Comparison of damping performances of constrained viscoelastic layers and passive piezoelectric networks

Lucie Rouleau, Boris Lossouarn, Robin Darleux, Jean-François Deü

MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Comparison of damping performances of constrained viscoelastic layers and passive piezoelectric networks

Rouleau, Lucie[1]
LMSSC - Conservatoire national des arts et métiers
292 Rue Saint-Martin, 75003 Paris, France

Lossouarn, Boris[2]
LMSSC - Conservatoire national des arts et métiers
292 Rue Saint-Martin, 75003 Paris, France

Darleux, Robin[3]
LMSSC - Conservatoire national des arts et métiers
292 Rue Saint-Martin, 75003 Paris, France

Deü, Jean-François[4]
LMSSC - Conservatoire national des arts et métiers
292 Rue Saint-Martin, 75003 Paris, France

ABSTRACT

This work aims at comparing the damping performances of two passive treatments based on piezoelectric or viscoelastic patches. The motivation for such a comparison stems from the fact that the two damping treatments have been developed fairly independently, and are rarely compared. Firstly, the dynamic response of a simply supported metallic plate, equipped with constrained viscoelastic patches or piezoelectric patches connected to an electrical network, is measured experimentally. Secondly, a numerical model of the structure is set up and validated to evaluate the damping performances of both passive treatments under different configurations (for instance equal-mass and equal-thickness configurations). Finally, with regard to this work, the advantages and the limitations in using viscoelastic or piezoelectric treatments are discussed.

Keywords: Dynamic response, Viscoelastic damping, Piezoelectric damping
I-INCE Classification of Subject Number:47

[1]lucie.rouleau@lecnam.net
[2]boris.lossouarn@lecnam.net
[3]robin.darleux@lecnam.net
[4]jean-francois.deu@cnam.fr

1. INTRODUCTION

In the context of noise and vibration mitigation, several damping technologies are proposed in the literature. Among them, purely passive treatments generally lead to low-cost and robust structural vibration control. These can be achieved by bonding constrained viscoelastic patches to the structure or by using piezoelectric patches connected to an electrical network. With piezoelectric patches, the vibrational energy is transfered to an electric circuit and dissipated in resistive components ; while with viscoelastic patches, it is transfered to the viscoelastic layer (undergoing shear deformations) and is dissipated in the damping material. Resonant piezoelectric shunts are commonly tuned to a single mechanical natural frequency to be controlled [1]. However, broadband vibration reduction can be obtained with multimodal damping, where the structure is coupled to a multi-resonant electrical network [2]. On the other hand, due to the frequency dependent damping properties of viscoelastic materials, viscoelastic patches naturally provide broadband damping [3].

Both passive damping treatments have been developed fairly independently and are rarely compared. The goal of this work is to provide an experimental and a numerical comparison of the damping performances of constrained viscoelastic layers and passive piezoelectric networks. A simply supported metallic plate, equipped with constrained viscoelastic patches or piezoelectric patches connected to an electrical network is under study. The next section describes the experimental set-up and reports the experimental results obtained using these panels. The efficiency of both passive treatments usually depends on the volume of material used, so that the performance is generally limited by weight and size constraints. Therefore, numerical models of the damped panels are implemented and validated in order to test the two damping technologies under different configurations, such as equal-mass and equal thickness configurations.

Finally, with regard to this work, the advantages and the limitations in using viscoelastic or piezoelectric treatments are discussed.

2. EXPERIMENTAL RESULTS

This section describes the geometry of the panels equipped with viscoelastic or piezoelectric patches and the experimental set-up used to measure the structural dynamic response. Experimental results are reported and compared.

2.2.1. Experimental set-up

The structure under study is an aluminium panel, of dimensions $420 \times 360 \times 3$ mm^3. 42 viscoelastic or piezoelectric patches are periodically distributed on the panel, as indicated in Figure 1. Each patch is of dimensions 50×50 mm^2.

Viscoelastic patches are composed of a 120 μm viscoelastic layer (Smacwrap®) and a 1.04 mm composite laminate which acts as a constraining layer. Piezoelectric patches are made of PIC 153 (PI Ceramic) and are 0.5 mm thick. A vacuum bonding technique is used to assemble all the layers. These damping solutions lead to a 15% added mass for the viscoelastic patches and a 33% added mass for the piezoelectric patches, not taking into account the mass of the electrical components.

The electrical network that interconnects the piezoelectric patches consists of 42 identical unit cells made of passive components such as inductors and transformers. Their values and interconnections are chosen so as to create, in the electrical domain, the analogue

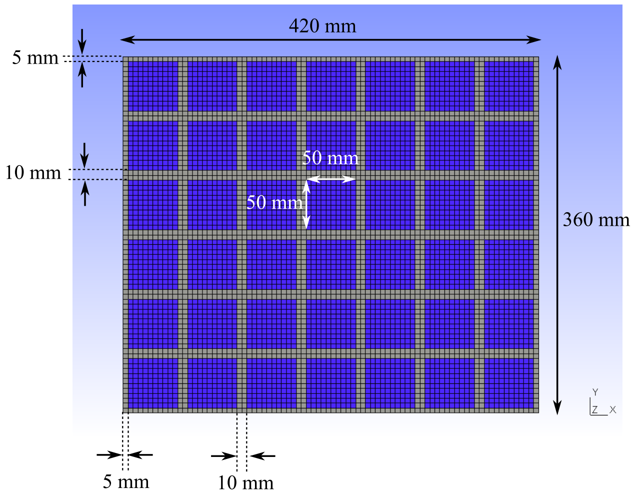
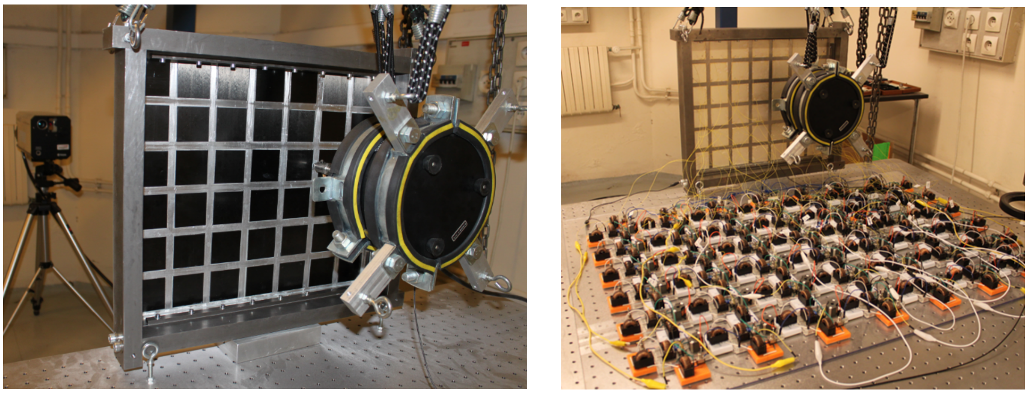


Figure 1: Dimensions and placement of patches on the aluminium panel.



(a) (b)

Figure 2: Experimental set-up for the panel with viscoelastic patches (a) and the panel with piezoelectric patches connected to an electrical network (b).

of the plate to be controlled [4]. This generates a multi-resonant network whose natural frequencies are tuned to that of the mechanical plate in order to obtain the equivalent of a multimodal tuned mass damper.

Panels are mounted in a specific frame to approximate simply supported boundary conditions [5, 6]. The whole structure is suspended and excited by a shaker, while the structural dynamic response is measured by a laser vibrometer. The location of the shaker is given by the coordinates $x = 0.12$ m, $y = 0.15$ m and $z = 0.003$ m, and a pseudo-random excitation is generated. The frequency response of the structure is measured at the excitation point, in the frequency range $0-900$ Hz, with a frequency step of 0.156 Hz.

2.2.2. Experimental comparison

Following the experimental procedure described in the previous section, three panels are tested: a bare aluminium panel, an aluminium panel with viscoelastic patches and an aluminium panel with piezoelectric patches connected to a multi-resonant network. The measured frequency response functions are plotted in Figure 3. Both damping treatments induce a drastic reduction of the dynamic response over the whole frequency range. Multi-resonant piezoelectric damping is more efficient than viscoelastic damping for the first

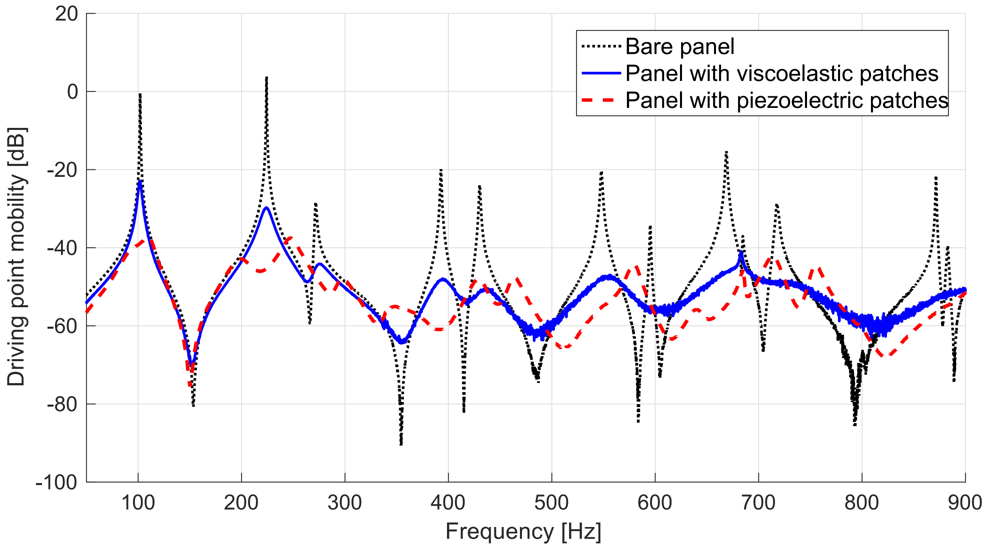


Figure 3: Frequency response functions measured on the bare aluminium panel, the panel with viscoelastic patches and the panel with piezoelectric patches.

Material	Young modulus [Pa]	Poisson ratio	Density [kg/m^3]
Aluminium	6.9 10^{10}	0.346	2700
Viscoelastic (static)	2.98 10^6	0.49	867
Laminate composite	5.94 10^{10}	0.273	1580

Table 1: Material properties considered in the finite element model of the sandwich panel.

vibration modes. However, they offer similar damping performances above 400 Hz.
For practical reasons, the configurations considered for piezoelectric and viscoelastic damping do not correspond to equal-mass or equal-thickness configurations. In order to compare the two passive treatments in a more objective manner, numerical models of the damped panels are implemented and experimentally validated.

3. VALIDATION OF THE NUMERICAL MODELS

This section describes the numerical models used to predict the dynamic response of a panel with piezoelectric or viscoelastic patches. Both models are validated by the experimental results presented in the last section.

3.3.1. Numerical model for the panel with viscoelastic patches

A finite element model of the panel with viscoelastic patches is implemented [7]. Each layer is meshed by 20-node hexahedron elements, so that the shear behaviour of the viscoelastic layer is properly represented. The material properties considered in the calculation are reported in Table 1, and the master curves of the viscoelastic layer are plotted in Figure 4. The frequency dependent properties of the viscoelastic layer are taken into account in the finite element model through tabular data.

Figure 5 compares the frequency response function computed with the implemented finite element model to the measured response on the panel equipped with viscoelastic patches. Numerical results are in very good agreement with the experimental results,

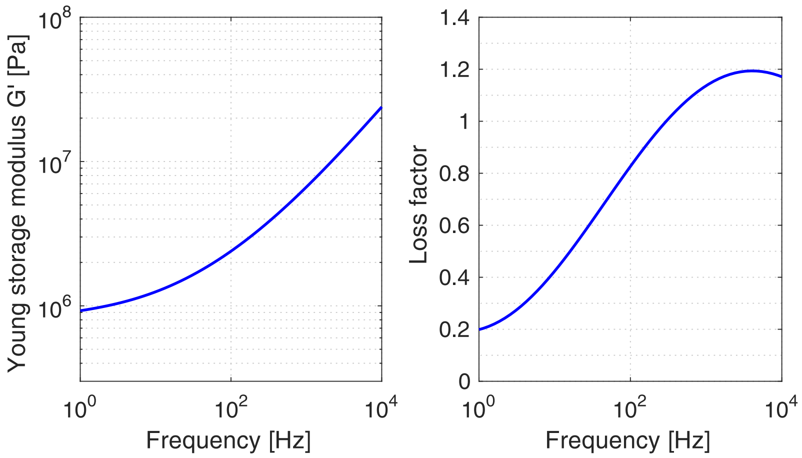


Figure 4: Master curves of the viscoelastic material (Smacwrap®) at the reference temperature $T = 20^o C$.

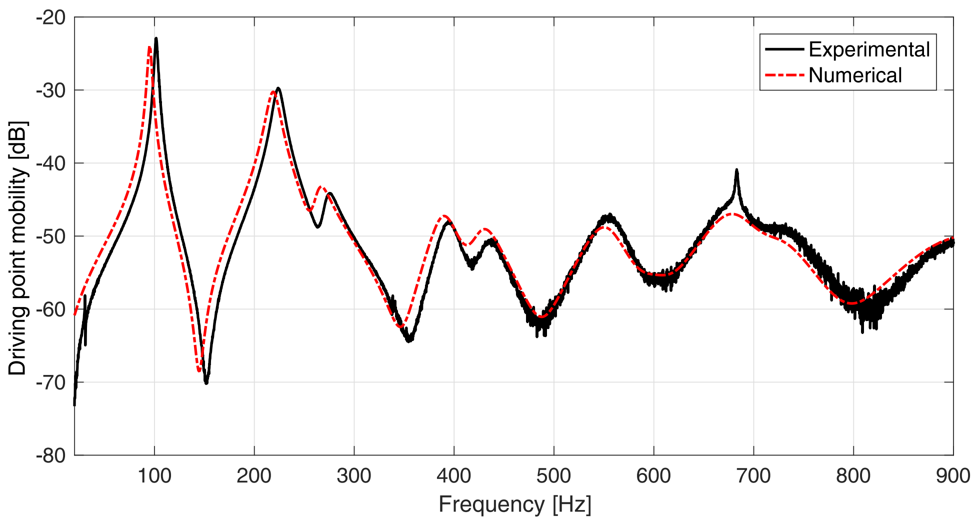


Figure 5: Experimental and numerical comparison of the frequency response functions of the panel with viscoelastic patches.

which validates our finite element model. The peak at 685 Hz corresponds to a flexural mode of the frame, which explains why the applied damping treatments have little influence on the amplitude of the response at this frequency.

3.3.2. Numerical model for the panel with piezoelectric patches

The numerical model used to predict the electromechanical response of the panel is based on a finite difference scheme with 9 elements for each of the 42 unit cells. Details about the numerical model of the piezoelectric plate coupled to its electrical analogue can be found in [2]. The frequency response function of the panel with piezoelectric patches computed with this model is compared to the measured response in Figure 6. Again, very good agreement is observed between numerical results and experimental results.

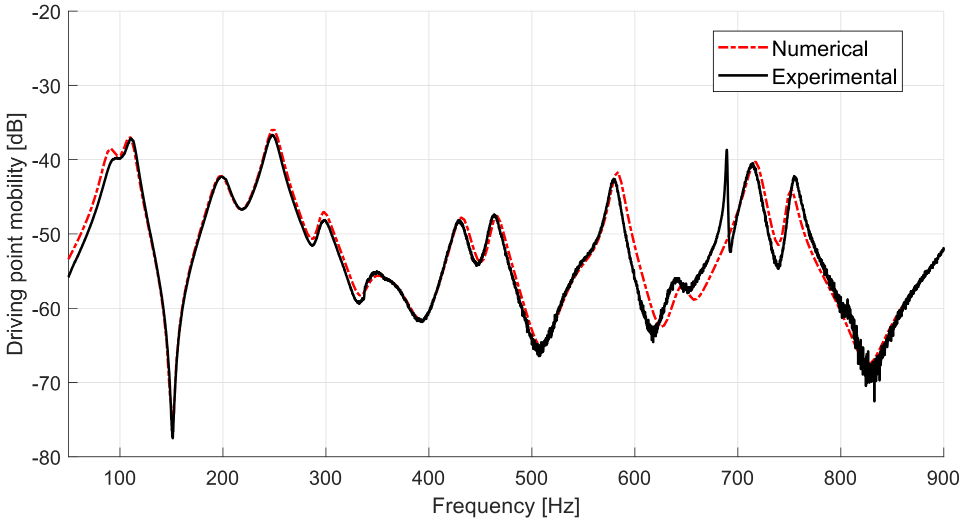


Figure 6: Experimental and numerical comparison of the frequency response functions of the panel with piezoelectric patches connected to a multi-resonant network.

Both numerical models can now be exploited to study various configurations, and compare the damping performances of constrained viscoelastic layers and passive piezoelectric networks.

4. COMPARISON AND DISCUSSION

Weight and dimensions are classical constraints in the design of a damping treatment. Therefore, this section is dedicated to the numerical study of two configurations : equal-mass and equal-thickness.

In order to obtain an equal-mass configuration for the viscoelastic and the piezoelectric treatments (the mass of the electrical circuit is not taken into account), the thickness of the piezoelectric patches is modified in the numerical model: 0.23 mm instead of 0.5 mm. It should be noted that the electrical network has been tuned accordingly in order to maximize the vibration damping of the second mode of the plate. In this way, both viscoelastic and piezoelectric patches have a total mass of 182 g (to be compared to the mass of the bare aluminium panel: 1.2 kg). The computed frequency response functions for both panels are compared in Figure 7. Results show that below 400 Hz, the damping performances of the piezoelectric patches are better than those of the viscoelastic patches. Above 400 Hz, the inverse tendency is observed.

The equal-thickness configuration is obtained by modifying the thickness of the viscoelastic patches in the numerical model: 41 μm for the viscoelastic layer and 0.359 mm for the constraining layer. Then, by considering 0.1 mm for each adhesive layer, viscoelastic patches and piezoelectric patches have the same thickness: 0.6 mm. The computed frequency response functions for both panels are compared in Figure 8. This configuration identifies the piezoelectric solution as the most efficient damping technique in terms of vibration damping, over the whole frequency range.

The results of this comparative study suggests that design constraints clearly have an impact on the relative damping performance of viscoelastic and piezoelectric patches.

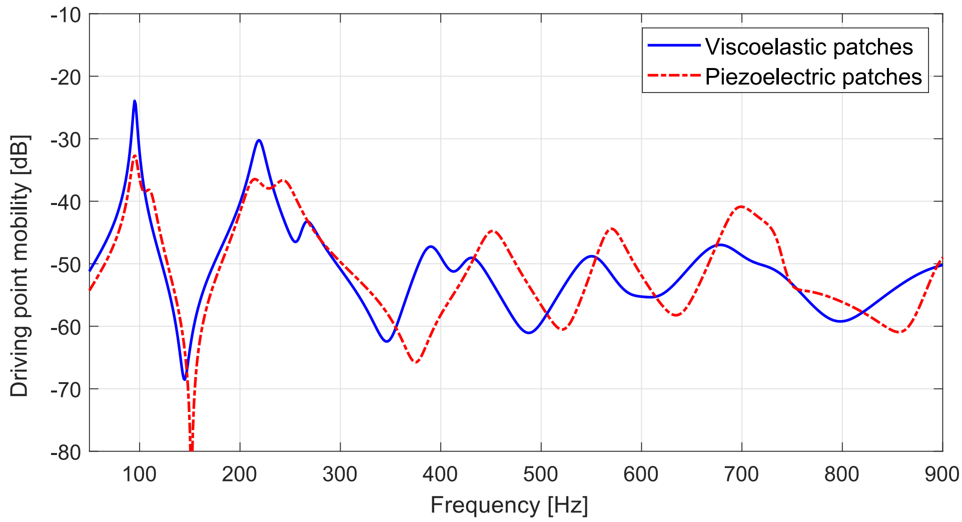


Figure 7: Comparison of frequency response functions in an equal-mass configuration.

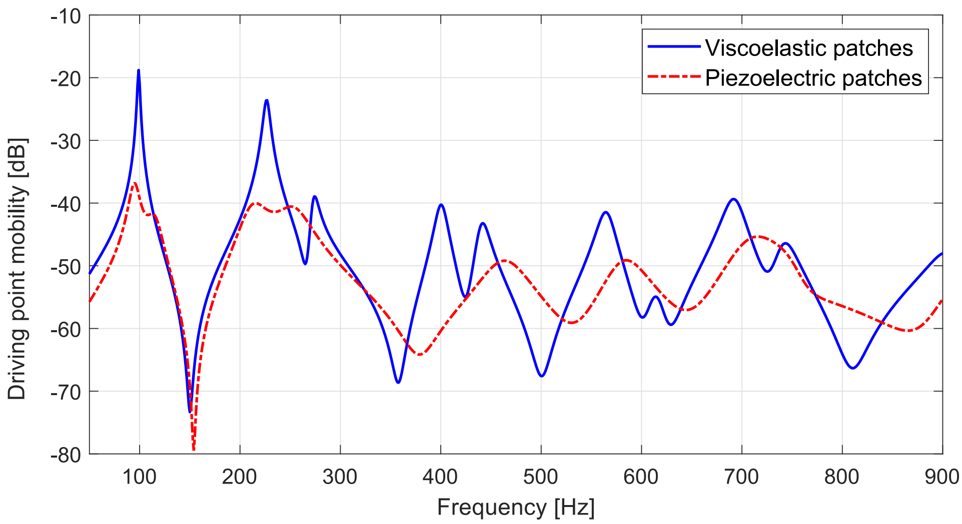


Figure 8: Comparison of frequency response functions in an equal-thickness configuration.

5. CONCLUSION

The goal of this work was to compare the damping performances of two passive treatments based on constrained viscoelastic layers or on piezoelectric patches connected to a multi-resonant electrical network. To this end, experimental and numerical tests have been carried out on a metallic panel, equipped with viscoelastic or piezoelectric patches. Numerical models of both panels have been experimentally validated, which enables the numerical study of two configurations: equal-mass and equal-thickness configurations.
The main conclusions of this work are :

- The damping performances of piezoelectric networks are generally more advantageous than those of viscoelastic materials to damped the first vibration modes.
- To damp higher modes of vibrations, the most efficient damping technique depends on the considered mass and dimension constraints.

The impact of other design constraints, such as cost, integrability or temperature, should be further investigated for an objective comparison of the damping performances of both passive treatments. For instance, when piezoelectric networks and constrained viscoelastic layers offer similar performances, the use of viscoelastic materials is preferable if the operating temperature remains constant, as it constitutes a low-cost solution with high integrability.

6. ACKNOWLEDGEMENTS

We acknowledge gratefully Safran Aircraft Engines for their contribution to the realization of the panel with viscoelastic patches.

7. REFERENCES

[1] O. Thomas, J. Ducarne, and J.-F. Deü. Performance of piezoelectric shunts for vibration reduction. *Smart Materials and Structures*, 21(1):015008, 2012.

[2] B. Lossouarn, J.-F. Deü, M. Aucejo, and K.A. Cunefare. Multimodal vibration damping of a plate by piezoelectric coupling to its analogous electrical network. *Smart Materials and Structures*, 25(11):115042, 2016.

[3] L. Rouleau, R. Pirk, B. Pluymers, and W. Desmet. Characterization and modeling of the viscoelastic behavior of a self-adhesive rubber using dynamic mechanical analysis tests. *Journal of Aerospace Technology and Management*, 7(2):200–208, 2015.

[4] B. Lossouarn, M. Aucejo, J.-F. Deü, and K.A. Kunefare. Design of a passive electrical analogue for piezoelectric damping of a plate. *Journal of Intelligent Material Systems and Structures*, 29(7):1301–1314, 2018.

[5] O. Robin, J.-D. Chazot, R. Boulandet, A. Berry, and N. Atalla. A plane and thin panel with representative simply supported boundary conditions for laboratory vibroacoustic tests. *Acta Acustica united with Acustica*, 102:170–182, 2016.

[6] O Robin, A. Berry, N. Atalla, M. Aucejo, B. Lossouarn, L. Rouleau, J.-F. Deü, C. Marchetto, and L. Maxit. Setting up plane and thin panels with representative simply supported boundary conditions: comparative results and applications in three laboratories. In *Proceedings of Inter-noise 2018*, Chicago, Illinois, August 2018.

[7] L. Rouleau, A. Legay, and J.-F. Deü. Interface finite elements for the modelling of constrained viscoelastic layers. *Composite Structures*, 204:847–854, 2018.