Folded planar resonator-based sonic crystal scatterer: Part II. Tuning the local resonance

Iwan Yahya\textsuperscript{a}, Suparmi\textsuperscript{b}, Cari\textsuperscript{c}, Ubaidillah\textsuperscript{d,e}

\textsuperscript{a}iARG Physics Dept. Sebelas Maret University, Surakarta, Indonesia
\textsuperscript{b}Graduate School of Physics, Sebelas Maret University, Surakarta, Indonesia
\textsuperscript{c}Mechanical Engineering Dept. Sebelas Maret University, Surakarta, Indonesia

Email: iyahya@mipa.uns.ac.id

Abstract. This paper emphasized the tuning local resonance approach for proposing folded planar resonator-based sonic crystal scatterers. The folded inward design gives similar performance to the conventional single degree of freedom split tube resonator (STR). The sound absorption performance shifted to a lower frequency band according to the enlarging total volume of the resulting structure's volume without any significant effect from its inner wall thickness. Contrary to the folded outward direction design, which is resulting in multi-degree of freedom response. As the planar resonator folded in an outward direction, the resonator depth became a thin slit connecting the two separated cavities. The test model is made of stiff paper, as mentioned in part one. The entire laboratory test also conducted with a similar procedure refers to ASTM E-1050-98.

1. Introduction

Studies on the properties of sonic crystals (SCs) have rapidly attracted the researcher's interest in recent years. Bragg scattering and sound waves propagation control being the most exciting issues. When the sound waves propagate through a periodic structure, including SCs, a scattering effect occurs. On a specific condition, when the SCs constant is comparable to the wavelength, the transmission spectra become zero on the associate frequency band. This zero transmission band is known as the bandgap phenomenon. As a consequence of the Bragg scattering condition, the SCs constant becomes too large to be practical when dealing with the low-frequency waves. This problem comes with the local resonant idea where the bandgap can occur on a particular frequency band two orders below the Bragg scattering characteristic frequencies [1,2].

Liu et al. [2] report the pioneering fundamental work explaining the phenomenon's origin through localized resonances associated with each scatterer. Various unique localized resonance on the SCs periodic structure inducing hybridization of the flat resonance and propagating band to produce the stopband. This effort leads to tuning the frequency with the varying scatterers' sizes and shapes [3,4]. Recent work by Zhou et al. introduce another approach for extending and lowering the band gaps. A multilayered locally resonant phononic crystals with unique properties shown new consideration that the bandgap can be determined by the single scatterer rather than periodic structures [5]. The latest works proposed by Ning et al. and Zhang et al. Ning et al. proposed a new different approach. Using equibiaxial compression, they are intentionally exploited deformation-induced geometry and material
nonlinearities of the elastomer matrix and the square array of holes in their acoustic metamaterial model to tune the dynamic response. Their finding indicates that Bragg scattering and band gaps can be simultaneous, controlled by deformation [6]. Slightly different from Ning et al., Zhang et al. exploited the material's stiffness ratio with two negative stiffness regions. They found that adjusting the stiffness ratio can effectively enlarge the negative stiffness region [7].

In this part, we proposed a simple approach for tuning localized resonant frequencies of the folded coplanar resonator (FCR) based SCs scatterer. Like Hall et al. thought, multiplying the number of resonances can effectively attenuate the sound waves [8]. We investigate how the FCR type two response changes when the mass-spring model adjusted through varying the cavity number.

2. Method
The modified type two FCR model used in this work shown in Figure (1). Two cavities construct the outer cavity of the folded outward FCR. One of them works as a Helmholtz resonator connected through a hole to the inner cavity, while the other one is a stepped cavity resonator. The model a made of the same stiff material as in Part 1 with the same geometrical dimension.

![Figure 1. Schematic illustration of advanced outward folded FCR](image)

Similar to Part 1, the entire test conducted by using transfer function based impedance tube method refers to ASTM E-1050 standard. Also, with the B&K 4206 impedance tube connected to Pulse LAN-Xi Multi analyzer. Data acquisition and analysis also using dedicated B&K Material Testing software.

3. Results and Discussions
Figure (2) shows the imaginary part of the impedance ratio of the type 1 FCR compared to the advanced type 2 FCR.

![Figure 2. The imaginary part of the impedance ratio](image)

The impedance ratio of type 1 FCR indicates that the structure has a single resonance, as reported in Part 1. The different phenomenon occurred on the advanced type 2 FCR model. The two peaks associate with two resonances mechanisms. The first peak at 240 Hz is related to the Helmholtz resonator's
resonance on the outer cavity, coupled with the inner cavity resonator. The coupled-cavity structure results in a bigger volume, thus shifting the resonance frequency slightly lower than the type 1 FCR model that occurred on 290 Hz.

The second peak at 700 Hz associated with the stepped cavity resonator indicates that the localized resonance can be adjusted using subwavelength geometrical dimension resonator inclusion. Thus, according to Chen et al. [9], this finding brings the possibility for tuning multi-local resonances in a single geometrical dimension SCs scatterer. In regards to Liu et al. [2] and Hall et al. [8], varying in number and dimensions of the stepped resonator inclusions inside the FCR based SCs scatterer will inducing hybridization localized resonances. Thus, it expected to extend band gaps and lowering the band stop frequencies.

![Figure 3. The corrected transfer function of coplanar resonator model](image)

**Figure 3.** The corrected transfer function of coplanar resonator model

Another proof is from the coplanar resonator with the single and dual cavity model. The model is a plate-shaped mode and made of similar stiff paper and tested with the same equipment. The real and imaginary parts of both models' corrected transfer function are presented in Figure (3). Similar to the phenomenon on the advanced FCR model, as shown in Figure 3 (b), an additional resonance frequency occurred at the higher band 1 kHz on the dual cavity model. It indicates that adjusting the spring-mass model can be implemented to vary the reactance of the SCs scatterers. Thus, the localized resonances can be adjusted and also be possible for extending to get the multi-local resonant feature.

4. **Conclusion**

Spring mass model-based tuning approach in terms of varying the cavity reactance of SCs scatterers can induce localized resonances. It also applies for extending the number of resonant frequencies to get multi-local resonances feature of the single geometrical dimension SCs elements and acoustic metamaterials.

**References**

[1] Liu, Z., Zhang, X., Mao, Y., Zhu, Y. Y., Yang, Z., Chan, C. T., and Sheng, P. (2000) Locally resonant sonic materials. Science. 289. 1734-1736

[2] Liu, Z., Chan, C. T., and Sheng, P. (2002) Three-component elastic wave band-gap material. Physical Review B. 65. 165116. 1-6

[3] Romero-Garcia, V., Krynkin, A., Garcia-Raffi, L. M., Umnova, O., and Sanchez-Perez, J. V.
(2013) Multi-resonant scaterrers in sonic crystals: Locally multi-resonant acoustic metamaterial. Journal of Sound and Vibration. 332. 184-198

[4] Gu, Y. W., Luo, X. D., and Ma, H. R. (2008) Optimization of the local resonant sonic material by tuning the shape of resonator. J. Phys. D: Appl. Phys. 41. 205402. 1-7

[5] Zhou, X., Xu, Y., Liu, Y., Lv, L., Peng, F., and Wang, L. (2018) Extending and lowering band gaps by multilayered locally resonant phononic crystals. Applied Acoustics. 133. 97-107

[6] Ning, S., Yang, F., Luo, C., Liu, Z., and Zhuang, Z. (2020) Low-frequency tunable locally resonant band gaps in acoustic metamaterial through large deformation. Extreme Mechanics Letters. 35. 100632. 1-7

[7] Zhang, Y. Y., Gao, N. S., and Wu, J. H. (2020) New mechanism of tunable broadband in local resonant structures. Applied Acoustics. 169. 107482. 1-7

[8] Hall, A. J., Dodd, G., and Calius, E. P. (2020) Multiplying resonances for attenuation in mechanical metamaterials: Part 1 – concepts, initial validation and single-layer structures. Applied Acoustics. 170. 107513. 1-13

[9] Chen, C., Du, Z., Hu, G., and Yang, J. (2017) A low-frequency sound absorbing material with subwavelength thickness. Applied Physics Letters. 110. 221903. 1-4