Simulation of Cylindrical Resonator with Spiral Neck and Straight Neck to Attenuate the Low Frequency Noise of Muffler

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Abstract:- This paper is concentrated for improving the transmission loss and reduces the low frequency noise level by development of Helmholtz Resonator within a limited space. The modified Helmholtz resonator, i.e. cylindrical resonator with spiral neck is used to occupy the small space. Introduction of spiral neck instead of straight neck with cylindrical cavity reduces the space of resonator. For first cut-off frequency (resonance frequency) the volume of resonator is fixed, so with the help of spiral neck its length increases, volume increases and its curvature effect is also helpful in the reduction of noise. The finite element analysis tool Comsol multiphysics is used to validate the result. The results shows interesting factor that resonator not only attenuate a particular low frequency noise as well it increases transmission loss with spiral neck. Helmholtz resonator with a spiral neck can achieve high sound reduction within a small space at low frequency.

Keywords: *Helmholtz resonator, FEA Acoustic Module- comsol multiphysics, Transmission loss, Spiral neck.*

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1. INTRODUCTION

The problem of low-frequency tonal noise is inherent in industries using internal combustion (IC) engines, compressors, fans, blowers, power transformers, gearboxes etc. The humming nature of a tonal noise not only causes annoyance to workers within the industry but also to the surrounding community [1] [2].A sound propagation without airflow through circular ducts with spiral element inside. Models are numerically computed in three-dimensions. The spiral element in duct is a newly analyzed acoustical element, geometrically similar to the well-known Archimedes screw [3]. Significantly it can be applied in ducted systems, such as ventilation, air-conditioning and heat systems. This practical modification can improve a sound attenuation performance in specified band of frequency [4]. There is also developed that the acoustic attenuation for spiral (helicoidal) ducts exists in consequence of an acoustical resonance. Hence a helicoidal resonator is considered. Acoustical properties, mainly attenuation of sound due to an acoustical resonance, of helicoidal resonators can be modified by doing a change in relations between its basic geometrical parameters,very important parameter of helicoidal resonator is the number of helicoidal turns *n*, which strongly determines the character of acoustical resonance. A substitutional transmittance function of helicoidal resonator as a first approach for this question based on computational results in COMSOL Multiphysics [5]. The intake noise of an automobile induced by firing of an engine accompanies acoustic resonance of ducts of an intake system. Conventionally, the adoption of the Helmholtz type resonator was one of possible ways to eliminate the booming noise due to acoustic resonances of air ducts. Although the Helmholtz type resonator is convenient to attenuate the intake noise of an automobile, the usage of the Helmholtz type resonator requires cost increase or big engine room space [6][7]. The effective frequency range of a HR is restricted to its resonance frequency, which is governed by the physical dimensions of neck area, neck length, and cavity volume. Accordingly, at low frequencies the HR needs to be very large, which is a challenge to accommodate within small spaces. In order to make the neck as long as possible, a spiral duct takes the place of the traditional short neck of the HR. The curved structure lengthens the neck without requiring a large space[8]. This study focuses on improving the noise reduction performance of HR at low frequency within a limited space. The wave propagation in the straight duct neck and spiral duct neck is analysed and computed on the basis of Pro-e and COMSOL Multiphysics.

2. MODELLING OF HELMHOLTZ RESONATOR

A resonator is attached to a reactive muffler in order to make evaluation of low frequency noise. The Helmholtz resonator works on resonance frequency. We have adopted the constant volume of Helmholtz resonator by making variation in its neck shape. This form of Helmholtz resonator decreases the low frequency noise. For this purpose in this paper we have adopted a neck shape in order to evaluate the maximum transmission loss to know about the first cut-off frequency observed at the time of noise flow by the means of pure muffler. Two shapes of neck has been developed for tha 340 Hz frequency noise these two shapes of neck are straight (cylindrical), spiral respectively.

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 neck is different shape like Straight (cylindrical) and Spiral neck.
5. Validation of result with existing one for maximum transmission loss measurement.

3. MODELLING AND SIMULATION OF MUFFLER BY USING COMSOL

A pure reactive muffler is modeled by using 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 45 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 Comsol multiphysics 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. Some of the boundary condition are taken as constant as they are not variant with the frequency source. Figure 1 shows that the first cut off at 340 Hz for test muffler.

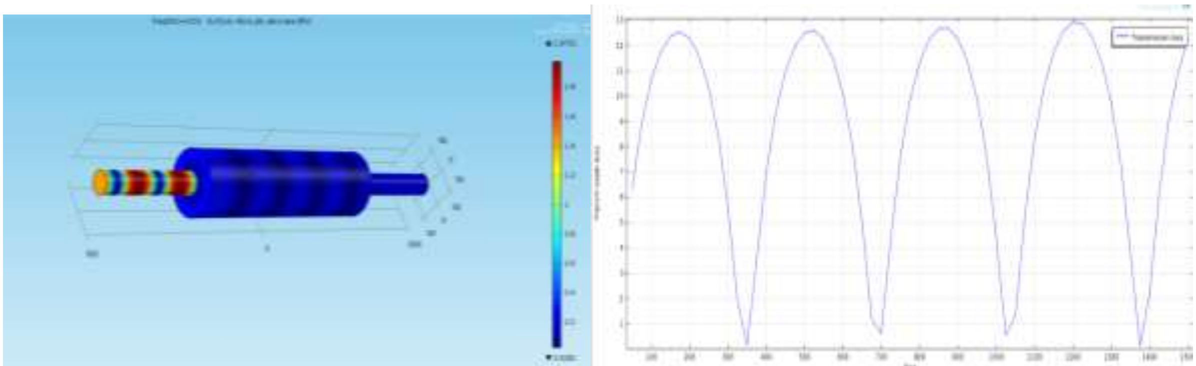

Figure 1: Schematic of Basic Muffler Model and TL Curve by using Comsol.

4. CALCULATION OF HELMHOLTZ RESONATOR VOLUME

There are two part in Helmholtz resonator, cavity and neck. The effective frequency range of a Helmholtz resonator is restricted to its resonance frequency, which is governed by the physical dimensions of neck volume and cavity volume. Overall volume is fixed according to its resonance frequency. Now, calculate the dimensions of Helmholtz resonator of straight neck and spiral neck at first cut-off frequency by analytical and computational approach.

The frequency of a resonator can be calculated as below

$$f_c = \frac{1}{2\pi}\sqrt{\frac{K}{M}} = \frac{C}{2\pi}\sqrt{\frac{S_b}{L*V}}$$

where,

C = Velocity of sound approx. 340 m/s, S_b = Neck area

L=Length of neck, V = Volume of resonator/cavity $=V_{Resonator} = \frac{\pi}{4} * D^2 * L_R$

L_R= Length of cavity , D = Diameter of cavity.

A. Cylindrical Resonator with straight neck

S_b = Neck area by taking neck diameter d= 45 mm

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L = Length of neck assume as 90 mm

L_R = Length of Cavity = 125 mm

$$340 = \frac{340}{2\pi}\sqrt{\frac{\frac{\pi}{4}*(0.045)^2}{(0.09)*\frac{\pi}{4}*D^2*(0.125)}}$$

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

B. Cylindrical Resonator with spiral neck

The volume of spiral shape is calculate by using Pro-e and other geometry volume is calculate by using analytical approach. The volume of spiral shape neck is 236817 mm^3, this is measured by Pro-e analysis.

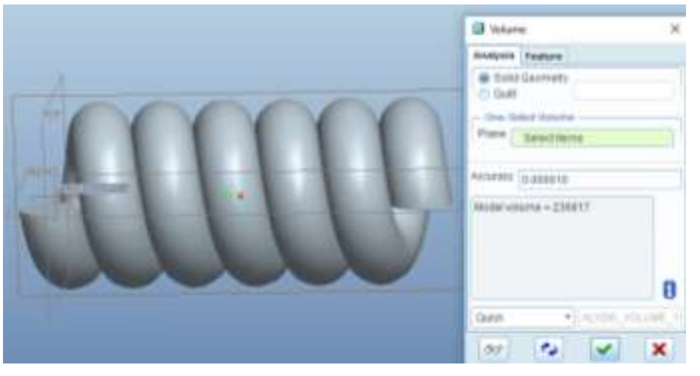

Figure 2: Volume measurement of spiral shape geometry by Pro-E

Dimensions

Diameter of neck (d) = 20 mm

Length of start and end part of neck (L) = 60 mm

Volume of start and end part of neck = $\frac{\pi}{4}d^2L = \frac{\pi}{4}\times(20)^2\times 60$ =18850 mm^3

Overall volume of neck = 236817 + 18850 = 255667 mm^3

Volume of Helmholtz resonator = Overall volume of neck + volume of cavity

447614 mm^3 = 255667 mm^3 + Volume of cavity

Volume of cavity = 191947 mm^3

Volume of cylindrical shape cavity = $\frac{\pi}{4}D^2L_c$ = 191947 mm^3

We take L_c/D ratio of 2 then we get the dimensions.

L_c= 99.25 mm

D= 49.625 mm

5. MODELLING OF HELMHOLTZ RESONATOR OF FIXED VOLUME

a. Cylindrical resonator with straight neck: There are two concentric tubes of different diameter, bigger is called cavity of resonator and smaller is called neck. Cavity is mounted on neck. In this resonator the L/D ratio of neck and cavity is taken as 2 and 1.85 respectively. This resonator is mounted at the inlet of muffler. Modelling is done in Pro-e and by simulation on COMSOL Multiphysics, noise is attenuate at first cut-off frequency i.e. particularly 340 Hz frequency noise gives Transmission loss is around 6.3 dB and average transmission loss is nearly 11.52 dB.

Dimensions

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Length of cavity = 125 mm

Diameter of cavity = 67.523 mm

Length of neck = 90 mm

Diameter of neck = 45 mm

Diameter of duct = 45 mm

Volume of Helmholtz resonator=447613.6823 mm^3

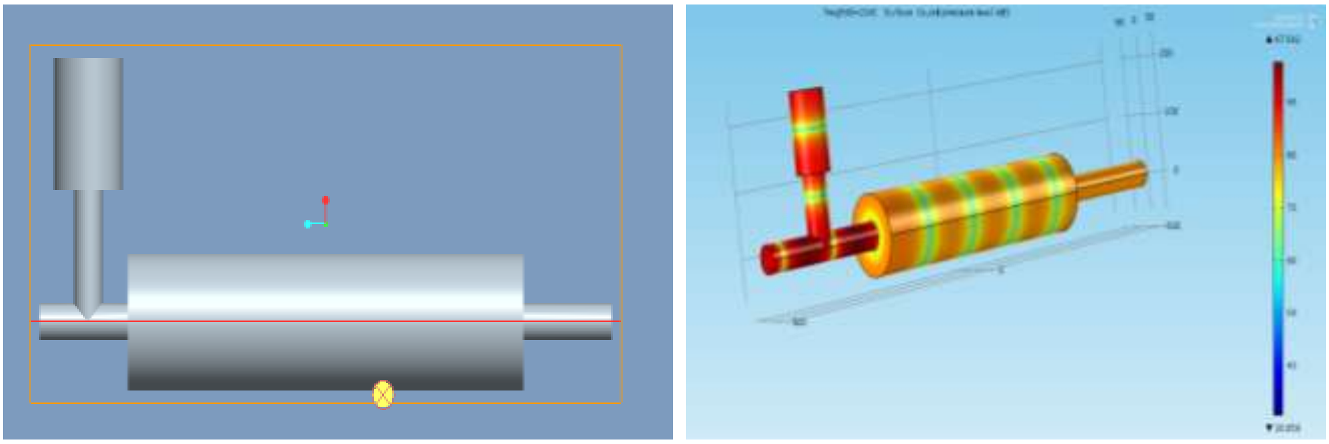

Figure 3: Modeling by Pro-e and simulation by Comsol Multiphysics of straight neck Helmholtz resonator

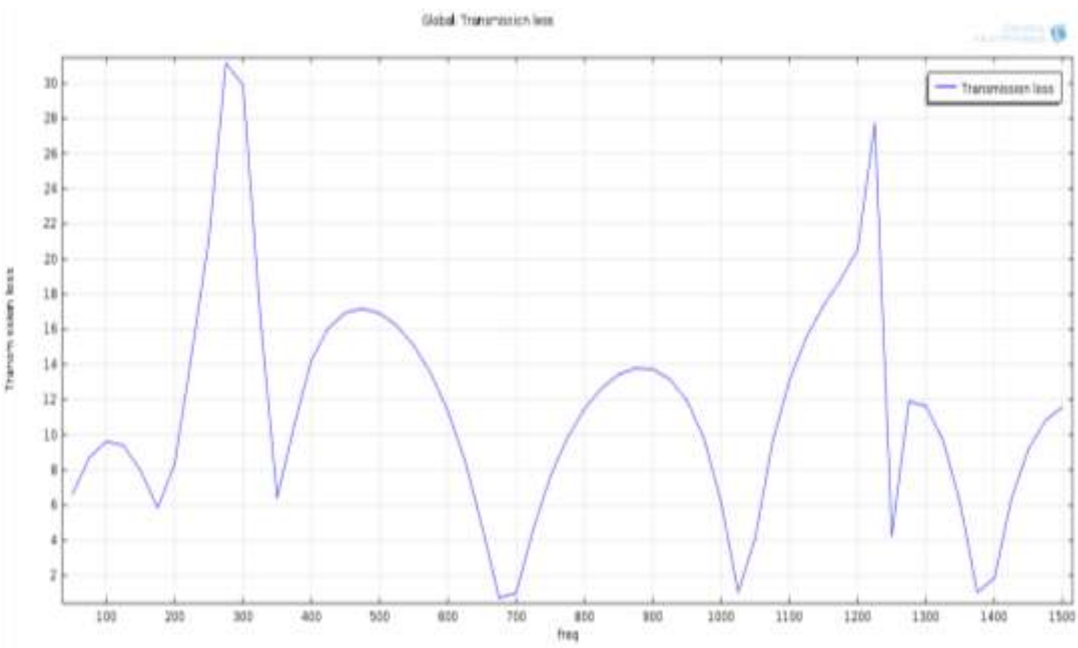

Figure 4: Transmission Loss curve of straight neck Helmholtz resonator

b. Cylindrical resonator with spiral neck : Unlike the traditional straight duct, the neck considered in this paper is a spiral duct of circular cross-sectional area. The spiral neck has six turns and compacts the long neck within a smaller space. The cavity is mounted on neck is cylindrical section. In this resonator, the L/D ratio of cavity is taken as 2. Modelling is done in Pro-e and by simulation on COMSOL Multiphysics, noise is attenuate at first cut-off frequency i.e. particularly 340 Hz frequency noise gives Transmission loss is around 10 dB and average transmission loss is nearly 27.65 dB.

Dimensions

Length of cavity = 99. 25 mm

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Diameter of cavity = 49.625 mm

Diameter of neck = 20 mm

Diameter of duct = 20 mm

Volume of neck = 255667 mm^3

Volume of Helmholtz resonator=447614 mm^3

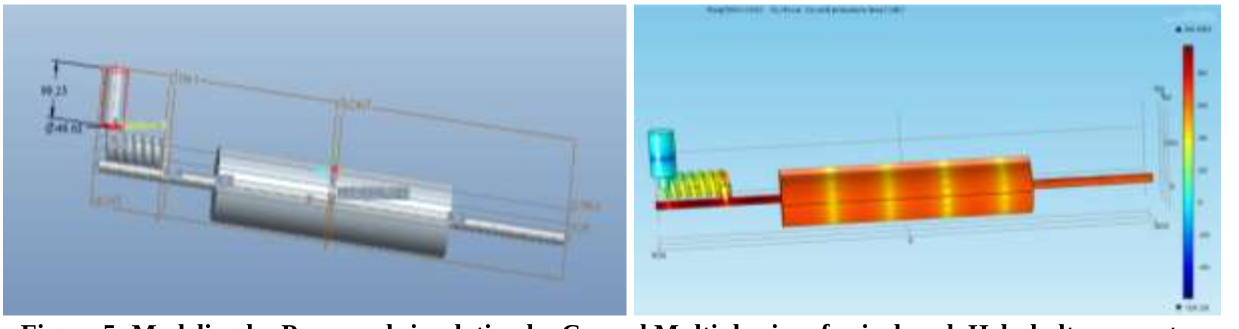

Figure 5: Modeling by Pro-e and simulation by Comsol Multiphysics of spiral neck Helmholtz resonator

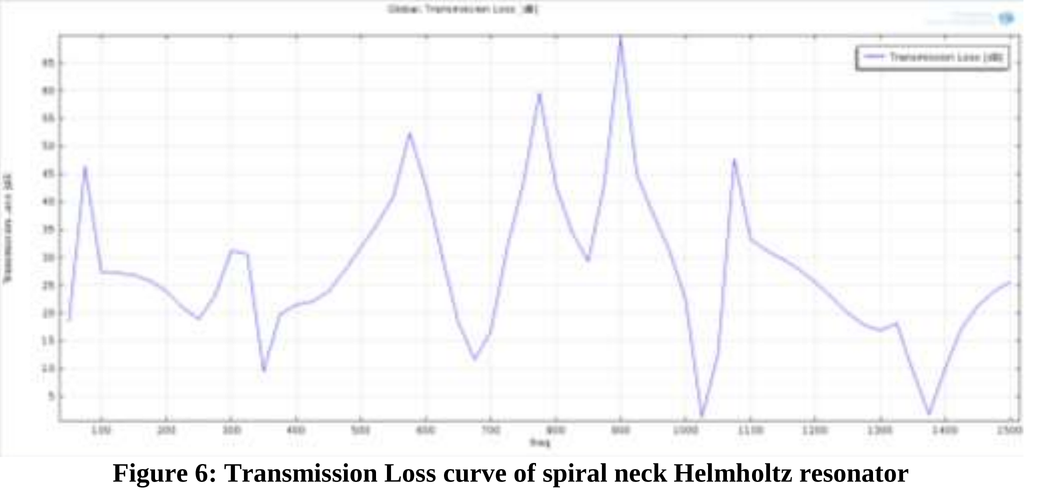

Figure 6: Transmission Loss curve of spiral neck Helmholtz resonator

6. RESULTS AND DISCUSSION

The result is represented the improvement in transmission loss. The three dimensional finite element analysis tool i.e. Comsol Multiphysics was used to simulate the modelling and comparison of two types of Helmholtz resonator. From this result, it can be concluded that the development of cylindrical resonator with spiral neck is best suited for the attenuation of first cut-off frequency as it increase the transmission loss at very much extent. The transmission loss is is evaluated in the two cases cylindrical resonator with straight neck and cylindrical resonator with spiral neck, volume is same in both the cases and muffler used in both the case is also same volume. The result shows that the transmission loss is attenuated at first cut-off frequency of 340 Hz as shown in figure, it attenuates the transmission loss nearly 6.2 dB for the cylindrical resonator of straight neck and nearly 10 dB for the cylindrical resonator of spiral neck. Figure 5 also shows that Cylindrical resonator of spiral neck is not only attenuates the transmission loss at first cut-off frequency of 340 Hz but it also increases the average transmission loss. The average transmission loss of straight neck and spiral neck resonator is 11.52 dB and 27.65 dB.

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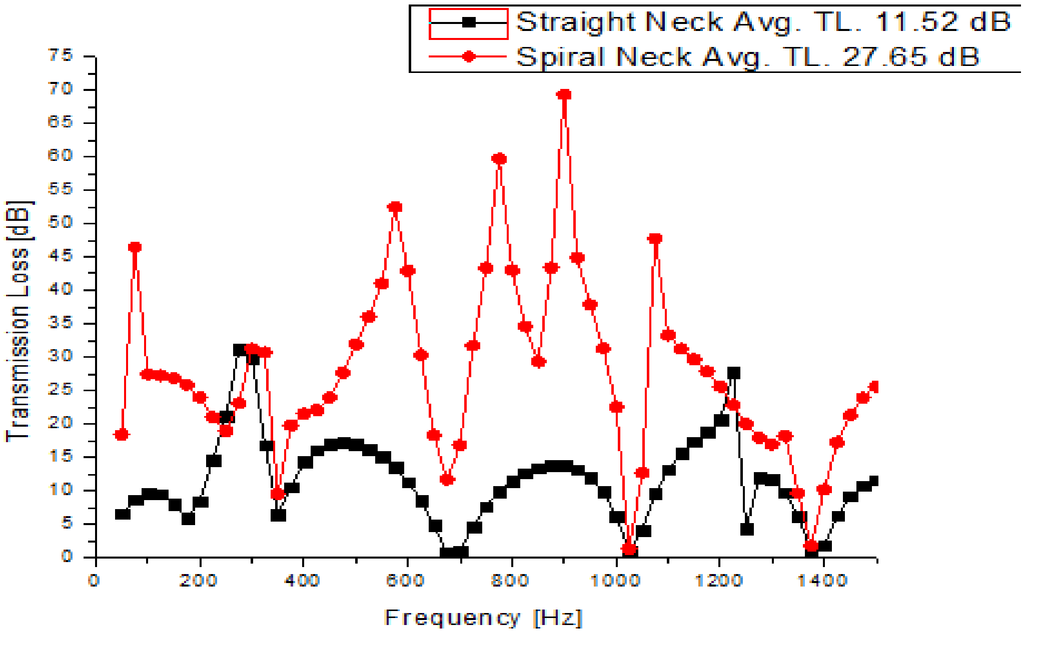

Figure 7: Comparison of Transmission Loss of Straight neck and Spiral neck.

7. CONCLUSIONS

This paper represent the way to increases the transmission loss at the frequency of 340 Hz forHelmholtz resonator with in small space. Due to space limitations, it is not possible to use long neck of Helmholtz resonator. By using Spiral neck instead of traditional long straight neck, short neck, the transmission losses can be effectively increased upto great extent. The potential tendency of spiral neck has ability to minimise tonal noise within a given space. With the help of the spiral neck, the HR can be designed to control different noise frequencies. Finally it can be concluded that the use of spiral neck focuses on increasing transmission losses with in a given space which can not be increased by using traditional straight neck.

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