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Random Incidence Transmission Loss of Miniature Helmholtz Resonator Embedded Acoustic Meta-material

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ABSTRACT

An array of light-weight miniature Helmholtz resonators (HRs), was shown to significantly enhance the low frequency absorption, when embedded in a PU foam material; this test was carried out in an impedance tube. This concept was then used to study the sound absorption in a cylindrical cavity. A series of tests were carried out by changing number of HRs, embedded circumferentially into foam, at various radial distances on top of the cavity, with a noise source at the bottom. About 8-14 dB reduction in noise levels was observed at lower frequencies. In this paper, the idea is now extended to examine the random incidence transmission loss (TL) of such an array of embedded HRs. Towards this purpose, a twin room reverberation chamber with a 300 mm x 300 mm panel in between is used; random incidence is carried out using first a 45 mm foam alone followed by the foam embedded with a periodic array of HRs. The effectiveness of this concept to increase TL at lower frequencies will be demonstrated. Also, by adjusting the resonator frequencies, by intruding the neck into resonator cavity, is shown to increase the TL over a broader range of frequencies.
Keywords: Miniature HR, Meta-material, Transmission Loss.

1. INTRODUCTION

Controlling low frequency noise is still a great challenge in industry and daily life. One of the earliest attempts to solve this problem was the development of a micro-perforated panel (MPP) absorber (1, 2). Following this idea, the use of Helmholtz resonator (HR) (3) with many modifications such as degenerate resonators (4), resonant patches (5) and multiple orifices (6) have been introduced. These solutions have typically been effective in narrow frequency bands and in the case of HRs lead to increased weight due to large dimensions of the HRs.

Another possible solution that has been suggested is to use porous material with mass inclusion (7). The embedded masses combined with porous material form an array of spring-mass-damper system and improve the acoustic performance. Later, this type of mass embedded material was named as heterogeneous blanket (HG). For further improvement in transmission loss and absorption capability, the proposed HG blanket was investigated with various embedded mass such as steel balls, Styrofoam balls and hollow aluminum balls (8). These again do not yield fairly broad band low frequency noise reduction.

The third and latest set of solutions to mitigate a low frequency sound is the acoustic metamaterials (AMM). In an AMM a periodic arrangement of masses is being done at a scale smaller than the wavelength to be captured. The first AMM, sonic crystal (9) was demonstrated using lead balls covered with silicone rubber. The author who proposed the HG blanket explored the transmission loss as well as absorption coefficient using mass embedded and MPP based AMMs (10, 11). At around the same time, the effect of a resonant inclusion in a porous material was investigated using TMM and P-TMM based analytical modelling approach (12). Apart from the porous media based AMM-honeycomb based AMM (13), membrane and plate-type (14) AMMs have been developed and their effectiveness demonstrated through experiments. But all of them are heavier because of either larger thickness of porous media or larger dimensions of HR/included masses and perform only over a limited low frequency range. Further, most of the researchers have examined mostly the normal incidence absorption coefficient and transmission losses characteristics of the developed materials.

This paper, after briefly summarizing the earlier work done by the authors on miniature HR based acoustic meta-materials, will focus on the experimental investigation of random incidence transmission loss (TL) of the miniature HR embedded AMM. The material is fabricated by embedding

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an array of cylindrical cavity miniature HRs into PU foam and tested in twin reverberation chamber. The relative transmission losses are reported here. Also the differences and advantages over other acoustic metamaterials will be highlighted.

2. SUMMARY OF PRIOR WORK

2.1 Idea of Miniature HR embedded AMM

To reduce the size and to get an enhanced absorption capability over a broader frequency range, the idea of miniature HR is proposed by using syringes of different sizes. The dimensions and geometry details of medical syringes for considered frequencies are given in the Table 1.

Table 1 – Different types of geometries of HR

Syringe Size (cc)	Geometry Type	Cavity Diameter (mm)	Cavity Height (mm)	Neck Diameter (mm)	Cavity Height (mm)	Targeted Frequency (Hz)
10	G1	14	24	2	9	480
10	G2	14	58	2	9	350
10	G3	14	86	2	9	265

A series of tests were conducted in a 6 inch impedance tube designed as per ISO standards at IIT Madras. For the proof of concept of miniature HR, detuning of HR, and formation of new AMM a total of four sets of experiments were carried out using the impedance tube. After confirming that the idea of using syringes as HRs does work further investigation was done with a sample, made of 9 syringes (3 G1 type, 3 G2 type and 3 G3 type) with one placed at the center and 8 at the circumference of a plate with a radius of 55 mm. The determined absorption coefficient is shown in Figure 1.

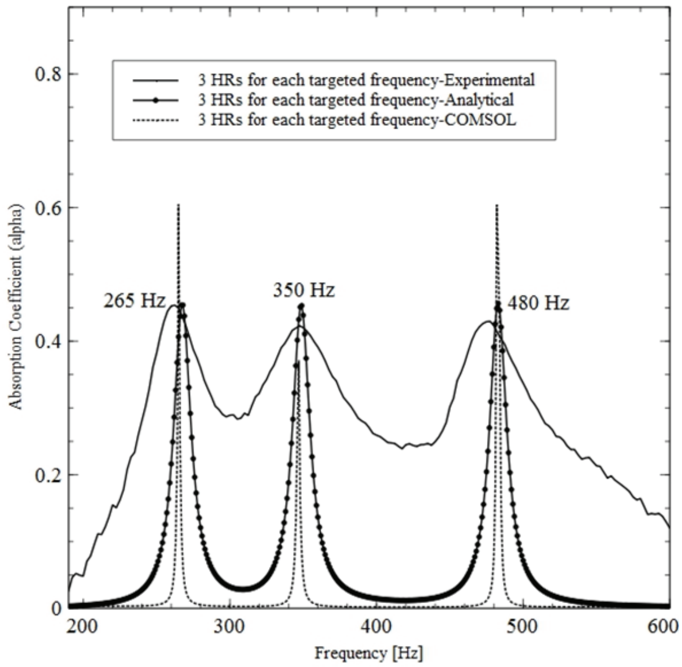


Figure 1- Absorption coefficient of multiple HRs.

One can see that the overall absorption between the peaks are also improved in experiment; the 1D analytical model has a model for radiation impedance included and hence the anti-nodal regions are somewhat higher compared to the finite element model (done in COMSOL), where only a small dissipation is added to the air medium and hence shows narrower peaks. The same set of experiments were repeated with HRs embedded in a 20 mm PU foam as shown in Figure 2 (a). In Figure 2 (b) a typical mass embedded 4 inch AMM is shown.

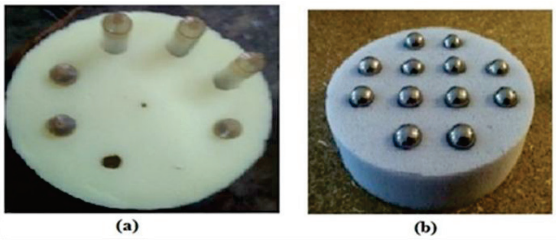


Figure 2- (a) 1 inch HR embedded AMM (b) 4 inch AMM (reproduced from reference 11)

The absorptive performance of 20 mm foam is quite low over the chosen band. At 265 Hz the combined effect of foam and HR, shown in Figure 3, is similar to the previous case as shown in Figure 1, but at and beyond 350 Hz its effect is visible.

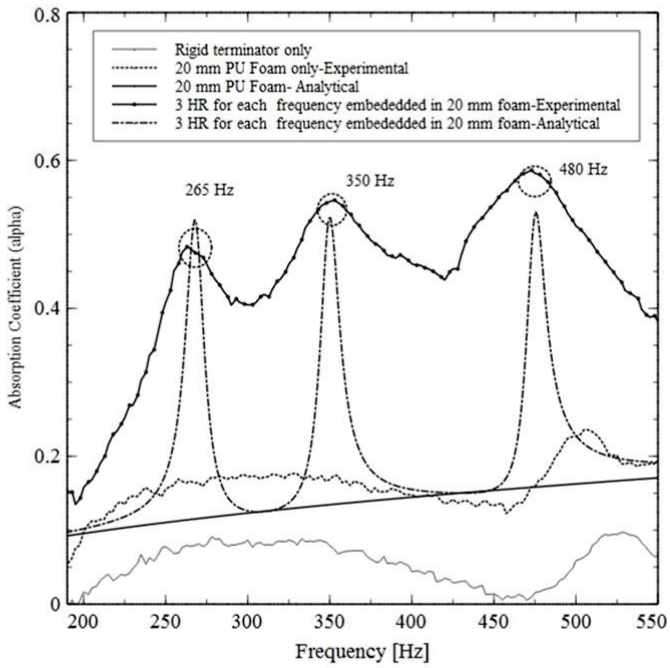


Figure 3- Absorption curve of HR embedded AMM

Also the anti-resonance deep between the peaks are also slightly lifted up which is good from an absorption view point. And more importantly, below 500 Hz, the new metamaterial has shown a greater broad band absorption capability when compared with the ideas proposed in the literature. The developed metamaterial is light in weight and cheaper in cost. So, newly designed HR embedded acoustic metamaterial is very much suitable for payload fairings and car cabins.

2.2 Cavity Demonstration of the new HR embedded AMM

For checking the effectiveness of the proposed novel material in real life or equivalent problems a demonstration was conducted in a cylindrical cavity shown in Figure 4.

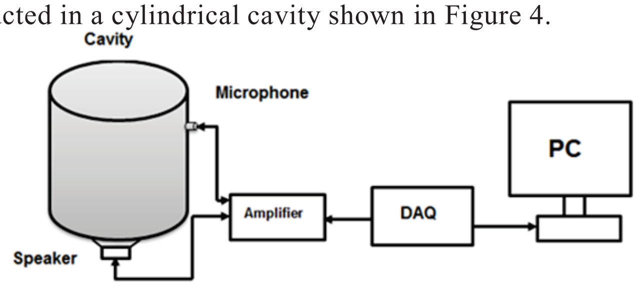


Figure 4. Schematic of cavity demonstration set up

A series of experiments were conducted with four different conditions, shown in Figure 5, as follows: cavity with top acrylic plate only, acrylic plate with 20 mm PU foam of density 16 kg/m^3 only, acrylic plate with HRs only and, and acrylic plate with new AMM (Foam+ HR).

Figure 5- Acrylic plates in different test conditions

The typical dimensions of HRs for the first axial mode 262 Hz are the same as mentioned in the Table 1. For case 3 and 4, a total of 36 HRs are placed in the acrylic plate at three different radii as shown in Figure 5. The number of HRs placed at the periphery of circle of radius 8 cm, 16 cm and 24 cm 8 are 8, 12 and 20 respectively.

The first set up was done with acrylic plate only and subsequently other three. For investigating the effect of the HR embedded AMM over a range of 200-550 Hz, a combination of different dimensions of HRs were placed at 3 different places. A combination of 18+18 HRs for targeting frequencies 265 Hz and 532 Hz was used. The positions of HRs were interchanged and investigated their effectiveness.

The red dotted line in Figure 6, shows 10 dB and 13 dB reduction in SPL at frequencies 265 Hz and 532 Hz respectively. It can be seen that around 265 Hz the noise reduction is entirely due to the resonators while at 532 Hz the resonators enhance the absorption offered by the foam.

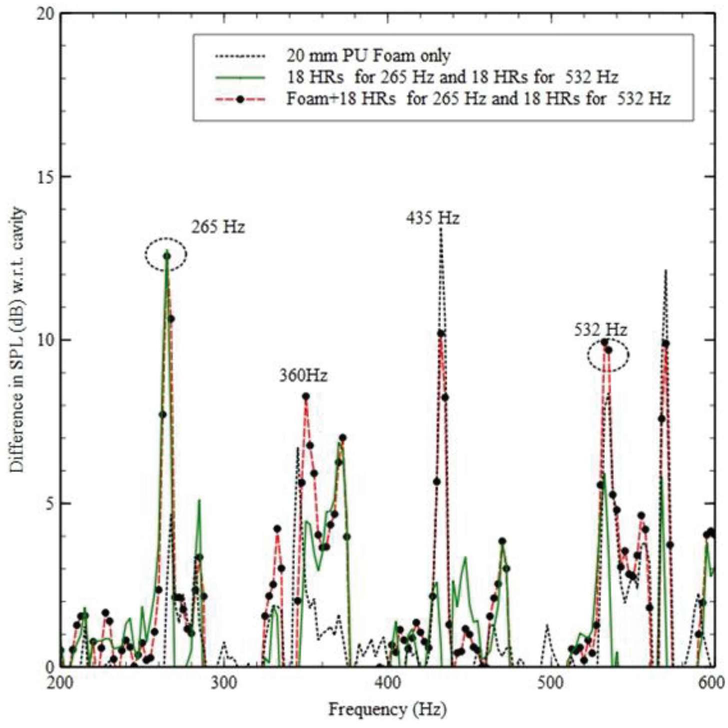


Figure 6- Reduction of SPL (dB) w.r.t. the cavity at different cases for 265 Hz and 532 Hz

3. TRANSMISSION LOSS MEASUREMENT

3.1 Experimental Set Up

The transmission loss measurement for random incidence of sound is usually done in a reverberation chamber. A reverberation chamber (RC) consists of two closed chambers. The sound source is placed in the larger chamber and sample is fitted in the junction of two chambers. A schematic diagram of twin reverberation chamber is shown in Figure 7.

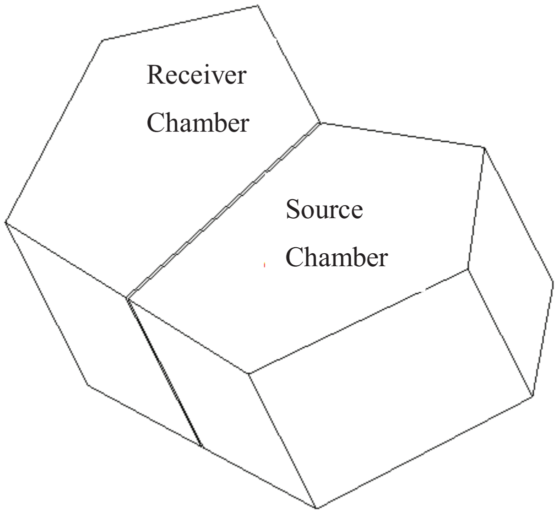


Figure 7- Schematic of twin reverberation chamber

Two quarter inch condenser type microphones, one in the source chamber and another in the receiver chamber, are placed to measure pressure level at various locations. Both the microphones are connected with data acquisition system for storing and post processing the measured data in frequency as well as time domains. The input which is a wide band sound in the source chamber is produced by B & K sound source at a particular dB level.

3.2 Sample Preparation

The sample tested in the chamber is made of PU foam in which miniature HRs can be embedded. Here instead of 20 mm a 45 mm PU of dimension 300 mm x 300 mm is used. It was done to make the sample leak-proof and fully embed HRs. The syringes which were used as HRs are now replaced by a standard cylindrical geometry as shown in Figure 8.

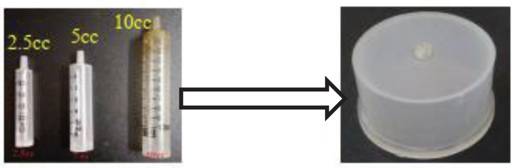
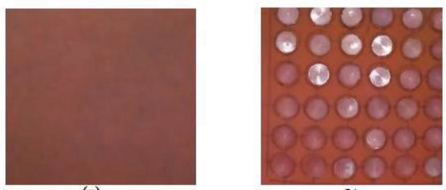


Figure 8. Equivalent miniature HR of syringes

For making the design of HR more compact the concept of intrusion of neck into to the cavity is also implemented. The neck length is fixed at 2 mm from the top surface of the cavity. Basically only two types of samples are investigated: one with only foam and other with HR embedded foam as shown in Figure 9 (a) and (b). The total number of HRs embedded are 36.



(a) (b)

Figure 9- (a) 45mm PU foam only (b) HR embedded foam

All 36 HRs tuned to a single frequency (360 or 465 Hz) or 18 of them to 360 Hz and 18 to 465 Hz. The change in the HR resonant frequency is accomplished by changing the intrusion length of the resonator neck into the cavity.

3.3 Results and Discussion

In the first phase of measurement, only PU foam is tested and transmission loss (TL) is evaluated. Keeping all boundary conditions same, the same measurement is repeated with HR embedded AMM tuned at 360 Hz. A point to note here is that in the calculation of the TL the term due to reverberation time is excluded. Since it is a constant so the nature of the curve will not change. Therefore, in Figure 10, the relative TL is shown demonstrates a significant improvement around the HR natural frequency.

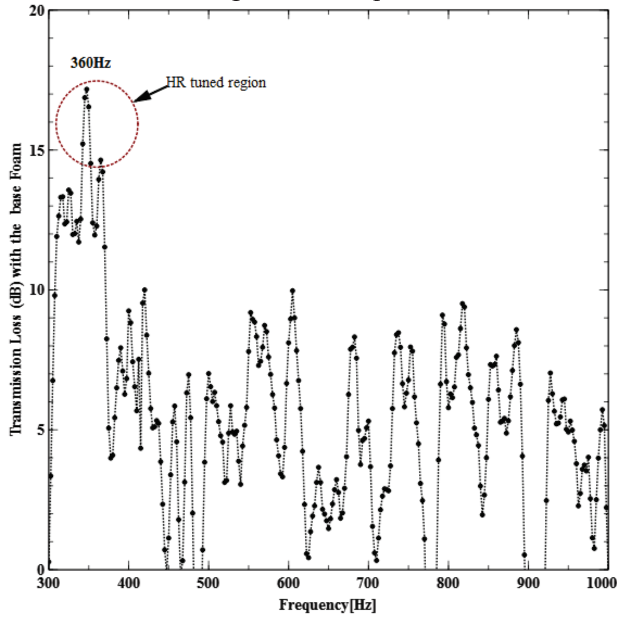


Figure 10- TL of HR embedded AMM relative to foam tuned at 360 Hz

It is interesting to note here that rather than a single sharp peak, one can see a spread around 360 Hz. The 360 Hz is achieved from the baseline 465 Hz design by intruding the neck into the cavity. Since this was done manually there are some small variations in the resonator frequency leading to better performance over a wider band Figure 11 shows the results for the resonators tuned to 465 Hz and here the peak is quite sharp as these form the baseline design.

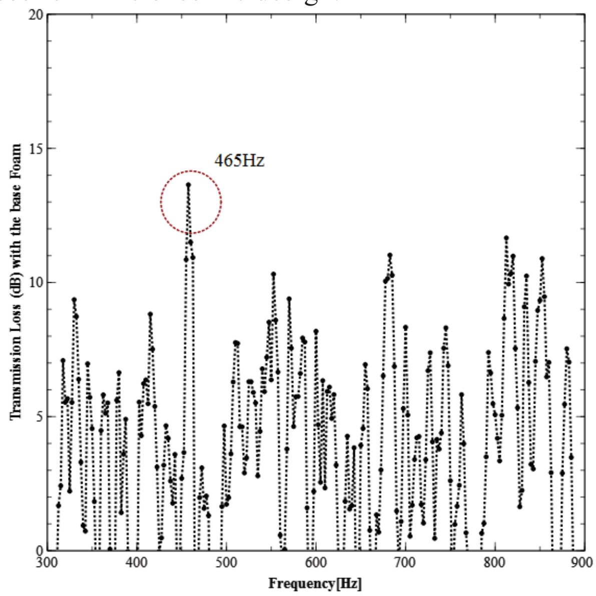


Figure 11- TL of HR embedded AMM relative to foam tuned 465 Hz

One of the prime objectives of the paper to obtain a broad band AMM for low frequency noise control. So, next an experiment is conducted targeting two frequencies. Out of 36 18 HR are tuned at 360 Hz and other 18 are at 465 Hz. The relative TL is shown in Figure 12.

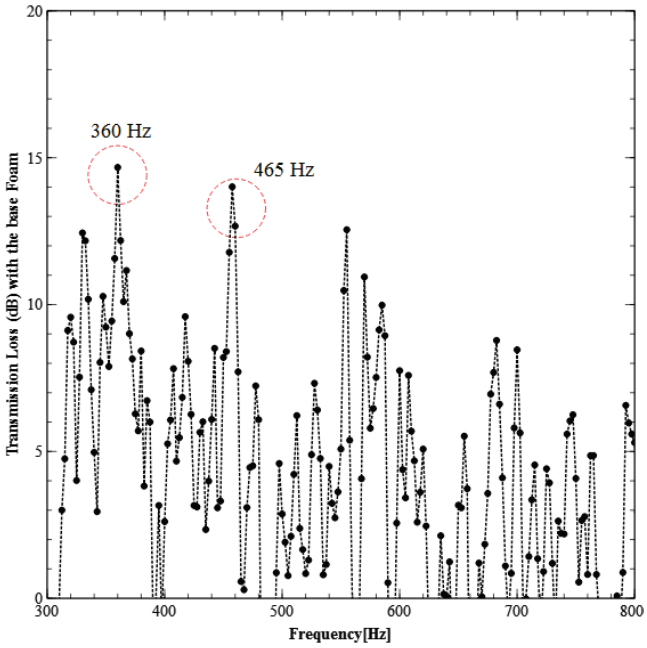


Figure 12- TL of HR embedded AMM relative to foam tuned at 360 Hz and 465 Hz

Again one can notice that there is a broader frequency range around the designed HR resonances where the material performs well. The prime reason behind it is that the HRs are made by assembling three parts (cavity, bottom cavity cap and neck) manually. This can lead to small detuning of the resonances and hence the broader range. This would suggest that detuning the resonators can be used to widen the improved TL region for such materials.

4. CONCLUSIONS

The experimental investigation of the miniature HR embedded AMM shown a relative transmission loss of 12-15 dB over a broader band of frequency in random incidence condition. Moreover, it is now confirmed that using multiple resonators with intrusions for different frequency the acoustic performance of AMM can be enhanced. And also the size of embedded HRs are smaller than proposed AMMs in the literature. It indicates that the material has great potential in real life applications such as building acoustics, car cabin, payload fairings etc. Future work will focus on the effect of the array periodicity on the acoustic performance of such AMMs.

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