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Active poro-elastic acoustic meta materials

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ABSTRACT

Previous work has demonstrated the potential of poro-elastic acoustic meta materials for providing increased sound absorption at low frequencies. This class of acoustic meta materials consist of a foam poro-elastic matrix supporting periodic arrays of small spherical masses or microporous sheets. The increase in sound absorption and/or transmission loss occurs either by the resonant dynamic motion of the embedded masses or by resonant wave scattering between the microporous sheets. In this paper we report preliminary work on extending the poro-elastic meta material to include active elements. The intention is to increase the bandwidth of the AMM attenuation which, due to it being based upon resonance conditions, is usually narrow. In the active poro-elastic meta material some of the embedded masses are replaced with small inertial active vibrators with the same weight and similar shape to the static masses. The control approach was a standard digital feedforward approach. Tests were carried out with narrowband and broadband plane wave signals in a standing wave tube. The results indicate there is potential in using active elements to broaden the frequency response of poro-elastic acoustic meta materials.

Keywords: Meta-material, active, poro-elastic

1. INTRODUCTION

There is a need to develop materials which have improved sound absorption with negligible mass increase, particularly at low frequencies. In addition, the availability of designable passive damping materials would be useful to the noise control engineer. Past work has demonstrated the potential of poro-elastic acoustic meta materials(AMM) to address these needs(1,2,3). These class of AMM generally consist of a poro-elastic matrix(foam fiberglass etc) containing embedded small spherical masses or thin, polymer microporous sheets. The embedded elements are often positioned in a periodic manner, in the general arrangement of meta materials, although this is not always necessary. Figure 1 shows a poro-elastic AMM consisting of periodically arranged steel spheres embedded in melamine foam. The left hand schematic shows the physical arrangement of the spheres embedded in a periodic arrangement inside the foam. The right hand picture is a section through a constructed HG material showing the spherical masses at one depth. In the finished HG material there is multiple layers of foam and masses stacked on top of each other. Other inserts such as plastic and hollow aluminum spheres were studied along with different poro-elastic matrices such as polyimide and fiberglass.

The normal incidence absorption coefficients and transmission losses of different free standing poro-elastic AMM samples were measured in a standard standing wave tube/TL test facility using two and four microphones respectively in conjunction with cross spectral techniques to extract the parameters. In this test, a 4in sample of polyimide foam was embedded with 36 periodic 7/16in diameter spheres of polypropylene and steel with densities 927.8 kg/m^3 and 7850 kg/m^3, respectively. The test results were also compared to COMSOL FEM predictions of the AMM material. Some example results are given in the Figure 2 below. As can be seen in Figure 2, the numerical results agree well with the experimental results using the different embedded masses. For the absorption coefficient, the embedded masses/spheres can be seen to significantly increase the absorption coefficient of the standard polyimide foam in the low frequency range near 200Hz. The transmission loss measurements also show a significant increase in the low frequencies near 250 to 500Hz for both steel and polypropylene masses/spheres.

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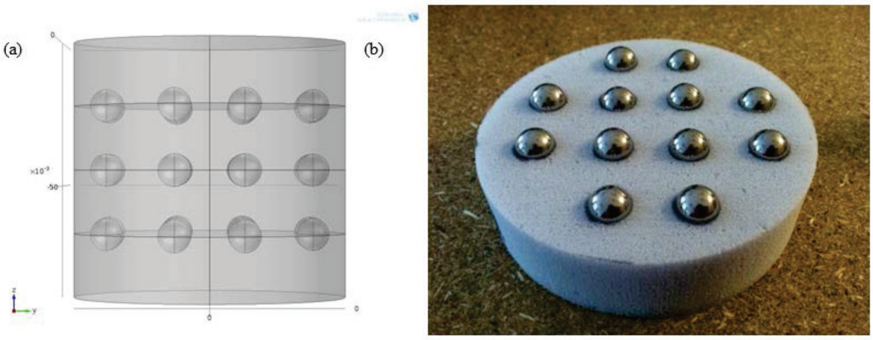

Figure 1. Arrangement of a typical poro-elastic AMM material; (a) schematic (b) section of a constructed AMM material.

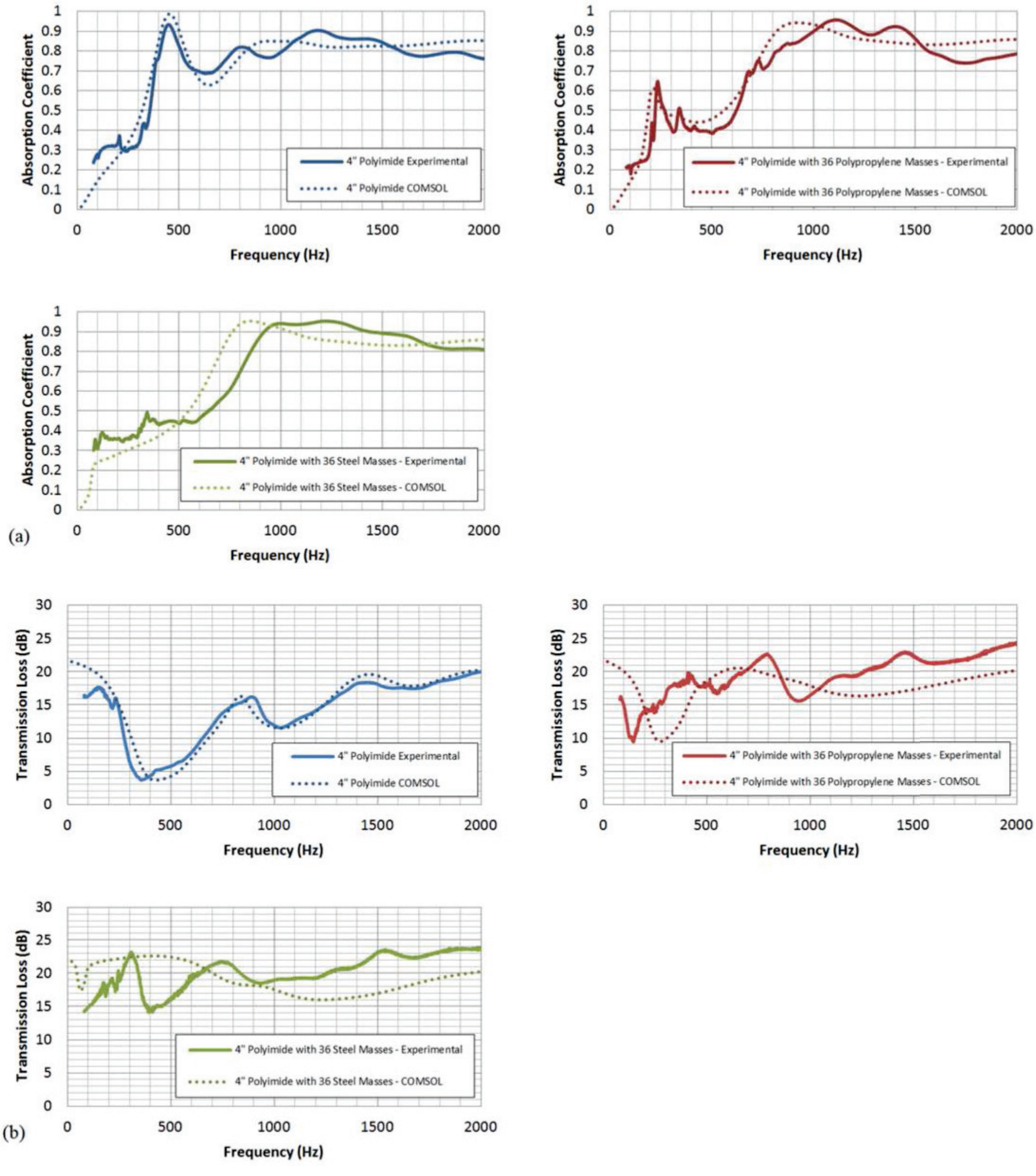

Figure 2. Measured and computed (a) absorption coefficients and (b) transmission losses of various free standing poro-elastic AMM materials.

While the results show much promise, they are limited to relatively narrow band behavior due to the controlling resonant dynamics of the AMM system. The AMM effect is either due to resonant wave scattering from spatially fixed elements or the dynamic resonance of the embedded elements. This narrow band characteristics limits the applicable frequency range (and potentially angle of incidence of impinging acoustic waves) of the AMM. In this paper, we summarize preliminary work in which active inputs were used in an attempt to broaden the increased absorption/transmission loss range of the AMM.

2. ACTIVE PORO-ELASTIC ACOUSTIC META MATERIALS

2.1 Active AMM arrangement

To create an active AMM we replaced two of the static masses with very small inertial actuators as shown in Figure 3. The active masses consist of a small plastic tube containing a circular magnet. Coils of wire were wound around the outside of the tube to create a linear inertial vibrator. The active mass can be seen to be of similar size and at 6gms, their mass was also very close to that of the embedded static masses.

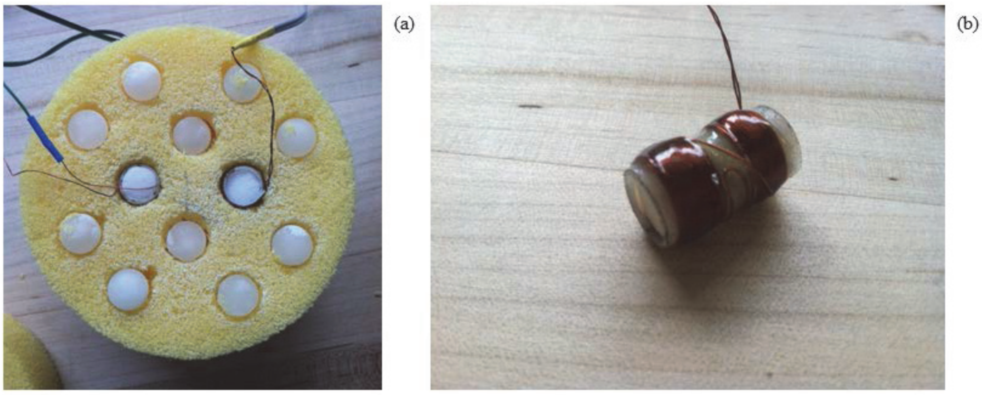

Figure 3. Cross section of a polyimide based AMM with 10 polypropylene masses and two active masses and (b) close up of an active mass.

The active AMM was positioned in a standard standing wave/transmission loss test tube as shown schematically in Figure 4. The control system used was a digital feedforward system utilizing an upstream reference microphone sensor to pick up the sound and downstream error microphone sensor(4). Since the control signal will appear on the reference signal, a feedback removal scheme was used in the reference loop(4). Both narrowband and broadband noise signals were played through the primary sound source speaker.

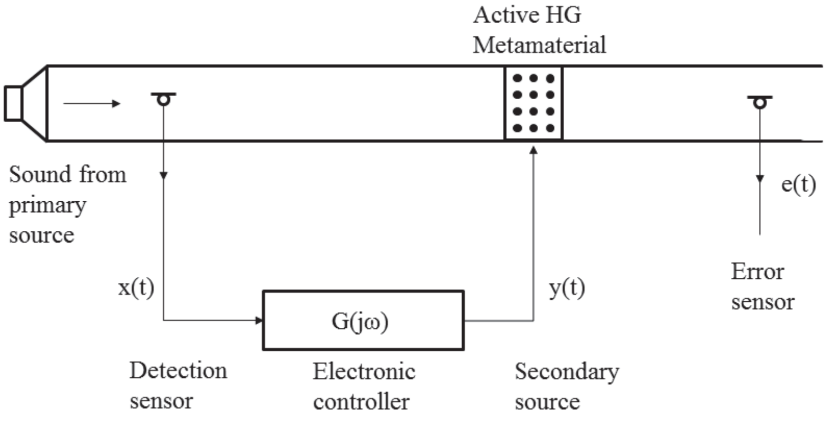

Figure 4. Schematic arrangement of active AMM positioned in a standing wave tube and digital active control system.

2.2 Results

For the first tests, we consider narrow band noise excitation at tonal frequencies of 130 and 250Hz. Note that for tonal noise, causality of the active system does not have an effect on control attenuation. For the second set of tests, we utilize a white noise excitation band limited to 400Hz. In this latter case, delay and hence causality through the control path is important in terms of performance. Figure 5 presents example test results. The narrowband results demonstrate that the use of active elements in the AMM enhance the transmission loss/noise reduction by close to 20dB. The broadband results show that the active elements provide increased noise attenuation over a bandwidth of 50 to 110Hz.

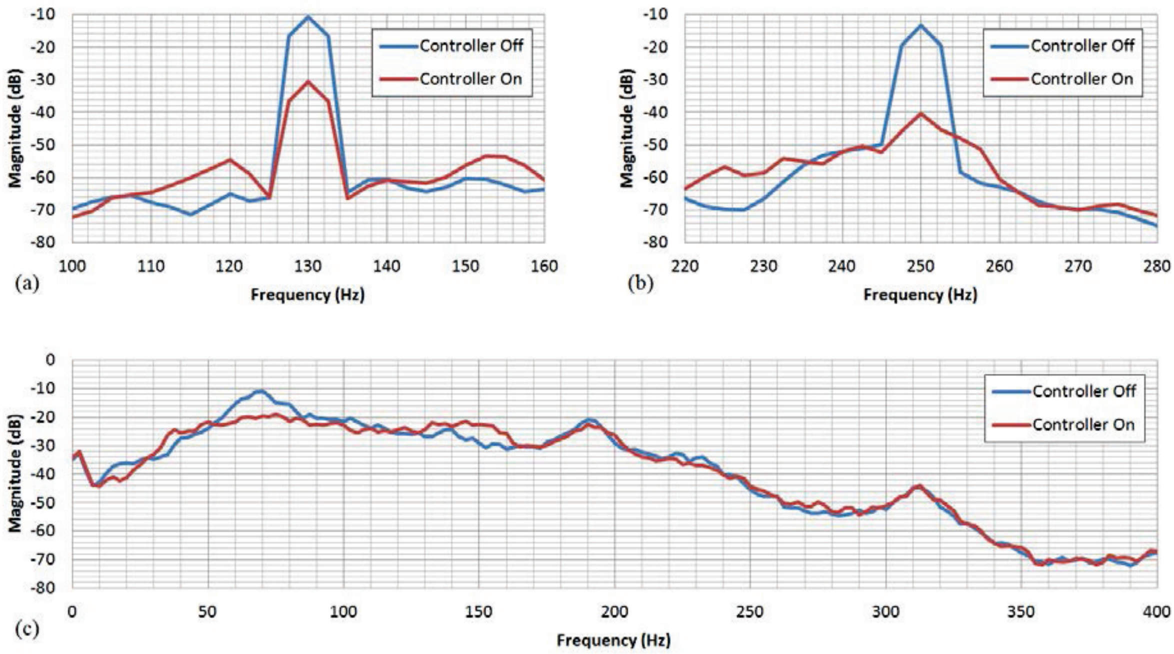

Figure 5. Performance of the active AMM (a) 130Hz noise signal (b) 250Hz noise signal and (c) white noise signal.

2.3 Active poro-elastic AMM for controlling vibration

In other related work active poro-elastic AMM was used to control the vibration of a cantilever beam(5), repeated here as it directly relates to this paper. Figure 6 shows a schematic arrangement of the test set up.

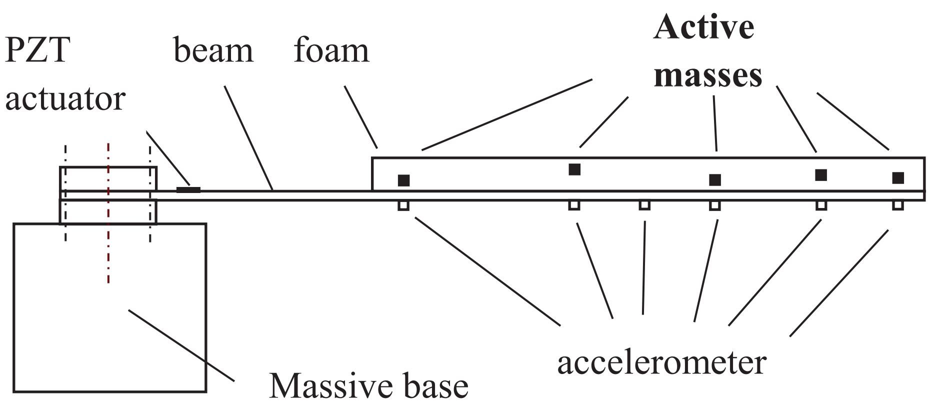

Figure 6. Schematic of test set up used to investigate active AMM for controlling vibration.

In the test set up a four inch layer of Melamine foam was glued to the surface of a 3mm thick Aluminum cantilevered beam. The beam was driven into motion by a piezo-ceramic actuator(PZT) located near the root of the beam. Five 6gm inertial masses were embedded in the foam as shown in Figure 6 and an array of six accelerometers were positioned on the bottom of the beam to provide a global estimate of the beam energy of vibration. A digital feedforward active control system was used to drive the inertial active actuators and minimize the vibration at the five of the six accelerometers. The reference signal was taken from the electronic disturbance signal to the PZT disturbance actuator. The noise drive signal was appropriately delayed after the reference signal to cause the control system to be causal. Figure 7 shows a photograph of the test set up.

Figure 7. Test set for active AMM control of beam vibration.

Figure 8 presents an example result. The solid black curve is the bare beam and can be seen to have a number of peaks in the energy of vibration at the beam resonant frequencies. Addition of the plain Melamine foam to the beam can be seen to provide some attenuation of vibration at the resonances due to damping but little attenuation of vibration away from resonance as is normal passive damping behavior. Addition of the active masses with control off and thus creation of a poro-elastic AMM can be seen to provide significant additional passive attenuation at the low frequency peak near 150Hz and also broadband attenuation from 70 to 125Hz. This behavior, as shown in previous work(1,2) , is due to the resonances of the embedded masses (inertial actuators) being in the range of 50 to 150Hz depending upon the depth to which they are embedded. When the active control system is turned on, the active AMM can be seen to provide high attenuation of broadband beam vibration over a range of 75 to 500Hz both on and off resonance. A global attenuation of beam vibration also generally implies an attenuation of the coupler radiated sound although this is somewhat dependent upon the radiation efficiency of the different structural mode shapes.

2.4 Discussion on status of active poro-elastic AMM

While the above work has demonstrated the potential of active AMM to enhance the frequency range over which they can be applied, this is preliminary work and there are many questions remaining. For the work on use of active AMM to directly reduce sound, the results are for normal incidence sound. How the active AMM performs under oblique and random incidence sound needs to be studied. Another important question concerns the actual physics of the active inputs to the AMM system; are the active inputs directly modifying the impedance distribution through the poro-elastic material and thus its absorption/transmission of sound. In addition suitable wave deconvolving sensors within the poro-elastic active AMM need to be developed in order to make the material realizable.

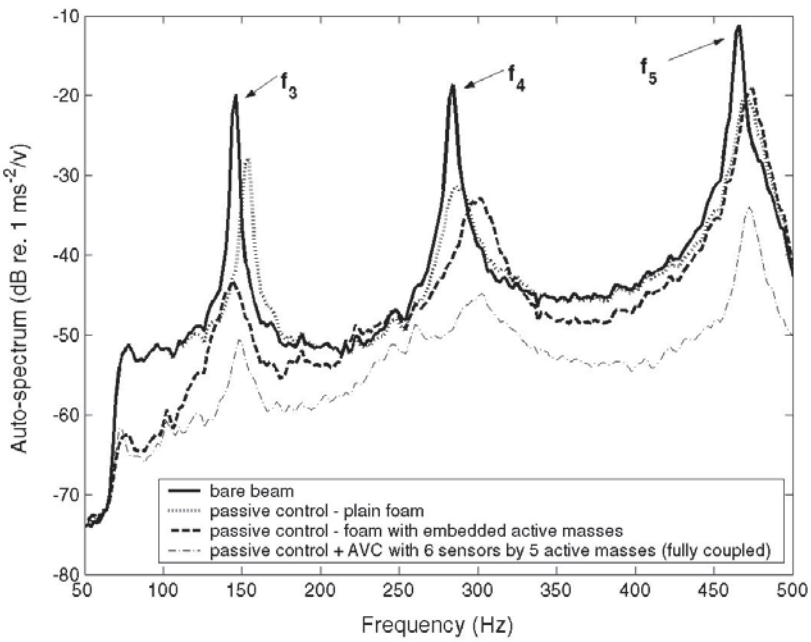

Figure 8. Results for active AMM control of beam vibration.

3. CONCLUSIONS

The preliminary work presented here has demonstrated the potential of using active inputs to broaden the frequency of application of poro-elastic acoustic meta materials for controlling sound and vibration. However this was a preliminary investigation and may questions relative to the practical development and use of such a material remain.

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