NOISE REDUCTION IN DUCTS USING HELMHOLTZ RESONATORS

Sourabh Dogra *[1], Arpan Gupta †[1], Umberto Berardi ‡[2]
[1]Indian Institute of Technology Mandi, Himachal Pradesh, India.
[2]Ryerson University, Toronto, Ontario, Canada

1 Introduction

Ducts are an important part of the modern-day building. Ducts are used to circulate the fresh air in the buildings. The movement of the air in the duct creates noise throughout the building. People residing in these building are exposed to these noises for a very long time and leads to various health issues like tinnitus, hypertension and loss of hearing [1,2]. Various researches are being carried out around the world on this issue. Helmholtz resonators are often utilized in the literature to address these issues [3,4]. Helmholtz resonators attenuate the sound of the desired frequency by properly dTapez une équation ici.esigning the geometry. But the attenuation band is very narrow. In this paper we have designed an arrangement of different Helmholtz resonators which are able to produce large amount of the transmission loss over large number of frequencies. These theoretical studies are validated with numerical results.

2 Methodology

2.1 Theoretical analysis

Helmholtz resonators are analysed as lumped mass system and modelled as spring mass system. The natural frequency of the lumped mass system is given by:

$$\omega_0 = \frac{c}{2\pi}\sqrt{\frac{A}{vL}}$$

Here ω_0 is natural frequency, *c* is the speed of the sound, *A* is the area of the neck, *v* is the volume of the back cavity and *L* is the length of the neck.

The Helmholtz resonators fitted over the ducts are shown in the Figure 1. These types of the configuration are analysed by using classical transfer matrix (TM) theory. According to this theory the transfer matrix of the Helmholtz resonator fitted over the duct is written as:

$$\begin{bmatrix} p_0 \\ u_0 \end{bmatrix} = \begin{bmatrix} 2\text{x}2 \\ \text{TM}_{Duct} \end{bmatrix} \begin{bmatrix} 2\text{x}2 \\ \text{TM}_{HR} \end{bmatrix} \begin{bmatrix} 2\text{x}2 \\ \text{TM}_{Duct} \end{bmatrix} \begin{bmatrix} p_d \\ u_d \end{bmatrix} \quad (1)$$

P and *u* are the pressure and velocity at inlet (0) and outlet (*d*) of the Helmholtz resonator.

The transfer matrix for the uniform duct is given by [5]

$$\begin{bmatrix} p_0 \\ u_0 \end{bmatrix} = \begin{pmatrix} \cos(kh) & jY\sin(k_0 h) \\ \frac{jY\sin(k_0 h)}{Y} & \cos(kh) \end{pmatrix} \begin{bmatrix} p_d \\ u_d \end{bmatrix} \quad (2)$$

For the Helmholtz resonator the mounted over the duct the tranfer matrix is

$$\begin{bmatrix} p_0 \\ u_0 \end{bmatrix} = \begin{pmatrix} 1 & 0 \\ \frac{1}{Z_{HR}} & 1 \end{pmatrix} \begin{bmatrix} p_d \\ u_d \end{bmatrix} \quad (3)$$

Here, Z_{HR} denotes the impedance of the Helmholtz resonator and is calculated as

$$Z_{HR} = \frac{\omega^2}{\pi c} + j\omega\lambda \frac{l_e}{A} + \frac{c^2}{j\omega v}, \quad l_e = l + 0.85d$$

Finally, Transmission loss (TL) is calculated using the elements of the Eq (1) as:

$$TL = 20\log_{10}\left|\frac{T_{11} + \frac{T_{12}}{\rho c} + T_{21}\rho c + T_{22}}{2e^{jkd}}\right| \quad (4)$$

2.2 Numerical analysis

The numerical analysis is carried in the Finite Element Software COMSOL Multiphysics 5.0. The frequency domain under pressure acoustic study in COMSOL are used to perform the analysis. The acoustic model of the different Helmholtz resonators mounted over the duct is shown in fig.1(a). The domain is discretized using tetrahedron element. The maximum size of the mesh element is kept λ/15 time the maximum investigated frequency. The acoustic analysis is performed by normally incidenting on the plane sound wave field of pressure 1 Pascal through sine sweep at one end. The transmission loss with in the duct is analysed using the expression.

(a)

(b)

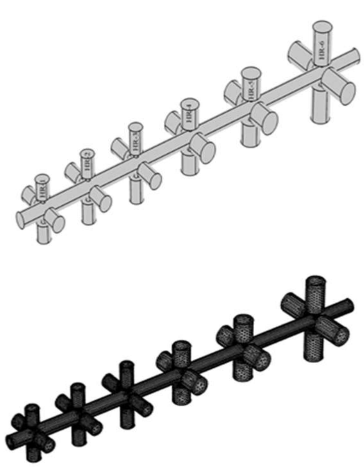

Figure 1: (a) Geometry of the different Helmholtz resonators mounted over the duct. (b) Mesh image of the different Helmholtz resonators in series.

* sourabh.sd47@gmail.com
† agupta@iitmandi.ac.in
‡ uberardi@ryerson.ca

3 Results

A 3D model of the Helmholtz resonators fitted over the duct is prepared in COMSOL. Twenty-four Helmholtz resonators of six different sizes are analyzed. The diameter of the duct is 22.5 mm. The size of the Helmholtz resonators is chosen is such that low range frequencies can be analyzed. The geometry and the natural frequencies of the different Helmholtz resonators are given in the Table 1. Plane wave radiation condition is used at the two ends of the duct. The rest of the boundaries of the duct and the Helmholtz resonator are assumed to be hard so that no sound transmission takes place through these boundaries.

Table 1: Geometric parameters of resonators.

Configuration	Cavity		Natural frequency (Hz)
	Radius(mm)	Height(mm)	
HR-1	22.5	50	530
HR-2	22.5	60	480
HR-3	22.5	70	442
HR-4	30	60	364
HR-5	32.5	65	322
HR-6	32.5	102	354

The system is analyzed in the frequency range of 50 to 1500 Hz. The theoretical transmission loss is calculated by using the Eq (4). The length of the neck is 15 mm whereas the radius of the neck is 7.5 mm. The dimension of the neck is same for all configurations.

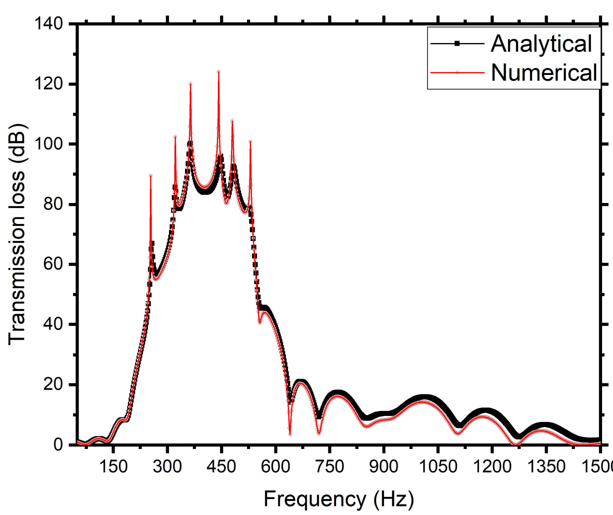

Figure 2: Comparison of theoretical and numerical Transmission loss.

Plugging the various parameters in the Eqs. (2) (3) transfer matrix for the duct and Helmholtz resonators is estimated. Finally multiplying these transfer matrices as given in Eq (1). gives the transfer matrix for one pair of the resonators. Similarly finding the transfer matrix of all the resonators pairs and then multiplying all gives the transfer matrix of the proposed arrangement.

4 Discussion

Transmission loss for the different Helmholtz resonators is given in the table. 2. The theoretical transmission loss is in good agreement with the numerical results as shown in Figure 2. The large increase in the transmission loss can be observed from the table corresponding to the natural frequency of different Helmholtz resonators. There is a widening of the transmission loss over the frequency near by the natural frequencies. This is mainly due to the combined effect of absorption of the sound waves due to the Helmholtz resonators and Bragg reflection phenomenon due to the periodic arrangement of the array of the Helmholtz resonators.

Table 2: Transmission loss corresponding to various HR.

Configuration	Transmission loss
HR-1	89 dB
HR-2	102 dB
HR-3	120 dB
HR-4	124 dB
HR-5	107 dB
HR-6	100 dB

5 Conclusion

In this paper we have designed a system of Helmholtz resonators to control the noise generated from the moving air in the duct. Helmholtz resonator can absorb the sound of the desired frequency by properly designing its geometry. We have used different Helmholtz resonators in the combination of the serial and parallel arrangements. The system is analysed numerically in COMSOL and validated by a theoretical model. The theoretical and numerical results both are in good agreement. The proposed model provides a significant amount of transmission loss. There is broadband low frequency attenuation due to combine effect of the Bragg reflection and Helmholtz resonance. These types of the model are very useful where the space is not a constrain.

Acknowledgments

This research is supported by DST India and IC-IMPACTS, Canada under project DST/INT/CAN/P-04/2020.

References

[1] Rajalakshmi, R., John, N. A., and John, J., 2016, "Review on Noise Pollution and Its Associated Health Hazards," Sch. J. Appl. Med. Sci., **4**(ISSN 2347-954X), pp. 500–503.

[2] Waddington, D. C., and Oldham, D. J., 2007, "Noise Generation in Ventilation Systems by the Interaction of Airflow with Duct Discontinuities: Part 1 Bends," Build. Acoust., **14**(3).

[3] Cai, C., and Mak, C. M., 2016, "Noise Control Zone for a Periodic Ducted Helmholtz Resonator System," J. Acoust. Soc. Am., **140**(6), pp. EL471–EL477.

[4] Wang, X., and Mak, C.-M., 2012, "Wave Propagation in a Duct with a Periodic Helmholtz Resonators Array," J. Acoust. Soc. Am., **131**(2), pp. 1172–1182.

[5] Fahy, F., 2001, *Foundations of Engineering Acoustics.*