i.e., air). Its value is taken as 340 m/s
\( S_v \) - Cross-section of the opening that picks the sound
\( V \) – Volume of the resonator
\( L \) - Depth of Opening

According to calculation the volume required by keeping value neck diameter \( d = 45 \text{ mm} \) and length \( l = 90 \text{mm} \) respectively and keeping length of resonator is 125 mm. The diameter of resonator is found 67.523 mm.

\[ 340 = \frac{340}{2\pi} \sqrt{\frac{\pi}{4}(0.045)^2}{(0.09)\frac{\pi}{4}d^2(0.125)} \quad (d = 67.523 \text{ mm}) \]

---

**Fig. 4.** (a) Muffler Modelling with single resonator (b) Improvement of Transmission loss at first cutoff frequency (at 340 Hz) of Circular Chamber Muffler by applying designed single resonator.
From figure 4 it is observed that the transmission loss is attenuated for 340 Hz from zero to 8 dB. This research work has two main objectives to first to introduce more than one Helmholtz resonator to increase transmission loss and providing relative spacing in the Helmholtz resonator for working frequency of 340 Hz.

The dimensions are kept constant for both cases: 1. Relative spacing between two resonators, 2. Relative spacing between three resonators, which are arranged in series at the inlet of a standard muffler having a duct diameter of 35 mm. The Helmholtz resonator for both cases was modeled by placing them at various relative spacing namely:

I. Closely spaced: \( \left( \frac{\lambda}{4} \right) \) equal to 200 mm.
II. 1st antinode: \( \left( \frac{\lambda}{4} \right) \) equal to 250 mm.
III. 1st node: \( \left( \frac{\lambda}{2} \right) \) equal to 500 mm.

The dimensions of the Helmholtz resonators were considered exactly same as mentioned in the Fig.5 and Fig.6 for the single 1-DOF and resonator and the main duct was considered as inlet pipe having circular cross-section of diameter 35 mm and length 1 m. The length and diameter ratio of neck and cavity ratio was considered as 2 and 1.85 respectively for the simulation of this work. The results from this work have validated by COMSOL which was already proven software for the acoustic noise measurement.

A simple drafting of spacing between two and three resonators has done by CAD module of Pro-e software and mention all the dimension.

**Fig. 5.** Case 1 Drafting of Two 1-DOF Helmholtz Resonator attached to a duct

**Fig. 6.** Case 2 Drafting of three 1-DOF Helmholtz Resonator attached to a duct.
3 Resonator Modelling and Simulation Using Comsol

Case I: -
Firstly, two 1-DOF resonators have been modelled by Pro-e by taking appropriate dimensions having L/D ratio of neck and cavity as 2 and 1.85 respectively. The save file of IGES format was further imported on COMSOL. The initial parameter has been selected from the geometry and integrated from the inlet of the duct to the outlet which helps this model to form a single domain for applying acoustic pressure field. The material for the noise source has been selected as air from the material browser. By using plane wave radiation from the pressure acoustic, frequency domain, the inlet and out boundary conditions had applied for the flow of the noise source. A pressure field has been incident at the inlet which considered whole the model as single geometry. After that, meshing of element has been done by selecting the free tetrahedral mesh parameter. In the meshing 340 Hz frequency noise source has been inserted for the maximum working frequency of 1000 Hz with an increment of 5 dB. Then, the study was computed and it gives the acoustic pressure and sound pressure level in showing in fig. 7 and fig. 9.

![Fig. 6. 3-D Modelling of Two 1-DOF Helmholtz Resonator using Pro-E Software](image1)

![Fig. 7. Acoustic Pressure field and Transmission Loss of Two 1-DOF Helmholtz Resonator](image2)
The noise attenuation by using of two 1-DOF resonator at \( \left( \frac{\lambda}{4} \right) \) distance between them gives the increased transmission loss up to 64 dB which is quit more than single resonator.

Case II : -
The above procedure has followed for three 1-DOF resonators. This attempt has also give the attenuation of same cut off frequency of 340 Hz but it increases the quantity of transmission loss about 99 dB shown in figure 9.

**Fig. 8.** 3-D Modeling of Three 1-DOF Helmholtz Resonator using Pro-e Software.

**Fig. 9.** Acoustic Pressure field and Transmission Loss of Three 1-DOF Helmholtz Resonator.

**4 Processing by Wave 1-D to Observe Distance between two and three 1-DOF Resonators**

The two and three 1-DOF Helmholtz resonators have also prepared on wave build 3D with inlet & outlet boundary condition. The acoustic piston was used to supply noise source and connected through a duct to the inlet of resonator model and a secondary duct was used to escape noise to ambient after attenuation. The simulation has been done for the four spacing provided in this analysis.

a) Very closely spaced :- \( \left( \frac{\lambda}{4} \right) \) equal to 125 mm
b) Closely spaced :- \( \left( \frac{\lambda}{4} \right) \) equal to 200 mm
c) 1st antinode :- \( \left( \frac{\lambda}{4} \right) \) equal to 250 mm
d) 1st node :- \( \left( \frac{\lambda}{2} \right) \) equal to 500 mm
These various positions give the maximum attenuation of noise by the use of two and three 1-DOF resonators.

Case I -

Fig. 10. Modelling of Two 1-DOF resonator by using Wave 1-D

(a)            (b)

Fig. 11. Graph plotted for Transmission Loss Vs Frequency at various spacing
(a) 500 mm spaced, (b) 250 mm spaced, (c) 200 mm spaced and (d) 125 mm spaced
Case II:

(a) Spacing = 500 mm  
(b) Spacing = 250 mm  
(c) Spacing = 100 mm

Fig. 12. Graph plotted for Transmission Loss Vs Frequency at various spacing  
(a) Modelling Layout, (b) spacing = 500 mm (c) spacing = 250 mm (d) spacing = 100 mm

5 Result and Discussion

The simulation on two and three 1-DOF Helmholtz resonators was successfully carried out by using wave 1-D and also gave a satisfactory result as compared to the single resonator. The results show that the attenuation of noise can be increased up to maximum by providing 250 mm spacing between them which is equal to $\left(\frac{\lambda}{4}\right)$. This is validated by simulation result of same geometry and case on the COMSOL software. This also validated by the result of quarter wave reactive muffler who can also attenuate noise at $\left(\frac{\lambda}{4}\right)$. The result also shows the use of no. of resonators for maximum transmission loss by using resonator tree aligned in series.
6 Conclusion

An optimized system for both the cases in terms of relative spacing has been investigated in this research work. Maximum noise attenuation of 117 dB for the case I and around 175 dB for the case II has been achieved comparative to a single 1-DOF resonator at cut-off frequency of 340 Hz. This result signifies the importance of this proposed procedure. The optimized system found from this research work is: Relative Spacing: ($\lambda/4$), and cavity ratio: 1.85 and neck ratio: 2.
References


[16] C. P. O. A. Guhan, G. Arthanareeswaran, K. N. Varadarajan, and S. Krishnan,


