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Numerical Vibration Characteristics of a New Helix-Acoustics Black Hole (*h*-ABH)

Kim, Sun-Yong[1]
School of Mechanical Engineering, Ulsan College
57 Daehak-ro, Nam-gu, Ulsan 44610, South Korea

Lee, Dooho[2]
Department of Mechanical Engineering, Dongeui University
176 Eomgwang-ro, Busanjin-gu, Busan, 47340, South Korea

ABSTRACT

It has been proposed a helix-acoustic black hole, *h*-ABH, to control effectively the vibration with a modular ABH structure as shown in Fig. 1. As a matter of fact that more ABHs provide a higher wave energy absorption. However, there is a spatial constraint to assemble the ABH structures in the modular ABH system. The ABH structure could be gathering the flexural vibration, which is usually normal to the surface of ABH region. When the *h*-ABH structures are considered, the input signal would be lateral vibration. Thus, we have performed a FE simulation comparing performance of wave energy absorption between conventional ABH and *h*-ABH. It shows that *h*-ABH provides a better performance than the other one.

Keywords: Acoustic Black Hole, Wave energy, Vibration control
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

It has been always challenging to control structural vibrations to improve performance of mechanical, aerospace and civil engineering system. Recently, a modular ABH [1] was introduced in order to apply ABH structure into real system such as plate/shell of structures and other vibrating structures, specifically vibrating thin layer structures. A modular ABH, Fig. 1, has multiple ABH structures, which can collect the wave energy for dissipating unwanted vibration and may control the location of unwanted vibration. In Fig. 1, 4 ABH structures are assembled in 90° degree angle from each other. The modular ABH has also great potential opportunities to implementing into real structures without any design changes.

Although a modular has many advantages, it still needs better performance. As the author's perspectives, there is one main restriction that is the 4 to 8 number of ABH structures could maximally be assembled due to the spatial constraints. As a matter of fact, more ABH structures higher level of wave energy.

[1] sykim2@uc.ac.kr
[2] dooho@deu.ac.kr

Therefore, we have proposed a new shape of ABH structures, helix-ABH, to improve performance of the modular ABH system for more ABH structures assembled. In this study, numerical simulations were conducted to compare performance between the conventional ABH and a new shape of ABH as a basic study.

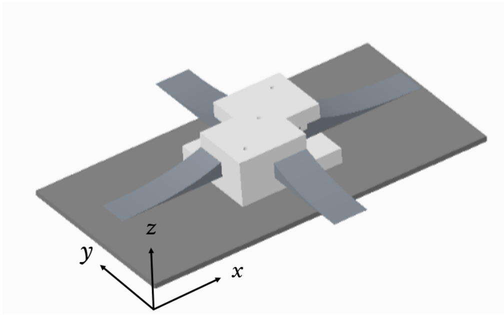

Figure 1. A modular Acoustic Black Holes

2. Acoustic Black Hole (ABH)

2.1 Basic principle of ABH

The basic principle of the ABH effects is based on the concept of "zero reflection", when the phase velocity and group velocity progressively decrease to zero with the propagating distance [2]. The zero thickness of structure would theoretically make the perfect ABH effects; zero reflection. However, there is finite thickness at the tip of ABH structure due to manufacturability limitations. The thickness of a plate has a constant h_1 and a tapered area (from x_1 to x_2) in Fig. 2. The thickness of the tapered region progressively varies as follows:

$$h(r) = \begin{cases} h_2, & (x \geq x_x) \\ \varepsilon x^m + h_1, & (x_1 < x \leq x_2) \end{cases} \tag{1}$$

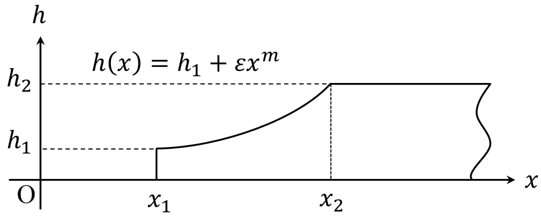

Figure 2. A scheme of ABH plate with truncated region

where m is a positive number and ε is a constant value. An ideal ABH structure has with $m \geq 2.0$.

One-dimensional wave propagation is simply considered where a flexural wave propagates through the tapered beam with a power-law profile in the x direction. The complex amplitude $U(x)$ from an arbitrary point x toward the zero point as:

$$U(x) = A(x)e^{i\Phi(x)} \tag{2}$$

where $A(x)$ is the varying amplitude, is the imaginary number and the total accumulated phase, $\Phi(x)$, is expressed as follows:

$$\Phi(x) = -\int_x^0 k(x)\,dx = \int_0^x k(x)\,dx \tag{3}$$

where $k(x)$ is the local wavenumber along with the variation of thickness. The flexural wavenumber could be varied by the thickness of the ABH region, which can be expressed as:

$$k(r) = \left(12k_l^2 / h^2(r)\right)^{1/4} \tag{4}$$

where $k_l = \rho\left(1-v^2\right)\omega^2 / E$ is the wavenumber associated with compressional waves in a thin beam with a uniform thickness. It is noted that ρ is the density, v is Poisson's ratio, ω is the angular frequency of the flexural wave and E is the elastic modulus. The corresponding phase and group velocities are expressed by

$$c_p = \left(\frac{E}{12\rho\left(1-v^2\right)} \cdot \left(\varepsilon\left(r-r_1\right)^m + h_1\right) \cdot \omega^2\right) \tag{5}$$

$$c_g = \left(\frac{4E}{3\rho\left(1-v^2\right)} \cdot \left(\varepsilon\left(r-r_1\right)^m + h_1\right) \cdot \omega^2\right) \tag{6}$$

The ABH system collects most of flexural waves, which is usually known as "focalization". Investigating the effectiveness of the energy in the ABH region, wave energy distribution is introduced. In order to compare and visualize the effectiveness of the focalization and the quantity of wave energy in ABH structure, the summation of the squared displacement of the whole and selected node points during a specific time period, which is defined as [3]:

$$E_i\left(x,y,z\right) = \int_0^T w_i^2\left(x,y,z,t\right)dt \tag{7}$$

where E_i is the summation of the wave energy of the i-th node. The time period, T, is defined as 1.2τ and w_i is the displacement of the i-th node. The definition of τ is the exploring time in which one-way flexural wave propagating from one-side to the other side.

2.2 Helix-Acoustic Black Hole (h-ABH)

Recently, a modular ABH [1] was introduced in order to implement the ABH structures into real structures controlling vibration. The ABH structure is usually designed in a thin plate or beam. However, the ABH region is usually located at the tip of structures, which may cause the constraints applying to real structures. To overcome the mentioned limitation, Lee and Park [1] proposed a modular ABH as shown in Fig. 1. A modular ABH enables to locate any place on a plate structure. It shows that the magnitude of FRF was efficiently reduced with the modular ABH compared to the ones without ABH structure.

The main idea of this paper is to propose the shape of ABH that enables to assemble more ABH structures in the modular ABH, which can effectively reduce vibration. As shown in Fig. 1, the number of ABHs is 4 and it maybe fix the ABH structures maximally 8 due to the spatial constraints. Since the ABH structures can reduce the z-directional waves in Fig. 1, the middle surface of ABH should be parallel to the x-y plane. The z-directional flexural wave travels to the modular ABH can be reduced by the ABH structures. In order to assemble more ABH structures, the ABH structure would be 90 degree rotating along with the y-direction and each ABH structure, helix-ABH, will be twisting to remain the bottom surface of ABH region parallel to the x-y plane as shown in Fig. 3.

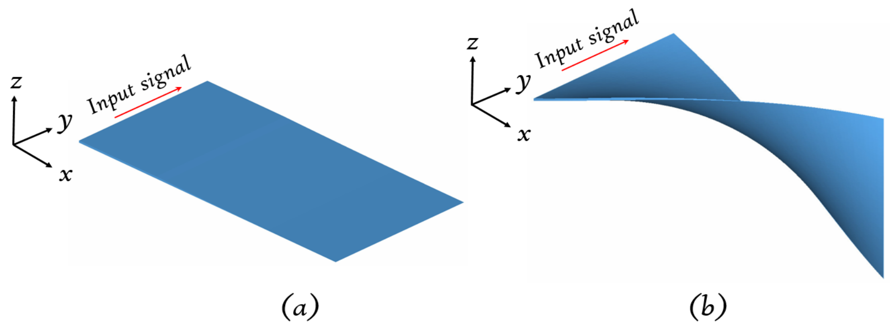

Figure 3. A scheme of ABH structures: (a) conventional ABH and (b) h-ABH

Since the bottom surface of ABH structure should be parallel with x-y plane in Fig. 3 (a) and the ABH structure would be rotating 90 degree along with the y axis of the ABH structure, which is called h-ABH as shown in Fig. 3 (b). It is the main work to estimate the performance of the h-ABH when the external force would be z direction compared to the conventional ones. In order to compare the performance the concept of wave energy, Eq. 7, would be adopted in this study.

3. Numerical Examples

In order to compare the effectiveness of the conventional ABH and h-ABH structures, numerical simulation was conducted by comparing the wave energy, which is the summation of the squared displacement over all nodes during a specific time duration. For the numerical simulation, a 8-node hexahedron elements were assembled and MSC.NASTRAN was used for the FE simulation. Those ABH structures were excited by a unit Hanning-windowed pure tone force with 5kHz frequency. The y directional external load is applied along with the left-side edge in Figs. 3 (a) and (b). The direction of applied load is not the transverse but the lateral external loading, which is a difference from the conventional ABH structure system.

It is also noted that the material is considered as aluminium and the dimensions are $400mm$ (x) $\times$ $800mm$ (y). The thickness h_1 and h_2 are $0.5mm$ and $5.806mm$, respectively. For the ABH region, ε and m are considered as 1.458e-06 and 2.2, respectively.

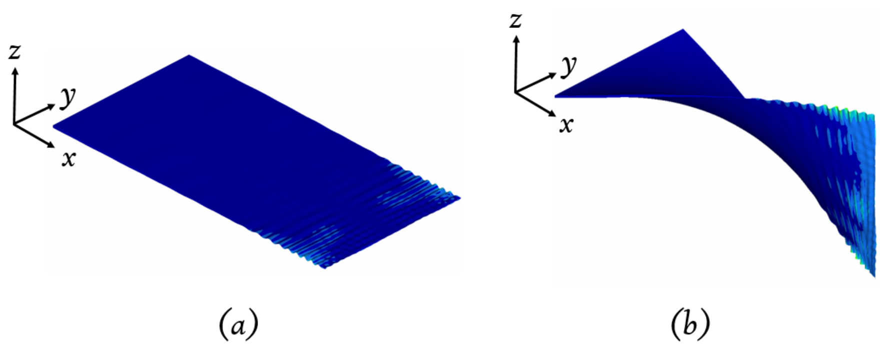

Figure 4. The comparison of wave energy distribution at 3ms

Fig. 4 has compared the wave energy distribution at the 3*ms* after an external loading wave traveling from the left-side edge. As it is shown in Figs. 4 (a) and (b), the level of wave energy is very high near the tip of the beams, which means that the phenomena of gathering wave energy is still affected regardless of the direction of external loading and the shape of ABH structure as well. Since the effectiveness of focalized wave energy is more important according to the shape of ABH structures, the wave energies between the conventional and *h*-ABH structures are compared in Table 1. The second column shows the total wave energy during the 3.1*ms* period and the third column shows the sum of wave energy only the ABH region during the 3.1*ms* period. The last column shows the effectiveness of focalization due to the ABH structure which shows that most of energy is focalized in the ABH structures on the both cases. The total wave energy of *h*-ABH is approximately 37.9% higher than the other one.

Table 1. The comparison of wave energies between the conventional ABH and *h*-ABH structures

	Total wave energy [J]	Wave energy in ABH region [J]	Ratio (%)
Conventional ABH	0.0229	0.0222	94.94
h-ABH	0.0316	0.0310	98.10

4. CONCLUSIONS

A new *h*-ABH structure was proposed in order to improve performance of ABH effects on a modular ABH. In this study, we have compared between conventional ABH and *h*-ABH structure for investigating the effectiveness of *h*-ABH, when a lateral wave energy considered as a basic research. A FE numerical simulations were conducted to estimate the performance. It shows that the level of wave energy of *h*-ABH would be higher than the other one, which means that the *h*-ABH structure would be better performance when a lateral directional vibration is considered as input signal. It can also resolve the spatial constraints as well.

5. ACKNOWLEDGEMENTS

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