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Sound Absorption of Thin Resonators Including a Winding Neck Extension in Surface Panel

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ABSTRACT

Acoustic resonant absorber like a perforated panel or a Helmholtz resonator can be tuned at a low frequency by extending its neck or enlarging cavity volume. However, a total size of the resonators is often quite large when the neck or the cavity is simply extended for tuning at a low frequency. Previous researchers have studied Helmholtz resonator shortened in its size by subsided neck into back air cavity, and confirm that this resonator is tuned at low frequency without a deep cavity. The author has studied effects of a winding built-in neck extension to sound absorption of perforated panels and Helmholtz resonators, which show same effects as the subsided neck into back cavity. This study measures and discusses sound absorption of thin resonator tuned at a low frequency. Test pieces have various neck extensions built in a surface panel and 15 mm total thickness of resonators to propose as sound absorption tiles attaching on walls or partitions. Discussions in this paper focus effects of opening size of the resonator, path length, patterns or number of turns of the winding neck extension and cavity volume to the sound absorption of the thin resonator.

Keywords: Sound, Absorption, Resonator

1. INTRODUCTION

The previous studies have studied effects of sound absorption by a small size resonator tuning at a low and middle frequency, and it is typical method to enlarge cavity volume or neck length of the resonator tuned at low frequency. These typical methods enlarge total size of resonators or sound absorption structures. Small size of sound absorbers are often needed for turning a reverberation time or reducing an environmental noise in small chamber room e.g. a meeting room, a practice room for music and a cabin in air plane or ship.

To shorten the size of resonator, Iwase et al.[1] have studied the effects on acoustic resonance by the subsiding changes of neck from original type Helmholtz resonator and by the adapting of extension parts to opening hole of perforated panel. From their experimental research to make shortening size of Helmholtz resonator and lowering resonant frequency of sound absorption of perforated panel, they conclude that use of extension parts to the opening hole on the perforated plate is effective to lower the resonance frequency simply. They have also obtained the same effects of extension parts with turn back shape in the cavity as with straight shape. And, Iwase et al.[2] have verified the high sound absorption at low frequency by the method adding extension part behind opening holes. They could also have the empiric model to calculate the acoustic impedance and the sound absorption coefficient for their new type resonator.

As applications from the previous study by Iwase et al., the author[3] considered that the extension parts are built in perforated panel with multi-turn back shape. Measurements of its sound absorption coefficient and considerations on effects of the winding extension to the resonant sound absorption show that the extension shifts its resonant peak to lower frequency without change of depth of air cavity which affects total thickness of the sound resonator. The shift amount of the resonant frequency is quite close between the straight extension and the winding extension when its section area is 3 mm side of square and 2.4 mm side of square, although the shift amount increases when the section area is 1.8 mm side of square as the winding extension including twice of rectangle corners to same length of the above cases.

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Moreover, the author[4] discussed sound absorption of the resonator included the various winding neck extension built in a surface panel. A winding neck extension built in upper plate of the Helmholtz resonator is useful method to tune it at lower resonant frequency. Structure of winding extension tube is generally made with any turn-backed tube, although this study show that the resonant does not appear for 1.8 mm side of square opening with 40 mm of extension tube. And, This study indicated that 8 turn back of 80 mm of extension tube shifts the resonance to 23 % higher frequency than designed resonance frequency, because a virtual path of air flow in the tube is narrower than the physical cross section[5]. It seemed to be caused by a vortex at inner wall of 180-degree turn due to turbulent flow separation in a rectangular tube.

This study measures and discusses sound absorption of thin resonator tuned at a low frequency. Test single Helmholtz resonators have various neck extensions built in a surface panel and 10mm or 15 mm total thickness of resonators to propose as sound absorption tiles attaching on walls or partitions. Discussions in this paper focus effects of opening size of the resonator, path length, patterns or number of turns of the winding neck extension and cavity volume to the sound absorption of the thin resonator.

2. MEASUREMENT

2.1 Procedure

The sound absorption coefficient of test Helmholtz resonator including a winding neck extension in a surface panel is obtained by surface normal impedance $Z_{n,EA}$ at the opening hole, which is measured by in-situ measurement method[6]. Figure 1 and Figure 2 indicate procedure of measuring their surface normal impedance in workshop of Hiroshima International University. The test Helmholtz resonator is built in a box of 120 mm side of upper square surface and 60 mm height which is placed on the rigid floor.

Two microphones are placed at the opening hole of test Helmholtz resonator for measuring transmission function H_{pp} between them, is needed to calculate normal surface impedance by in-situ measurement method. Incoherent pink noise from five loudspeakers in the workshop makes random sound incidence to the surface of test Helmholtz resonator.

The normal surface impedance of test perforated panel is obtained by following equation:

$$Z_{n,EA} = \rho c \frac{H_{pp}\left(1 - e^{2jk(l+d)}\right) - e^{jkl}\left(1 - e^{2jkd}\right)}{H_{pp}\left(1 + e^{2jk(l+d)}\right) - e^{jkl}\left(1 + e^{2jkd}\right)} \tag{1}$$

Here, d is distance between the surface of test piece and lower microphone, l is 14 mm distance between centers of two microphones, ρ is air density, c is sound speed in the air, k is wave number and j is the imaginary unit.

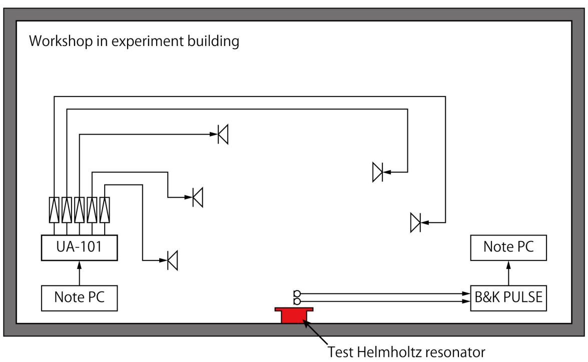
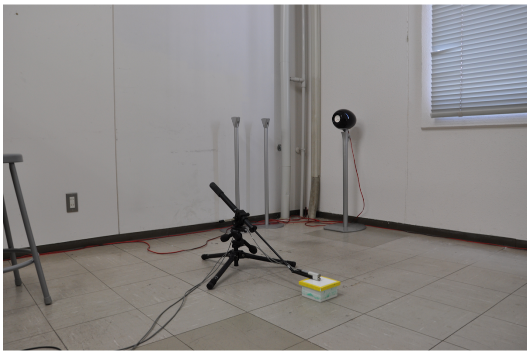


Figure 1 – Procedure of in-situ measurement method for measuring normal surface impedance at an opening hole of test Helmholtz resonator.



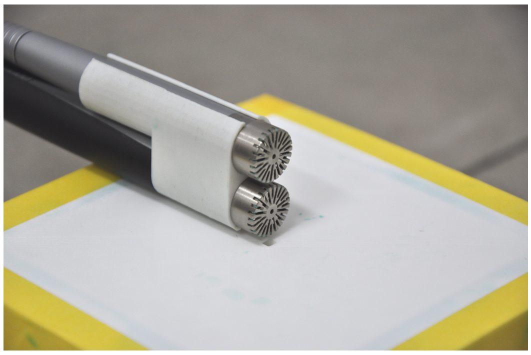


Figure 2 – Positions of the test Helmholtz resonator on a floor in the workshop and two microphones at an opening hole of the resonator.

2.2 Structures of test Helmholtz resonators

Figure 3 shows a test Helmholtz resonator built in the box like double shells filled clay between them. The clay is used to fix vibration of shells by its large mass and large viscosity. Each part is modeled by Google SketchUp and is made by 3D printing (MakerBot, Replicator2) with polylactic acid plastics. The resonator has a square opening hole, a winding neck extension tube with a square section and a rectangular cavity behind it. Each resonator is designed to be tuned at 200 Hz by the following formula:

$$f_{res} = \frac{c}{2\pi}\sqrt{\frac{S}{V(l + 0.8\,d')}} \quad [\mathrm{Hz}] \tag{2}$$

Here, c is sound speed in the air [m/s], S is area of opening hole [m^2], V is volume of cavity [m^3], l is length of neck and d' is diameter of equivalent circle with same area of the square opening hole.

Test Helmholtz resonators have 10 mm or 15 mm of total thickness from a surface plate to a bottom of the cavity. A extension tube attached at opening hole has 80 mm length for all test Helmholtz resonators. A side length of its square opening holes has 2.4 mm, 3.0 mm and 3.6 mm, and numbers of turn backs of extension tube are 1 to 13 turn backs, 1 to 10 turn backs and 1 to 8 turn backs respectively. And, a resonant frequency of these resonators is tuned 100 Hz or 200 Hz. Detail specifications are indicated in Table 1.

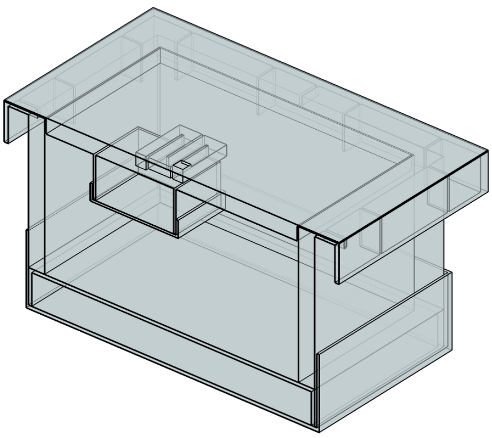


Figure 3 – A cross section of a test Helmholtz resonator built in a box of 120 mm side of upper square surface and 60 mm height filled clay between them.

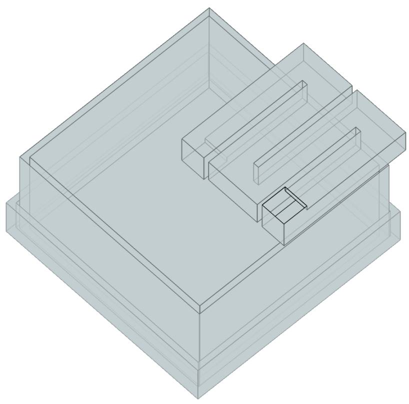


Figure 4 – Examples of the Helmholtz resonator having 3 turn backs of winding extension tube built in the upper plate.

Table 1 – Specifications of test Helmholtz resonators with 80 mm length of neck built in surface plate.

Total thickness (mm)	Square hole size (mm)	Cavity volume(mm^3) (section area × depth)	Number of turn backs
(1) Resonant frequency is 200 Hz.			
	2.4	$21.2^2 \times 10.2$	1 to 13
15 mm	3.0	$26.4^2 \times 10.2$	1 to 10
	3.6	$31.6^2 \times 10.2$	1 to 8
	2.4	$28.3^2 \times 5.2$	1 to 13
10 mm	3.0	$35.3^2 \times 5.2$	1 to 10
	3.6	$42.2^2 \times 5.2$	1 to 8
(2) Resonant frequency is 100 Hz.			
	2.4	$42.4^2 \times 10.2$	1 to 13
15 mm	3.0	$52.9^2 \times 10.2$	1 to 10
	3.6	$63.2^2 \times 10.2$	1 to 8

3. RESULTS AND DISCUSSION

3.1 Frequency characteristics of absorption coefficient

This section focuses sound absorption of thin Helmholtz resonator and discusses effects of turn backs in the winding extension tube to the sound absorption.

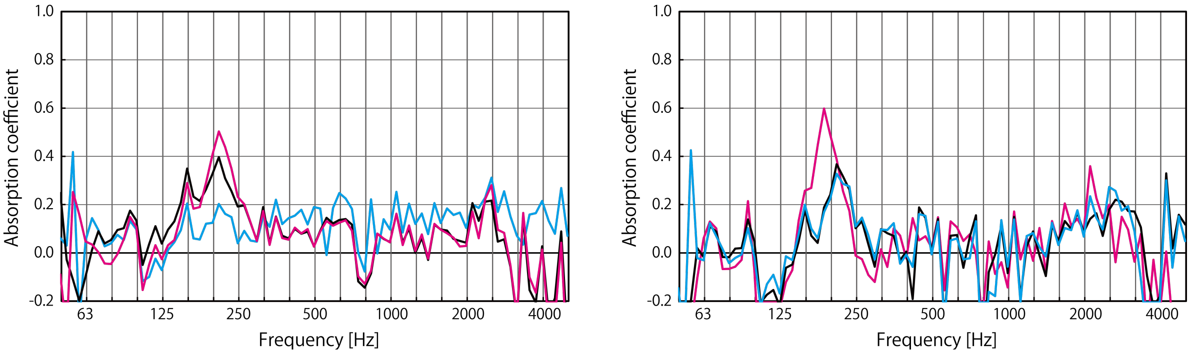
All test resonators with a 2.4 mm squared opening hole have no resonant peak around 200 Hz or 100 Hz designed by Eq. 2. As mentioned previous study[4], it is well known that resonance of the resonator becomes weak and small value due to a large pressure loss ΔP of a straight cylindrical duct is inversely proportional to its diameter as following formula:

$$\Delta P = \lambda \frac{L}{d} \frac{\rho\, v^2}{2} \quad [\mathrm{Pa}] \tag{3}$$

Here, λ is a friction factor of the duct, L [m] is its length, d [m] is its diameter, ρ [kg/m^3] is the density of the air and v [m/s] is speed of air flow in the duct. When the pressure loss enlarges with narrow tube, the pressure at a bottom of extension tube attached the cavity becomes small pressure from the opening hole and can not compress a volume of the cavity as air spring consisting a resonator with mass of air in the neck. As the results, a significant peak of the absorption coefficient of the resonator with 2.4 mm squared opening hole.

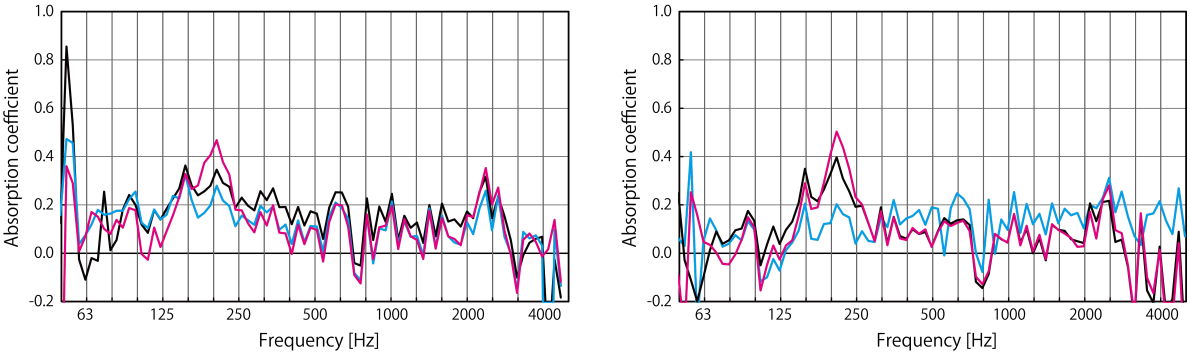
Figures 5,6 and 7 indicate three examples of absorption coefficient of test Helmholtz resonators with 3.0 mm or 3.6 mm squared opening holes, which have a peak around 200 Hz or 100 Hz as a resonant frequency designed by Eq. 2. In the figures, black solid line has a median peak value around the resonant frequency of the resonator with various numbers of turn back in the winding extension tube. Red solid line and blue solid line have a maximum and a minimum peak value respectively, and show a variation range of effects by turn back of the winding extension tube.

These figures show that a significant peak around 200 Hz or 100 Hz designed by Eq. 2 is found in absorption coefficient of each test resonator. This study obtained a unit resonator consisting thinner sound absorption structure even with 10 mm of total thickness, in compared with 19.8 mm of total thickness of Helmholtz resonators in the previous study[4]. This study also suggests that thin plane resonant sound absorber with 15 mm of total thickness tuned at 100 Hz can be assembled many small unit resonators. Here, the resonator with 3.6 mm squared opening hole tuned at 100 Hz has a large peak value of absorption coefficient.



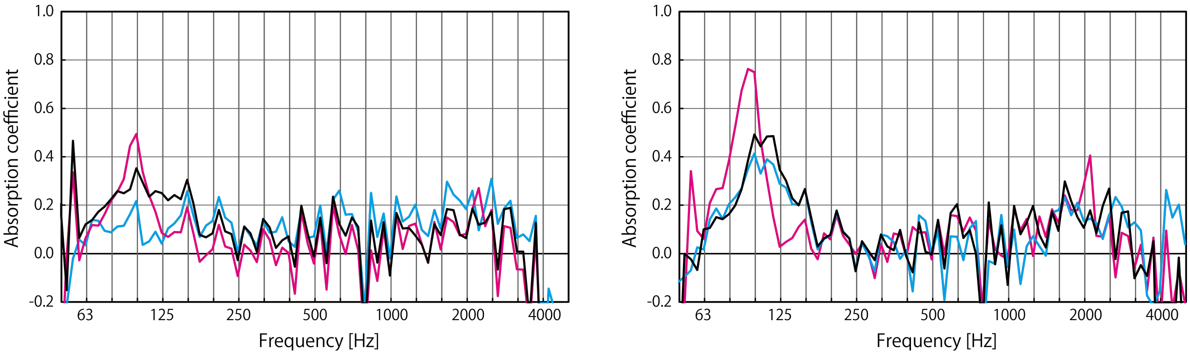
(1) 3.0 mm squared of opening hole (2) 3.6 mm squared of opening hole

Figure 5 – Three examples of absorption coefficient of the resonator. Resonant frequency is tuned at 200 Hz and the total thickness 15 mm. Black solid line indicates median peak value, red solid line indicates maximum peak value and blue line indicates minimum peak value



(1) 3.0 mm squared of opening hole (2) 3.6 mm squared of opening hole

Figure 6 – Three examples of absorption coefficient of the resonator. Resonant frequency is tuned at 200 Hz and the total thickness 10 mm. Black solid line indicates median peak value, red solid line indicates maximum peak value and blue line indicates minimum peak value



(1) 3.0 mm squared of opening hole (2) 3.6 mm squared of opening hole

Figure 7 – Three examples of absorption coefficient of the resonator. Resonant frequency is tuned at 100 Hz and the total thickness 15 mm. Black solid line indicates median peak value, red solid line indicates maximum peak value and blue line indicates minimum peak value

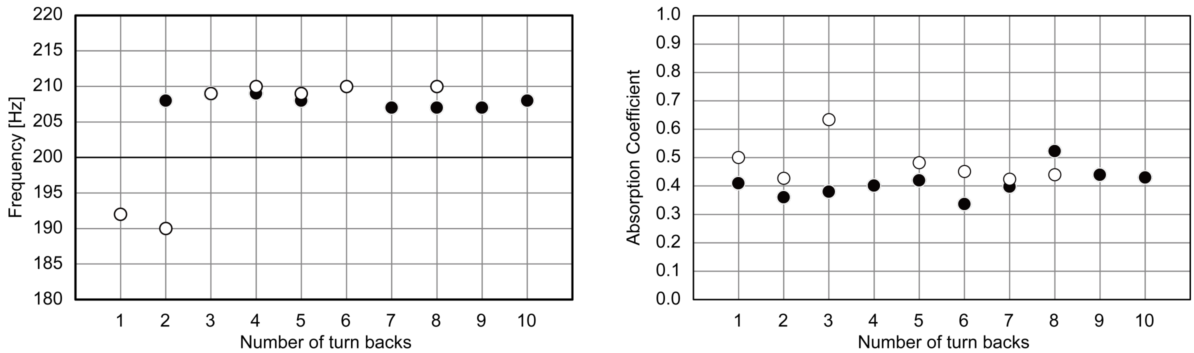
3.2 Peak frequency and peak value of absorption coefficient

This section focuses peak frequency and peak value of absorption coefficient of the test Helmholtz resonators with various number of turn back of neck extension tube.

Figures 8 and 9 indicate peak frequency and peak value of absorption coefficient of the resonators tuned at 200 Hz. Almost of all resonators have a peak frequency at around 209 Hz shifted toward higher frequency than a designed resonant frequency of 200 Hz with its difference of 9 Hz (4.5 %). This shift difference seems to be independent from number of turn back of neck extension tube and between 3.0 mm and 3.6 mm squared opening hole. Previous study[4] shows that peak frequency shifts toward higher as increasing numbers of turn backs of neck extension tube with 3.6 mm squared opening hole up to 246 Hz with 8 turn backs.

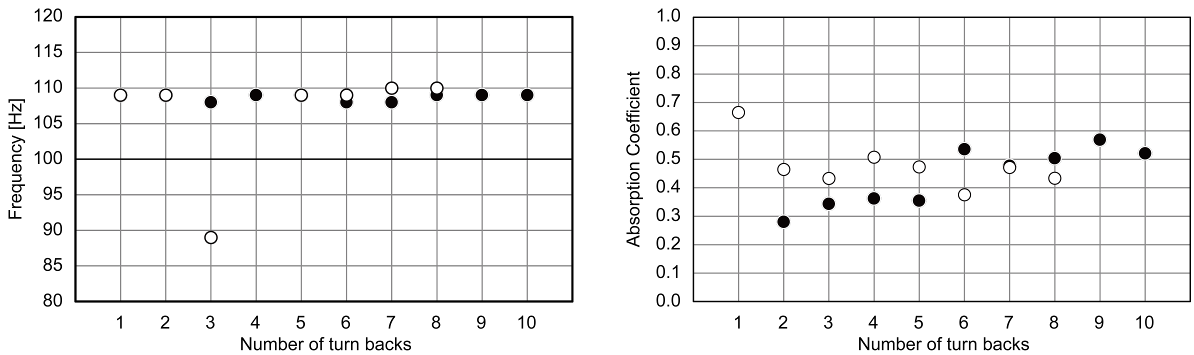
Peak values of absorption coefficient vary 0.3 to 0.6 in case of 15 mm total thickness of resonators tuned at 200 Hz and seem to be independent from number of turn backs of neck extension tube. And, the peak values for the resonators with 3.6 mm squared opening hole are slightly larger than 3.0 mm squared opening holes in case of 1 to 6 turn backs of neck extension tubes. Moreover, peak values of absorption coefficient vary 0.3 to 0.7 in case of 10 mm total thickness of resonators tuned at 200 Hz. Similarly, peak values for the resonators with 3.6 mm squared hole are larger than 3.0 mm squared opening hole in case of 1 to 5 turn backs. Previous study[4] shows that large peak values are obtained in case of 3, 4 and 5 turn backs and that their values of absorption coefficient are around 0.6. In previous study and this study, test Helmholtz resonators ware made by 3D printing (MakerBot, Replicator2) with polylactic acid plastics. Because this 3D printing is based on Fused deposition modeling, inner wall in neck extension tube fluctuates and varies its friction loss.

Figure 10 indicates peak frequency and peak value of absorption coefficient of the resonators tuned at 100 Hz. Peak frequencies are around 100 Hz except for the resonator with 3.6 mm squared opening hole and 8 turn backs. Although the resonators with 3.0 mm squared opening hole shows that peak value varies 0.3 to 0.5, the resonators with 3.6 mm squared opening hole shows that peak values reduce as increasing number of turn backs of the extension tube.



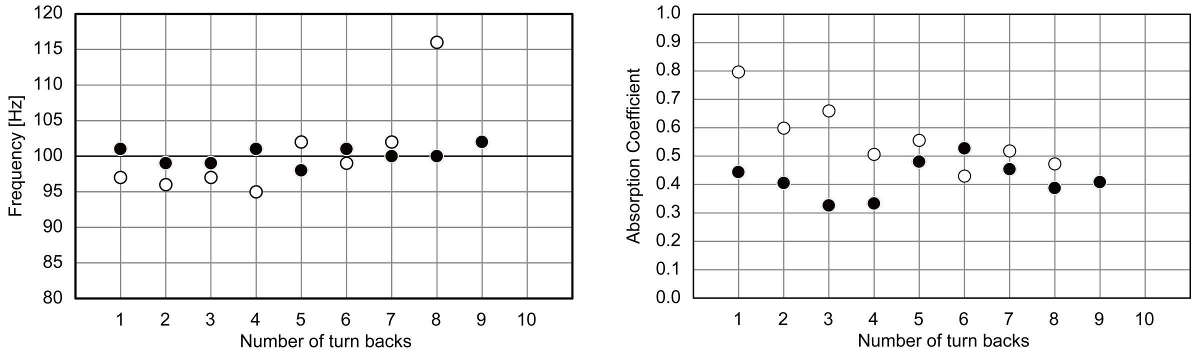
(1) Peak frequency of absorption coefficient (2) Peak value of absorption coefficient

Figure 8 – Effects of number of turn backs of winding neck extensions to peak frequency and peak value of absorption coefficient around resonant frequency designed for test Helmholtz resonators. Resonant frequency is 200 Hz and total thickness is 15 mm. Open circles indicate the resonator with 3.6 mm squared hole and black circles indicate the resonator with 3.0 mm squared hole.



(1) Peak frequency of absorption coefficient (2) Peak value of absorption coefficient

Figure 9 – Effects of number of turn backs of winding neck extensions to peak frequency and peak value of absorption coefficient around resonant frequency designed for test Helmholtz resonators. Resonant frequency is 200 Hz and total thickness is 10 mm. Open circles indicate the resonator with 3.6 mm squared hole and black circles indicate the resonator with 3.0 mm squared hole.



(1) Peak frequency of absorption coefficient (2) Peak value of absorption coefficient

Figure 10 – Effects of number of turn backs of winding neck extensions to peak frequency and peak value of absorption coefficient around resonant frequency designed for test Helmholtz resonators. Resonant frequency is 100 Hz and total thickness is 15 mm. Open circles indicate the resonator with 3.6 mm squared hole and black circles indicate the resonator with 3.0 mm squared hole.

4. CONCLUSIONS

This study measured and discussed sound absorption of thin resonator tuned at a low frequency. Test single Helmholtz resonators have various neck extensions built in a surface panel and 10mm or 15 mm total thickness of resonators to propose as sound absorption tiles attaching on walls or partitions. Discussions in this paper focused effects of opening size of the resonator, path length, patterns or number of turns of the winding neck extension and cavity volume to the sound absorption of the thin resonator.

The author suggests following conclusions.

(1) A winding neck extension tube built in surface plate can give a thin resonant sound absorber, which will be used as tiles set on a wall or a partition to control the reverberant time or noise reduction in small camber room.

(2) This study confirmed that peak frequency equally shifts toward higher than the designed resonant frequency for the resonators tuned at 200 Hz as shown in previous study[4], although previous study shows peak frequency becomes higher as increasing number of turn backs.

(3) The resonators tuned at 100 Hz are available for producing thin sound absorber at low frequency. Future study will discuss sound absorbing tile at low frequency by assembled many resonator unit.

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