AN OPTIMAL DESIGN OF 1D ACOUSTIC BLACK HOLE WITH DAMPING LAYER FOR PLATE GEOMETRY

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Acoustic Black Holes (ABH), a new method of passive vibration damping, have received much interest recently due to their lightweight and economically efficient properties. This paper aims to establish the optimal shape of the damping layer treated on ABH under harmonic loading. Firstly, a validation of numerical scheme that is used throughout this paper is carried out. A good agreement of the numerical simulation and the experiment is shown. Then, a numerical study of ABH with different dimensions of damping layer treated is performed. It is shown that treating the whole surface of ABH with damping layer is not necessary since only a small portion of damping layer near the tip is responsible for most of the vibration absorption. Future areas of application of the optimized ABH include lightweight damping of vehicle panels such as cars, trains, ships and airplanes.

1. Introduction

Lightweight control or damping of flexural waves in thin structures is a significant issue in many systems since flexural waves are the main cause of low frequency vibration and noise. However, thick viscoelastic damping materials were conventionally applied on vibrating structures for their ease of use, often leading to the inevitable increase of total structure weight. Alternatively, Acoustic Black Hole (ABH), a novel mean of passive vibration damping in thin structures has been recently proposed as a solution to lightweight and efficient damping. By smoothly reducing the thickness of thin structures with a power-law profile, wave group speed is predicted to be infinitely slowed down. Therefore, in principle, no waves can be reflected back from edge since vibration energy never reaches the edge of the structure. [1,2] Instead of using thick and heavy damping materials on structures, ABH can be a good candidate for more efficient and economical solution to vibration damping in systems that require lightweight damping such as transport systems.

Active studies on ABH and its applications have been performed since 2000s. Representative studies include applying a small amount of damping material on the tip of ABH to absorb the reflected flexural waves at the tip [2,3], a two-dimensional counterpart of one-dimensional ABH [4,5], experimental realization of ABH concept [6] and etc.

However, only a relatively few papers focused on optimizing the damping performance of ABH with and without damping layer treatments. In this paper, authors aim to establish the optimal shape of the damping layer by a sweep of damping layer parameters (length and thickness). Firstly, a validation of numerical scheme that is used throughout the research is performed. Then, the driving point mobility is compared between the plate only, plate with ABH, and the four cases of damping layer attached ABH.
2. Methods and materials

2.1 Methods and materials

Figure 1: (left) Plane view of ABH with damping layer applied on the tip. (right) Cross sectional view of ABH.

The numerical results in this paper were produced by solving the Navier’s equation using the finite element method in the frequency domain (from 20 Hz to 7000 Hz with increment of 20 Hz.). All the boundaries are free of force and moments. As shown in Figure 1, three dimensional analyses of ABH with and without the damping material under harmonic excitation applied in the center of the plate are performed. The driving point mobility (re \( \text{1m/s/N} \)) is examined for all the cases. The geometrical dimensions and material properties of plate and ABH are chosen in accordance with the reference as in Table 1. [7] The material property of the damping material is chosen as summarized in Table 1. as well. [5]

Table 1: Material properties of the plate and the damping layer.

<table>
<thead>
<tr>
<th>Material</th>
<th>Cold-rolled steel</th>
<th>Damping layer</th>
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<tbody>
<tr>
<td>Young’s modulus</td>
<td>190 GPa</td>
<td>10 MPa</td>
</tr>
<tr>
<td>Density</td>
<td>7850 kg/m(^3)</td>
<td>1000 kg/m(^3)</td>
</tr>
<tr>
<td>Poisson ratio</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Loss factor</td>
<td>0.6 %</td>
<td>10 %</td>
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2.2 Validation of plate

Figure 2: (left) Comparison of driving point mobility. (right) Comparison of driving point mobility – low frequency range.

Figure 2 shows the result of numerical scheme validation. A simple free plate with the geometric dimensions and material properties chosen as in O’Boy’s paper is used as the validation example. Throughout the whole frequency range, the results of our numerical scheme shows a good agreement with the performed experiment.
3. Discussions

In order to establish the optimal dimension of the treated damping layer, four cases of damping layer treatments are compared in driving point mobility. Of many parameters defining the damping layer dimensions, the length and thickness are chosen to be varied. Four combinations of length and thickness are: (10,1), (10,2), (45,1) and (45,2) (mm).

![Figure 3: Comparison of driving point mobilities between the plate only, plate with ABH, and 4 cases of damping layer treatment.](image)

Figure 3 shows the comparison of driving point mobility for the plate only, plate with ABH and the four cases. Naturally, the largest peaks appear in the plate only case. Then, about 2 dB decrease in peak mobilities occur by attaching ABH in one of its edges. About 5 dB more damping is introduced by treating the ABH surface with damping layers. However, difference between the four cases seems almost negligible even though treated amount differs significantly. The sizes of the four treatments are each 10 mm\(^2\), 20 mm\(^2\), 45 mm\(^2\) and 90 mm\(^2\). Treating even a small bit (10 mm) has almost the same effect as treating the whole surface (45 mm) with damping layer. This implies that, most of the vibrational energy are concentrated near the tip region and the size of the treatment may not be a crucial factor on the damping performance. When treating the ABH with damping layer, one should pay more attention on the appropriate thickness of damping layer and treat it on the tip part.

4. Conclusion

We have validated the numerical scheme of the research with experimental result for a simple free plate and then compared the driving point mobility of the plate only, plate with ABH, and four different dimensions of damping layer treated ABHs. It is concluded that, the damping performance of ABH can be enhanced by treating the tip with the appropriate size of damping layer. Furthermore, unlike the conventional damping treatments, only a relatively small amount of damping layer is required for ABH.

REFERENCES


