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NOISE CONTROL FOR A BETTER ENVIRONMENT

Black hole damping control with a thermally-driven shape memory polymer

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ABSTRACT

Acoustic black holes are an emerging passive solution to control the propagation of waves without added mass. They consist in locally decrease the thickness of a main structure with an adequate power-law profile to slow down flexural waves. The higher the thickness contrast is, the higher the efficiency is. The control of damping in the low stiffness area is important to ensure the vibration waves trapping: the stiffness decreases goes with a gradual damping increase. A strategy is developed in the presented work to actively control this damping by local heating of a memory shape-polymer like the tBA-PEGDMA whose elastic modulus and loss factor strongly depend on temperature. Studies are carried out to optimize the position of the viscoelastic material inside a given black hole, and the temperature distribution to decrease the reflection coefficient . Is is shown that an optimize thermal field distribution in the adaptive polymer improves the properties of the black hole.

1. INTRODUCTION

Acoustic Black Holes (ABH) are passive solutions for wave attenuation based on the integration in a structure of adequate gradual changes in local wave velocity with distance

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thanks to gradual changes in the local thickness [1, 2]. The theoretical behaviour is difficult to obtain because of manufacturing constraints that lead to a non-zero thickness at the border, inducing some reflections of flexural waves. It is possible to use a damping layer [3] to damp the waves in the ABH but it is not compulsory as local imperfections may induce dissipation [4]. Upgraded designs have recently emerged to extend ABH to other applications than structural damping such as energy harvesting [5] or wave energy focalization [6]. The purpose of the paper is to present an extended ABH that is thermally-controlled: a damping layer with mechanical properties strongly varying with temperature is glued on an ABH and adequate geometrical and temperature profiles are define to optimize the damping efficiency in the case of a beam.

2. COMBINATION OF AN ACOUSTIC BLACK HOLE (ABH) WITH A DAMPING LAYER

An Acoustic Black Hole is introduced ad the end of a host beam made with aluminium (E=70 Gpa, ρ=2700 kg.m^{-3}, η=0.002). It consists in a local decrease of the thickness h according to a power law such that

$$h(x) = h_0 \left(\frac{L_{ABH} - x}{L_{ABH}} \right)^2 \tag{1}$$

where $h_0 = 5$ mm is the thickness of the host beam and L_{ABH} is the length of the back hole. The width of the beam is 2 cm and its length before the hole is 54 cm. The question at stake in this part is the increase of the damping effect thanks to a viscoelastic layer glued to the ABH. This layer is assumed to be constituted by a virtual material (thickness: 1 mm and length: 15 cm, Young's modulus: 3 MPa, density: 900 kg/m3, loss factor: 0.8, considered constant in frequency). Its impact on the ABH effetct is evaluated computing the reflection coefficient R that is the ratio between the incident and the reflected propagative waves,

$$R = \frac{B}{A} \tag{2}$$

where

$$w(x) = Ae^{-jkx} + Be^{jkx} + Ce^{-kx} + De^{kx} \tag{3}$$

w is the flexural displacement of the beam and k the wavenumber. It is computed using the technique proposed in [7]: the transverse displacement $w(x_i)$ is computed or measured at n locations x_i along the beam, the wavenumber is given by the analytical formula and a pseudo-inverse is used to estimate the wave coefficients A and B,

$$\begin{bmatrix} e^{-jkx_1} & e^{jkx_1} \\ \cdots & \cdots \\ e^{-jkx_n} & e^{jkx_n} \end{bmatrix} \begin{Bmatrix} A \\ B \end{Bmatrix} = \begin{Bmatrix} w(x_1) \\ \cdots \\ w(x_n) \end{Bmatrix} \tag{4}$$

Three measurement points are used for the study, $x_1 = -17.5$ cm, $x_2 = -20$ cm and $x_3 = -25$ cm. These points are chosen to be far enough from the force or the discontinuity in the beam to consider that the main contributions are the propagative waves of the transverse displacement. Figure 1 presents the modulus of the reflection coefficient, without and with the viscoelastic layer: it can be observed that the layer has a great influence on the dissipation, the ABH with a finite termination and without damping layer reflects almost all the energy.
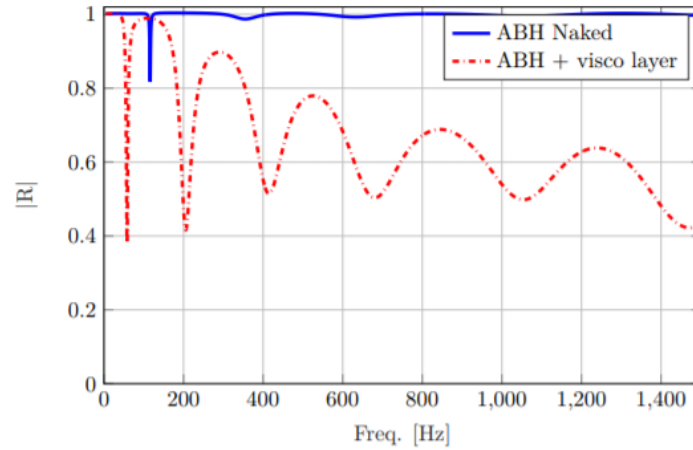
Figure 1: Numerical reflection coefficient for a finite host beam with and without a viscoelastic layer

3. TEMPERATURE CONTROL OF DAMPING IN VISCOELASTIC LAYER

In this section a specific viscoelastic material is used for the layer, the tBA/PEGDMA. It is a Shape Memory Polymer (SMP) with strongly frequency dependent mechanical properties [8]: the loss factor can be as high as 2.4 at the glass transition, occurring around 70 °C. Figure 2 presents the control of the reflection coefficient that can be obtained when using the SMP at different temperatures: it is shown that the reflection efficiency of the ABH can be tuned thanks to temperature control, in this case the most dissipative configuration occurs between 60 and 70°C.
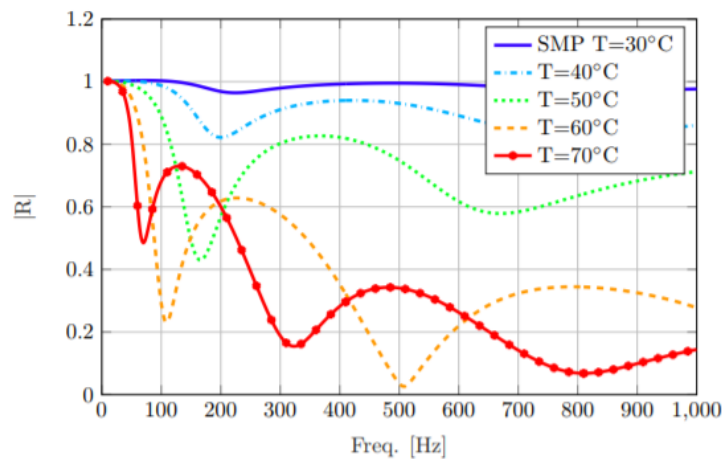

Figure 2: Numerical reflection coefficient for a finite host beam with a SMP layer at different temperatures

4. OPTIMAL DESIGN OF THE DAMPING LAYER

A work has thus been done to determine an optimal temperature control of a viscoelastic layer glued to an ABH. In this optimization study, the temperature was fixed to 70°C and two geometrical parameters were considered, namely the thickness and the width of the SMP layer. The thickness is considered in the range 0.3 mm to 3 mm. The width is considered relatively to the ABH length and varies from 0.25 to 1.5: 1 consists in a exact covering of the termination while 0.25 consist of 25 percent covering from the free end of the ABH. A global approach has been chosen considering as an indicator the mean value of the amplitude of the reflection coefficient over the frequency range of interest. A non-damped system leads to 1 and the purpose is to minimize this value. For the considered ABH application, the indicator was evaluated on two frequencies ranges (0-200 Hz and 0-1000 Hz) in order to find the best design for the full range and check the consistency with results computed only for the lower frequencies. By performing a full factorial design of experiment with large number of levels it has been shown that an adequate optimal compromise for the two frequency bands was 3 mm for the thickness of the layer, and 0.5 (50% covering) for the ABH ending covering.

An experimental validation of this result has been done using an ABH beam provided by LAUM-Le Mans University, and a damping layer elaborated in FEMTO-ST-University Bourgogne Franche-Comté, according to the optimal configuration. The experimental set-up is shown in Figure 3

Figure 3: Experimental setup - host beam with ABH and damping layer suspended in the thermal chamber

The beam is suspended in a thermal chamber to evaluate the temperature impact. The harmonic excitation force is generated by a contactless actuator consisting in a fixed coil accompanied with a magnet glued on the beam. Figure 4 presents the comparison between the numerical reflection coefficients and the experimental coefficients obtained at different frequencies for the optimal layer configuration. The correlation is very good. The closer the glass transition the temperature is the larger the discrepancies are because in the range the elatic modulus and the loss factor of the SMP are very sensitive to the temperature.

5. CONCLUSIONS

This study shows that it is possible to control the damping in order to improve the acoustic black hole effect In this case a SMP layer is geometrically optimized and
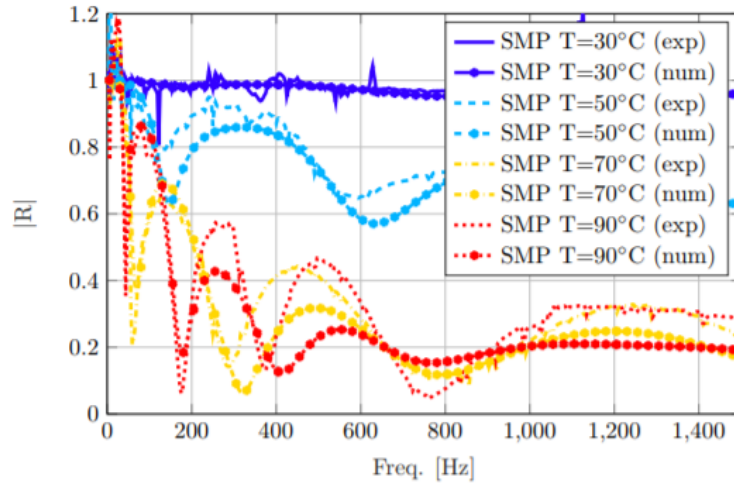
Figure 4: Comparison of numerical and experimental reflection coefficients for the optimal SMP layer at different temperatures

thermally controlled in order to maximize the damping effect at a temperature close to the glass transition on the basis of the mean value of the amplitude of the reflection coefficient, computed on the frequency range of interest.

6. ACKNOWLEDGEMENTS

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