Hybrid passive-active sound absorption in a standing wave tube using a thin plate actuator as secondary source

P. Cobo, J. Pfretzschner, M. Cuesta, and A. Fernández

Instituto de Acústica. CSIC
Serrano 144, 28006 Madrid (Spain)
iacpc24@ia.cetef.csic.es

Abstract

This paper deals with the design and optimization of a hybrid passive/active liner for broadband noise reduction in a standing wave tube. The thickness of the multilayer absorbent is reduced in two steps: firstly a porous layer backed by an air gap is substituted by a microperforated panel followed by a reduced air gap; and secondly, the secondary loudspeaker is replaced by a thin plate driven by a piezoceramic patch. Experimental results show that high absorption may be achieved in a wide frequency range (100-900 Hz) with a thin hybrid passive/active absorber.

1. Introduction

Noise may be controlled by passive and active techniques. Passive control affords satisfactory noise reduction at medium and high frequencies. However, at low frequencies (under 500 Hz), active control may be used in order to avoid the excessive size and weight of the passive solution. Active techniques are based on the minimization of an unwanted acoustic field by introducing an analogous field opposite in phase. An electronic controller drives the secondary actuator to reach an acoustic pressure minimum at the error sensor [1]. Broadband noise requires a hybrid solution combining both passive and active techniques [2].

Many researches have been involved in the design of new hybrid methods based on the input acoustic impedance control in multilayer liners [3,4]. Such liners improve the low frequency absorption of the passive two-layer system, using an active controller at the back of the air layer [5,6]. It has been showed that a two-layer passive/active absorber can afford absorption coefficients grater than 0.9 over a wide frequency bandwidth in duct applications [4-6]. The main advantage of such hybrid devices is the enhancement of low frequency control with smaller size (thickness and weight) than the traditional absorbers.

The main goal of this paper is to show that absorption of broadband noise in ducts is feasible with a thinner two-layer hybrid absorber. The size of such liner may be reduced in two ways: using smaller passive layers, as microperforated panels, and replacing the secondary loudspeaker by thinner actuators made of thin plates excited mechanically. The theoretical and practical design of the hybrid absorber in a standing wave tube is presented. The preliminary results illustrate the control capability of the developed prototype.

2. Description of the hybrid absorber

Figure 1 shows the scheme of a hybrid passive/active two-layer prototype in a standing wave tube.

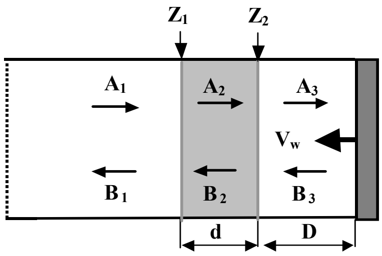

Figure 1: Scheme of a hybrid two-layer absorption system

The two-layer hybrid device, located at the end of the tube, controls the primary noise that is propagating downstream from the source. The system consists of a passive layer, an air cavity, and an actuator for the active control system. The acoustic properties of the passive material as well as the thicknesses of the two layers must be well set for optimizing the hybrid absorption. In this paper we consider two kinds of materials, a porous layer and a microperforated panel.

2.1. With a porous layer

Following [5,6], the absorption coefficient at the input of the liner is

$$\alpha = \frac{Z_1 - Z_0}{Z_1 + Z_0} \ , \qquad (1)$$

where Z_1, the input impedance to the porous layer, is

$$Z_1 = Z_a \frac{Z_2 \cosh(\Gamma_a d) + Z_a \sinh(\Gamma_a d)}{Z_a \cosh(\Gamma_a d) + Z_2 \sinh(\Gamma_a d)} \ , \qquad (2)$$

which depends on the input air gap impedance (Z_2) and the acoustical characteristics (Z_a, Γ_a) and thickness (d) of the passive material. The input impedance to the air layer is

$$Z_2 = Z_0 \frac{V_w Z_0 + 2B_3 e^{jk_0 d}\cos(k_0 D)}{V_w Z_0 + 2jB_3 e^{jk_0 d}\sin(k_0 D)} \quad (3)$$

which depends on the active wall velocity (V_w), the acoustic propagation properties in this layer $(Z_0,\ k_0,\ B_3)$, and the cavity thickness (D). Under passive condition (with rigid wall), $Z_2 = -jZ_0 cot(k_0 D)$. A pressure release at the entrance of the air gap, on the other hand, yields $Z_2=0$.

Both empirical and analytical models can be used to describe the acoustic propagation through a porous layer. The empirical equations of Allard and Champoux [7] for the acoustic impedance , Z_a, and the propagation constant, Γ_a, are

$$\Gamma_a = i2\pi f\sqrt{\rho(f)/K(f)} \quad (4)$$

$$Z_a = \sqrt{\rho(f)K(f)}\,, \quad (5)$$

with

$$\rho(f) = 1.2 + \left[-0.0364E^{-2} - i0.1144E^{-1}\right]^{1/2} \quad (6)$$

$$K(f) = 101320\frac{i29.64 + \left[2.82E^{-2} + i24.9E^{-1}\right]^{1/2}}{i21.17 + \left[2.82E^{-2} + i24.9E^{-1}\right]^{1/2}}\,. \quad (7)$$

In Eqs. (6)-(7), the nondimensional parameter $E = \rho f/R_1$, where ρ is the air density , f is the frequency, and R_1 is the flow resistivity of the material.

Using Equations (1)-(7) the hybrid absorption coefficient of a two layer absorber may be described once the material characteristics, the geometrical parameters and the control conditions are specified [6]. Figure 2 shows the absorption coefficient for a 4 cm thick fibrous layer of R_1=12400 mks rayls, backed by an air gap of 7 cm, in both passive and active conditions. The absorption coefficient is almost optimized over the plotted frequency range. Active control enhances the passive absorption from 100 Hz to 600 Hz.

2.2. With a microperforated panel

The use of microperforated panels (MPP) as wide band sound absorbers has already been described [8,9]. Such panels consist of thin plates perforated with sub-millimeter holes whose acoustic resistance determines the MPP absorption mechanism. By inserting an air cavity behind the plate, the acoustic mass reactance is low enough to provide wideband sound absorption, without the need of additional porous material [9,10].

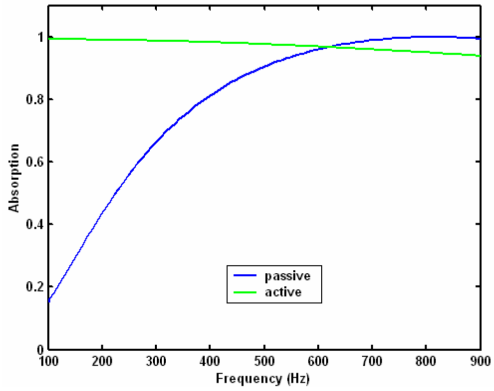

Figure 2: Absorption coefficient of a two-layer system with a porous layer (d= 4 cm and D=7 cm), in passive (blue) and active (green) conditions

The input acoustic impedance Z_1 of an MPP backed by an air gap [9,10] can be expressed as

$$Z_1 = Z_m + Z_2\,, \quad (8)$$

where Z_m, the MPP acoustic impedance is

$$Z_m = j\frac{\omega\rho t}{p}\left[1 - \frac{2\ J_1(x\sqrt{-j})}{x\sqrt{-j}\ \ J_0(x\sqrt{-j})}\right]^{-1} + \frac{\sqrt{2}\eta x}{pd} + j\frac{0.85\omega\rho d}{p} \quad (9)$$

and Z_2, the input acoustic impedance to the air layer, is whether $Z_2 = -jZ_0 cot(k_0 D)$, for the passive condition, or zero for a pressure release in the air layer. In Eq. (9), the variable x is

$$x = \frac{d}{\sqrt{\frac{4\eta}{\rho\omega}}} \quad (10)$$

where η is the viscosity coefficient of the air, and ω is the angular frequency, t is the panel thickness, d is the diameter of the perforations, and p is the perforation ratio of the open surface to the total surface of the panel.

Therefore, the absorption coefficient of this system depends on the MPP parameters (t, d, p) and the thickness of the air layer (D). Figure 3 illustrates the absorption coefficient of an MPP with t=1 mm, d=60 µm, p=1.61%, and D=4.5 cm. In comparison with the hybrid system in Fig. 2 with the porous layer as the passive absorber, which requires 11 cm as total thickness, the MPP yields high absorption (between 0.8 and 1) over a wide frequency range with a total thickness of 4.6 cm.

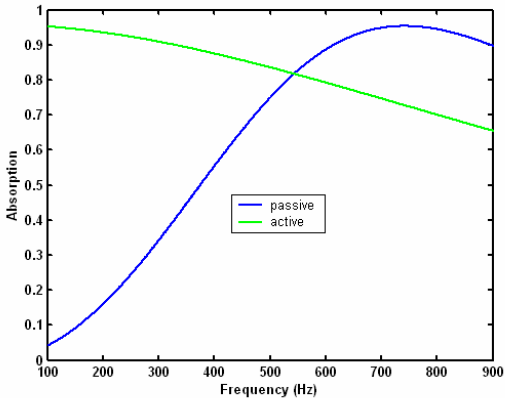

Figure 3: Absorption coefficient of a two-layer system with an MPP backed by an air cavity of 4.5 cm, in passive (blue) and active (green) conditions

3. Experimental setup

The whole experimental setup for measuring the absorption coefficient of the hybrid passive/active system is shown in Figure 4. A standing wave tube with 10 cm of diameter and a length of 1 m, is used. The absorption coefficient is measured with the transfer function method [11], using two microphones separated 18 cm. Both, the tube dimensions and the distance between the measuring points set a frequency band from 100 to 900 Hz.

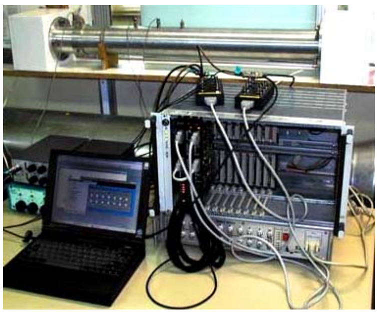

Figure 4: The hybrid two-layer experimental rig

The primary broadband noise is generated by the loudspeaker located at one end. The two-layer absorber is placed at the opposite side of the tube. The passive layer (porous material or MPP) is backed by an air layer where the active control system is implemented. This system consists of a secondary actuator located at the back of the air cavity, an error microphone just behind the back surface of the passive layer, and a digital controller to implement the pressure release condition at the error sensor. In the case of passive control, the tube is ended by a rigid termination.

Since one of the goals of this paper is to show that high absorption can be still reached reducing the thickness of the hybrid device, the secondary loudspeaker has been substituted by a thin actuator. It was made with an Al plate of thickness 0.5 mm and diameter of 9.5 cm. It is driven by two piezoceramics of 2 mm of diameter and 0.24 mm of thickness. Figure 5 shows the characteristics of this new actuator and its positioning at the end of the tube. The control authority of this secondary actuator has been verified. This simple setup allows reducing the air cavity behind the passive layer.

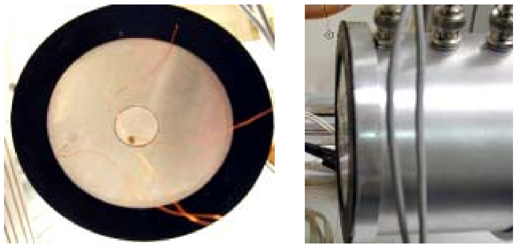

Figure 5: The thin actuator attached at the end of the impedance tube

Two passive layers, with analogous characteristics of the materials tested theoretically, are used for hybrid experiments: a 4 cm porous layer having a flow resistance close to Z_0, and a thin panel (1 mm thick) with hole diameter of 60 μm. Both systems allow for an air gap between the passive layer and the active actuator. A feedforward strategy implemented with FIR filters and using the generator signal as reference is configured to produce the pressure release at the rear face of the passive layer.

4. Results and discussion

Figures 6 and 7 show the absorption coefficients of the two-layer systems analyzed in Section 2, in both passive and active conditions. Active control has been tested with the loudspeaker and the thin actuator as the secondary source. The absorption coefficients in both results are quite well adjusted to the predictions. Passive control affords high absorption above 600 Hz, while active control improves the absorption below this frequency. Concerning the comparison between the secondary actuators, it is patent that the thin actuator provides analogous results to those obtained with the loudspeaker.

In reference to the type of passive layer, the use of thinner hybrid liners, as the MPP (with t=1 mm, d=60 μm, p=1.61%) backed by a reduced air cavity (D=4.5 cm), provides high broadband noise absorption. The absorption curves in Figure 7 show a maximum around

400 Hz corresponding to a mechanical resonance of the MPP that could be suppressed using a more rigid plate.

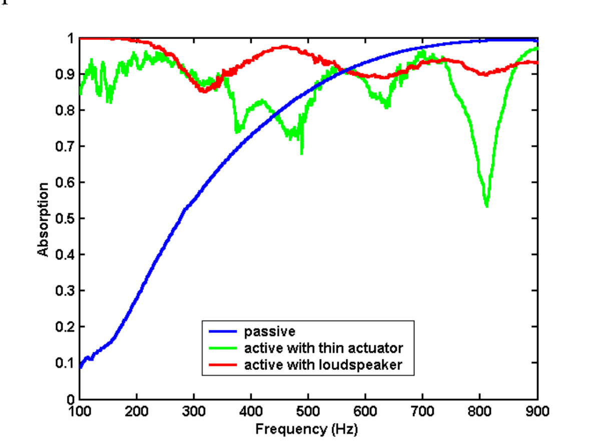

Figure 6: Absorption coefficient of a two-layer system with porous material (d= 4 cm and D=7 cm), in passive (blue) and active conditions, with the actuator (green) and the loudspeaker (red)

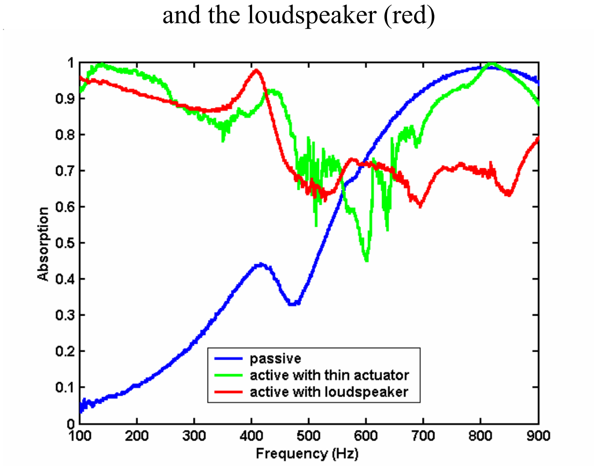

Figure 7: Absorption coefficient of a two-layer sytem with an MPP (1 mm thick and air cavity of 4.5 cm), in passive (blue) and active conditions, with the actuator (green) and the loudspeaker (red).

5. Conclusions

The main objective of this work has been to show the achievability of obtaining hybrid passive/active absorption in a standing wave tube, using both thinner actuators and thinner passive layers.

The performance of the hybrid liner, including the passive condition and the pressure release behind the material, has been theoretically predicted, for a porous material and a microperforated panel (MPP). High absorption is predicted over a broadband frequency range (100-900 Hz) for the case of 4 cm porous layer backed by a 7 cm air gap. For a much thinner MPP (4.6 cm), the absorption in the same range is comprised between 0.8 and 1. The main advantage of using MPP with the active system is that high absorption can be still achieved over a wide frequency range with a reduced size. Experimental results in the standing wave tube confirm these predictions. To reduce further the size of the hybrid liner, the secondary loudspeaker has been substituted by a thin plate actuator driven by a piezoceramic patch. Very promising results show the potential of this new absorber.

6. Acknowledgements

This research has been funded by the Spanish Ministry of Science and Technology under Grant No. DPI2001-1613-C02-01.

7. References

[1] Elliott, S.J., *Signal Processing for Active Control*, Academic Press, London, 2001.

[2] Cuesta, M., and Cobo, P., "Optmization of an active control system to reduce the exhaust noise radiated by an small generator", *Applied Acoustics*, *Vol. 62(5), 2001, 513-526.*

[3] Guicking, D., Karcher, K., and Rollwage, M., "Coherent active methods for application in room acoustics", *J. Acoust. Soc. Am.*, *Vol. 78, 1985, 1426-1434.*

[4] Furtoss, T., Thenail, D., and Galland, M.A., "Surface impedance control for sound absorption: direct and hybrid passive/active strategies", *J. Sound and Vib., Vol. 203, 1977, 219-236.*

[5] Beyene, S., and Burdisso, R.A., "A new hybrid passive/active noise absorption system", *J. Acoust. Soc. Am.*, *Vol. 101, 1997, 1512-1515.*

[6] Cobo, P., Fernández, A., and Doutres, O., "Low frequency absorption using a two-layer system with active control of input impedance", *J. Acoust. Soc. Am.*, *Vol. 114(6), 2002, 3211-3216.*

[7] Allard, J.F. and Champoux, Y., "New emprirical equations for sound propagation in rigid frame fibrous materials", *J. Acoust. Soc. Am.*, *Vol. 91, 2002, 3346-3353.*

[8] Maa, D.Y., "Wide band sound absorber on microperforated panels", *Internoise 84 Proc., 1984, 415-420.*

[9] Maa, D.Y., "Microperforated panel wide-band absorber", *Noise Control Eng. J., Vol. 29, 1987, 77-84.*

[10] Pfretzschner, J., Cobo, P., Bote, D., Fernández, A., and Doutres, O., "Active control and microperforated panels", *Acta Acustica united with Acustica, Vol. 89(Pt.1), 144.*

[11] Chung, J.Y., and Blaser, D.A., "Transfer function method of measuring in-duct acoustic properties", *J. Acoust. Soc. Am.*, *Vol. 68, 1980, 907-921.*