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A MULTIPLE QUARTER-WAVE RESONATOR SYSTEM FOR THE ATTENUATION OF NOISE ENTERING BUILDINGS THROUGH VENTILATION OPENINGS

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1. INTRODUCTION

This paper continues ongoing research into the attenuation of noise entering buildings using a system of quarter-wave resonators. Previous work demonstrated the ability of a single quarter-wave resonator to achieve 6dB attenuation in the 1/3 octave band to which the resonator was tuned[1],[2]. This paper extends this research to a multiple resonator system to achieve attenuation over a wider range of frequencies, with an attempt to explain the mechanism of resonator action. It is demonstrated that in addition to attenuation at the predicted resonant frequencies of the resonators, additional attenuation is achieved in neighbouring 1/3 octave bands.

2. POSSIBLE MECHANISM OF RESONATOR ACTION

The mechanism of the resonator reducing noise entering buildings could be thought of as an "active-passive" interference effect. Theoretically, the length of the resonator corresponds to a quarter wavelength of the sound desired at resonance. Hence direct sound propagating towards the resonator opening will be half a wavelength out of phase with sound that has travelled the length of the resonator cavity, reflected off the rigid end and travelled back towards the resonator opening. The direct sound would therefore be 180° out of phase with the resonator sound, resulting in an overall reduction in sound level at the mouth of the resonator in a frequency range centred on the resonant frequency of the resonator. This frequency range would be dependent on the Q factor of the resonator. To verify this prediction, the phase difference between sound at the closed end of the resonator and sound at the mouth of the resonator was measured. In order to do this, a quarter-wave resonator was built in which a hole was made for the insertion of a B&K Type 4133 ½ inch microphone at the rigid end of the resonator. A second microphone (identical to the first microphone) was suspended at the mouth of the resonator. Utilising the frequency response capabilities of a B&K Type 2034 Dual Spectrum Analyser, the phase difference of sound detected at the two microphones was measured when an acoustic driver radiated white noise in the range of 20Hz to 20kHz towards the resonator. The driver was a distance of 200mm from the resonator in line with the mouth of the resonator propagating over a reflective ground surface with grazing incidence. This distance was chosen to minimise path difference effects but to maintain the point source properties of the acoustic driver.

Figure 1 shows phase difference versus frequency. From Figure 1 the phase difference at the first three resonant frequencies was found to be approximately 90°. This was expected since the direct sound has only travelled one length of the resonator cavity before it reaches the rigid end where the second microphone is located, corresponding to a quarter wavelength phase difference. Since there is not a state of resonance at frequencies other than the set resonant frequencies for a given cavity length (according to the Q factor), there is a constant phase relationship between the sound detected at the two microphones (0° or -180° for the scale shown in Figure 1). Note the sudden jump from negative to positive phase change at approximately 3.6kHz in Figure 1 is an artifact required to keep the measurement within the upper and lower limits provided.

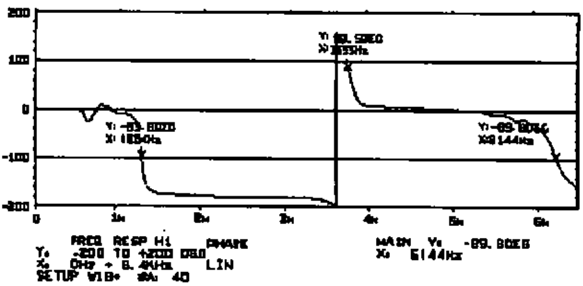

Figure 1: Phase Difference of Sound at Rigid End and Mouth of a 1.25kHz Quarter-wave Resonator

3. MODEL ROOM USED IN FURTHER EXPERIMENTS

The facade of the model room exposed to noise was altered from that used in previous experiments [2]. Firstly, the ventilation opening was moved from the centre of the facade to the bottom in order to minimise path difference effects from direct and reflected sound arriving at the opening. These effects were particularly evident in previous experiments [2]. Secondly, the dimensions of the opening were adjusted while keeping the percentage open area of the opening to the total wall area the same. This was done to avoid any dimension of the opening having any relationship with the length of one of the resonator cavities. Previously, the height of the window of the opening was found to be twice the length of the 3.15kHz resonator cavity, preventing the resonator from achieving any noticeable attenuation of sound within the model room.

4. EXPERIMENTS WITH NEW MODEL ROOM

Experiments were carried out on the new model room(645mm×405mm×530mm) with the new ventilation opening(60mm×35mm) in a similar way to previous experiments[2]. An acoustic driver radiating white noise over the frequency range of 20Hz to 20kHz was used as the source of noise. A microphone was mounted at the ventilation opening in the room. A reflective ground surface was present between the source and receiver microphone. The sound level was then measured at the receiver microphone without any resonators in place in the range of 1kHz to 10kHz which corresponded to a full scale frequency range of approximately 160Hz to 1.6kHz using a B&K Type 2034 Dual Spectrum Analyser. Third octave analysis was then carried out to obtain the sound level in third octave bands measured at the receiver located at the ventilation opening. A multiple resonator system was then placed on each side of the ventilation opening. The sound level was then remeasured. The difference between the two sound levels measured gave the attenuation provided by the resonators. The experiment was performed for different source locations and resonator orientations. Firstly, the source was kept at a constant height and moved horizontally to different positions as shown in Figure 2. The attenuation provided by the resonators at each of the five locations was measured giving an indication of the attenuation for a line source. The resonators were then placed in position at the ventilation opening with the rigid ends of the resonators closest to the opening. This was done to observe the diffraction effects of the resonator casings while suppressing the resonator action. By separating the effect of resonator action from casing diffraction and reflection, the combined result of these effects could be easily isolated.

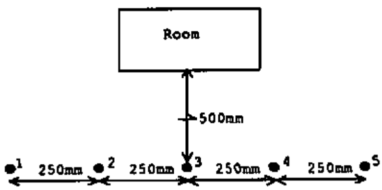

Figure2: Different Source Positions for Experiments

Results

The results for the attenuation provided by the resonator systems for different source locations are shown in Figure 3(a). The effect of the resonators when the rigid ends were closest to the ventilation opening (i.e. cavities closed) for different source locations is shown in Figure 3(b). Figure 3(a) demonstrates the attenuating capabilities of the multiple resonator system including the effects of diffraction and reflection off the resonator casing and inner partitions while Figure 3(b) illustrates diffraction and reflection from the resonator casing and rigid end. The strong similarity of the two figures at frequencies other than the resonant frequencies of the multiple resonator system indicates that the attenuation (and amplification in some cases) provided by the resonator system at these frequencies is due to reflections and diffraction off the casing. Significant attenuation was achieved in both 1/3 octave bands to which the resonators were tuned to. For the 1.25kHz resonator a maximum attenuation of over 8dB occurred when the noise source was directly in line with the ventilation opening. The attenuation at positions on either side of the opening was approximately symmetrical and ranged from 5 to 7dB. For the 3.15kHz resonator, however, the minimum attenuation was measured when the source was in line with the opening. The maximum level of attenuation was achieved at the extreme positions on either side of the ventilation opening (over 6dB). Attenuation was also achieved in the 6.3kHz 1/3 octave band which coincides with the third harmonic of the 1.25kHz resonator. Attenuation characteristics in neighbouring third octave bands to the resonator frequencies could not be attributed to diffraction or reflection off the resonator casing i.e. in both the 1.6kHz and 2.5kHz bands the nature of the attenuation in Figure 3(a) was not consistent with that of reflection off the resonator casing as indicated in Figure 3(b). This suggests that the Q factor of each of the resonators (1.25kHz and 3.15kHz) is low enough to cover a frequency range greater than a 1/3 octave band but still high enough to obtain significant attenuation at the resonator frequency and noticeable attenuation across the entire 1/3 octave band.

3(a)

3(b)

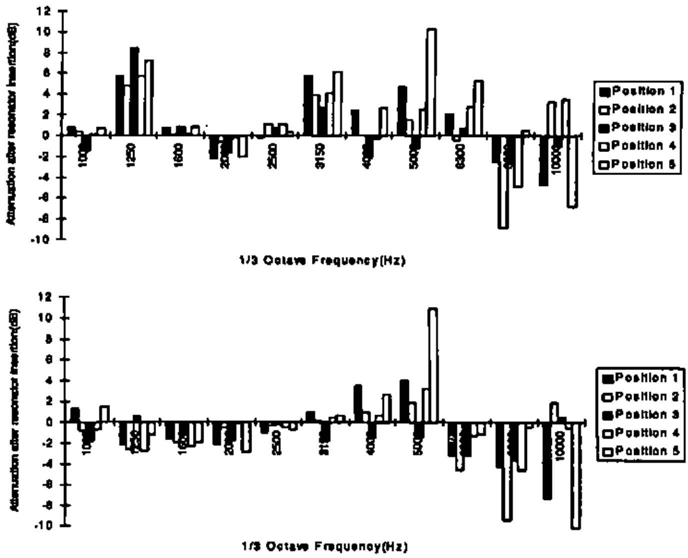

Figure 3 Attenuation with Multiple Resonators vs 1/3 Octave Frequency (a) resonators open (b) resonators closed

CONCLUSIONS AND FUTURE WORK

A model multiple quarter-wave resonator system has been demonstrated to achieve significant levels of attenuation in the 1/3 octave bands to which the resonators are tuned. In addition to attenuation at the specified frequencies, neighbouring 1/3 octave bands are affected. Further investigation into the Q factors of the resonators will be carried out in order to optimise the level of attenuation achieved over a wide frequency range as possible including the use of finite element analysis to predict the Q factors of resonators with different cross-sections. Other work will involve shaping the outer casing of the multiple resonator to minimise reflections that may amplify the level of noise entering the ventilation opening and analysing the interaction between resonators tuned to a similar frequency.

Acknowledgment
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References

[1] Field, C.D. and Fricke F. (1995). **Ventilation of Buildings in Noisy Environments**, 15th International Congress on Acoustics, Trondheim, Norway, 26-30 June.

[2] Field, C.D. and Fricke F. (1995) **Attenuation of Noise Entering Buildings Using Quarter-wave Resonators**, Proceedings of the Australian Acoustical Society Annual Conference, Perth, W.A. November 15-17.