Preliminary laboratory testing on the sound absorption of coupled cavity sonic crystal

R. Kristiani\textsuperscript{1,2}, I. Yahya\textsuperscript{*}, Harjana\textsuperscript{1,2} and Suparmi\textsuperscript{2}

\textsuperscript{1}. The Iwany Acoustics Research Group (iARG), Department of Physics, Faculty of Mathematics and Natural Sciences.  
\textsuperscript{2}. Graduate School of Physics, Sebelas Maret University, Jl. Ir. Sutami 36A Kentingan, Surakarta 57126, INDONESIA

E-mail: iyahya@mipa.uns.ac.id

Abstract. This paper focuses on the sound absorption performance of coupled cavity sonic crystal. It constructed by a pair of a cylindrical tube with different values in diameters. A laboratory test procedure after ASTM E1050 has been conducted to measure the sound absorption of the sonic crystal elements. The test procedures were implemented to a single coupled scatterer and also to a pair of similar structure. The results showed that using the paired structure bring a better possibility for increase the sound absorption to a wider absorption range. It also bring a practical advantage for setting the local Helmholtz resonant frequency to certain intended frequency.

1. Introduction

Sonic crystals were greatly attracting among researchers in last decade. The local resonant feature brings the possibility for tuning the acoustical properties and response to the propagation of sound waves [1,2]. The various approach has proposed by researchers to create sonic crystal assisted sound absorber and diffusers [3-5]. As the Helmholtz local resonant and the coupling effect is the most important mechanism in this task, some modification, and manipulation on scatterer and the crystal lattice has been reported in the literature. Those modification and manipulation techniques could be divided into two main categories. First is related to the single and multi local resonant scatterer, and the second is associated with crystal defect. Theoretical development [6,7] and laboratory experiment [8] on single and multi local resonant scatterer has been conducted. While crystal defect problems also reported by other researchers [9-11].

That mentioned approach has the limitation according to the scatterer geometrical shapes and dimensions. For example, the scattering effect which is related to the scatterer dimension and configuration was investigated by using the various size of scatterer or by replacing it from the initial position on the lattice. The same issue also happened to the modification of scatterer local resonant which is all approaches are based on various geometrical dimension scatterer.

A preliminary laboratory study on the sound absorption performance of a new coupled scatterer sonic crystal is reported in this work. The basic structure of the proposed scatterer design is constructed by a
couple of cylindrical tubes with a different diameter to form multi degree of freedom Helmholtz resonator. It gives the possibility for varying the local Helmholtz resonant by using a single size scatterer.

2. Methods

The proposed coupled scatterer element are illustrated in Figure (1). It is constructed by a pair of the cylindrical tubes with the radius of \( r_1 \) and \( r_2 \) attached to one another with the axis distance \( a \). The first resonator has a single opening that could be rotated to arbitrary angle \( \beta \). The second resonator has a bigger diameter. It has two slit-shaped inlets fixed along the connecting wall of the cylindrical resonator. The coupled scatterer could be set to arbitrary skewness angle \( \theta \). The inlet, outlet, and first resonator orifice have the same width \( s \). The scatterer was made from PVC tube with the detailed geometrical dimensions provided in Table (1).

Figure 1. Basic model of the coupled scatterer

![Figure 1](image)

Table 1. Scatterer dimension

| Parameters     | Dimensions |
|----------------|------------|
| Radius (mm)    | \( r_1: 8.5 \), \( r_2: 13 \) |
| Axis distance (mm) | all fixed: \( a = 10 \) |
| Height (mm)    | all fixed: 30 |
| \( \theta \) (degree) | \( \theta = 0, 30, 45 \) |
| \( \beta \) (degree) | \( \beta = 0, 90 \) |
| Slits (mm)     | all fixed: \( s = 1 \) |

The experiment was conducted by using two microphone impedance tube technique refer to ASTM 1050 laboratory test procedure. B&K 4206 impedance tube complete apparatus was utilized for measuring the various samples of single and also the pair of the coupled scatterer. The sample \( K_1, \theta, \beta \) denotes a single coupled scatterer while the \( K_2, \theta, \beta \) denotes a pair of coupled scatterer.

3. Results and Discussion

Results from a laboratory test for the single coupled scatterer is presented in Figure (2) while the paired scatterer in Figure (3). Figure (2a-c) shows a similar pattern that when the coupled scatterer has the \( \beta = 90^\circ \), each resonator works separately as a single degree of freedom Helmholtz resonator with a different resonant frequency. It is indicated by the similar two peaks around 300 Hz and 1.5 kHz on the sound absorption coefficient graphs.

It differs to the pattern when the first resonator is set to \( \beta = 0^\circ \). Since the slit of the first resonator is situated inside the second resonator, the coupled cavities become a two degree of freedom Helmholtz resonator. When the sound waves propagate through the two inlets of the secondary resonator, it produces an instability and fluctuated sound pressure circumstance inside the cavity of the secondary resonator. This fluctuated pressure flows through the outlet slit of the secondary resonator and at the same time also stimulating resonant effect on the first resonator. The coupling between the first and secondary resonator affecting and changes the value of the structure reactance, and it changes the sound absorption pattern accordingly. Despite it does not increase the sound absorption performance significantly, varying on values of \( \beta \) and \( \theta \) shows an interesting result occurred on both low and high frequency. Sound absorption performance is increased at the low frequency band and followed by the shifting absorption range on the high frequency band. The phenomenon indicates the possibility for
the proposed coupled scatterer design to be use for tuning the Helmholtz local resonant and in the same time to increase the acoustic performance.

![Diagram](image.png)

**Figure 2.** The sound absorption coefficient of a single coupled scatterer on three different $\theta$ (0, 30, 45) and $\beta$ (0, 90) configurations.

The almost similar phenomenon also occurs with the paired coupled scatterer models. Two peaks around of 300 Hz and 1.5 kHz and several small peaks indicates that the paired scatterer configuration has a little bit different absorption mechanism compared to the single coupled scatterer model. The two main peaks are associated with the resonant frequency of the two resonators while the other small peaks are related to the coupling of the scatterers with the surrounding air space.

It shows from Figure (3), the paired design brings a better sound absorption performance. The model with skewness $\theta = 30^\circ$ and $\beta = 45^\circ$ has the best performance both for low and high frequency range. The pair of coupled scatterer performance is associated with the response and the sound absorption the four independent single degrees of freedom Helmholtz resonators. Even though cavity of the first scatterer is not coupled to the cavity of the secondary scatterer, it forms coupling effect with empty air space surrounding it. In the same time, the secondary scatterer also forming the similar coupling through the two slits on its cavity walls. Both the first and the secondary cavity construct a higher degree of freedom resonant system with the surrounding empty air space.

![Diagram](image.png)

**Figure 3.** The sound absorption coefficient of the paired coupled scatterers.
It can conclude from the laboratory test results that the using of paired of coupled scatterer shows a better sound absorption compared to the single coupled scatterer. It brings the possibility of improving the sound absorption both through the local Helmholtz resonant and also increases the number of the independent resonators that can perform a coupling effect with its surrounding empty air space.

4. References

[1] Maldovan, M, 2013 Nature 503
[2] Khelif, A., Deymier, P. A., Djafari-Rouhani, B., Vasseur, J. O., and Dobrzynski, L, 2003 J. of Appl. Phys. 94.3 1308-1311
[3] van der Aa, B., and Forssen, J, 2013 Applied Acoustics 74 89-101
[4] Redondo, J., Pico, R., and Sanchez-Morcillo, V. J, 2013 J. Acoust. Soc. Am. 134-6 4412-4417
[5] Morrandi, F., Miniaci, M., Marzani, A., Barbaresi, L., and Garai, M, 2016 Applied Acoustics 114 294-306
[6] Romero-Garcia, V., Krynkin, A., Garcia-Raffi, L., M, Umnova, O., and Sanchez-Perez, J. V, 2013 JSV 332 184-198
[7] Hirsekorn, M., Delsanto, P. P., Batra, N. K., and Matic, P, 2004 Ultrasonics 42 231-235
[8] Alberti, A., Gomez, P. M., Spiousas, I., and Eguia, M. C. 2016 Applied Acoustics 104 1-5
[9] Wang, X. P., Jiang, P., Chen, T.N., and Yu, K. P, 2016 Intl Journal of Modern Physics B. 30 1650025 (17 pages)
[10] Shelke, A., Banerjee, S., Habib, A., Raahani, E. K., Ahmed, R., and Kundu, T, 2014 Journal of Intelligent Material Systems and Structures, 25-13 1541-1552
[11] Li, Y., Chen, T., Wang, X., Ma, T., and Jiang, P, 2014, J. of Appl. Phys. 116, 024904 (7 pages)