

# Study on vibration transfer characteristics of acoustic supermaterial plate structure

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**Abstract:** The problem of low frequency vibration and noise control is a huge challenge in the engineering environment. The bandgap characteristics of phononic crystals can suppress the propagation of acoustic waves and provide a new solution for low-frequency vibration and noise control. In this paper, an acoustic supermaterial structure plate is proposed. By the finite element calculation, two band gaps of 71Hz~120Hz and 315Hz~400Hz are obtained. Finite element method is used to analyze the variation of the transverse and longitudinal periodic number of the acoustic supermaterial plate, and the relationship between the vibration transmission characteristics and the band gap is obtained. The research shows that the number of original cells of acoustic metamaterial structural plates is at least 8.

## 1. Introduction

Phononic crystals are a kind of artificial composite materials [1], which can effectively control the scattering characteristics of vibration waves. This new method of elastic wave control has proposed a new scheme for controlling low-frequency vibration [2-3]. After years of research [4-5], its superior low-frequency band gap characteristics [6-7], with the study and discovery of such phononic crystals [8-9], have played a prominent role in engineering application[10-11].

Whether by Bragg scattering motivation or through local resonance mechanism application to affect the scattering of the wave [12-13], these two kinds of materials can exhibit down space, wave vector space and phase space to show a large number of special wave propagation characteristics.

The band gap characteristic is the landmark of the phononic crystal. The band structure is expressed as the dispersion relation of the elastic wave in the infinite periodic phononic crystal, and the band gap can be clearly defined by the band structure analysis. It is obvious that the actual structure or equipment cannot have infinite period, this paper further studies the finite element simulation of the periodic number of the structure and analyze the transmission characteristics of the phononic crystal structure of different period number. It is found that the transmission rate in the band gap decreases with the increase of the number of cycles, while the transmission rate in the passband does not change significantly. This will provide some reference for the practical application of the project.

## 2. Computing method

A resonator with an array sorted phononic crystal structure is surrounded by a vacuum. The dispersion relation of the infinite system is considered and calculated. Because the infinite system is periodically



arranged along the X and Y directions, it is necessary to adopt Bloch periodicity for the boundary between cell units. According to the Bloch theory, because of the periodicity of phononic crystals, the study of the vibration characteristics in the phonon crystal structure can be converted into the unit structure by introducing the periodic boundary conditions. The Bloch wave vector  $k$  is introduced into the periodic boundary condition and only needs to be obtained along the irreducible Brillouin boundary of the unit structure, then the eigenvalues can be solved, and the inherent vibration characteristics of the whole phononic crystal structure can be described. For the structures involved in this article, as shown in Figure 1 (a) and (b), the natural frequencies of different directions are arranged in the direction of the band structure in the phononic crystal. The band and forbidden band frequency can be directly identified from the band structure.



(a) Planform

(b) Side view

Fig.1 Resonant cell structure of mass block-support beam

In this paper, the energy band of the structure is calculated using the finite element software COMSOL Multiphysics. In the discussion of the scattering of free space sound waves, the perfect matching layer (Perfect Match Layer, PML) can be used in the COMSOL software to replace the infinite domain in the face of infinite computing space. PML is an applied region, which is fully absorbed by any angle of incident wave and does not produce any reflection, so it does not affect any wavefront shape.

### 3. The band gap calculation of the model

In the COMSOL software, the finite soft simulation analysis is carried out, including  $a=30\text{mm}$ ,  $h=10\text{mm}$ ,  $p=2\text{mm}$ ,  $t=5\text{mm}$ ,  $w=2\text{mm}$ ,  $r=8\text{mm}$ . The material of the flat surface is plexiglass, and the cylinder is made of stainless steel. The material parameters of stainless steel are as follows: the density is  $7890\text{kg/m}^3$ , the modulus of elasticity is  $196\text{GPa}$ , the Poisson's ratio is  $0.3$ , the material parameters of the organic glass are  $1142\text{kg/m}^3$ , the modulus of elasticity is  $2.0\text{GPa}$ , and the Poisson's ratio is  $0.4$ .

The model of this calculation belongs to a supporting beam structure in which the cylinder is a stainless steel core, the panel and the supporting beam connected to the cylinder are organic glass, which provides an elastic support. At the same time, because of the different material properties, it can provide a better band gap characteristic.

COMSOL software is used to build the model, and the model is simulated and analyzed. Finally, the energy band diagram of the model is obtained, as shown in Figure 3.

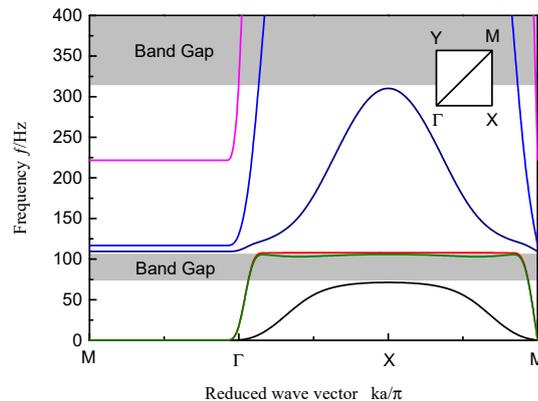


Fig.2 The band gap graph of the model

According to the calculation and analysis of the energy band diagram of the above model, Fig. 2 is the energy band structure in which the flexural wave propagates. There are two band gaps formed, and the band gap ranges are 71Hz~120Hz and 315Hz~400Hz respectively.

#### 4. Calculation and analysis of transmission characteristics of acoustic supermaterial

##### 4.1. Analysis of the band gap characteristics of the longitudinal primary cell number

Due to the band gap characteristics of acoustic metamaterials, the corresponding vibration transfer characteristics are based on the ideal assumption that the transverse and longitudinal directions are infinite cycles. However, in practical engineering applications, the assumption of infinite periodicity cannot be satisfied. Therefore, in this section the number of primary cells of the phononic crystal in the longitudinal direction is set horizontally as an infinite period, simulation analysis is carried out to determine the influence of the number of longitudinal primary cells of the phononic crystal plate and its effects on the vibration transmission characteristics.

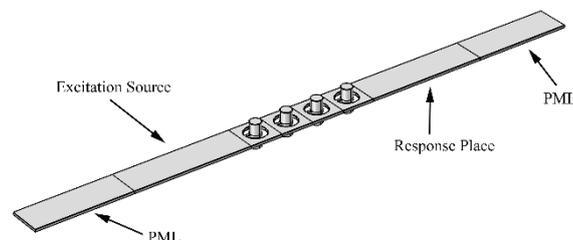


Fig.3 There are 4 primary cell simulation models in the longitudinal direction of the plate

In the COMSOL software, the model is set up. As shown in Figure 3, the acoustic supermaterial structure plate is set horizontally for an infinite period, and the plate has eight phonon crystals in the longitudinal direction. The displacement excitation of a 1mm is given at the left end of the plate. By calculating the vibration transfer characteristics of the plate, the displacement signals at the response are obtained, and the transfer loss is obtained accordingly.

The influence of the cell structure including 4, 6, 8 and 10 phononic crystals on the vibration transfer characteristics is studied by finite element software simulation. The transfer properties of phononic crystal plates containing 4, 6, 8 and 10 cells can be obtained, as shown in Fig. 4.

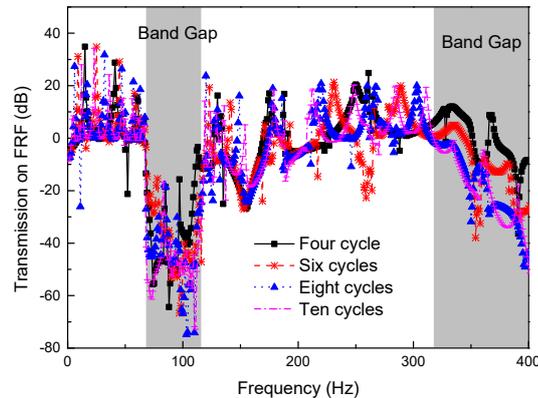


Fig.4 Vibrational transfer properties of phononic crystal structural plates with different cell numbers

From the analysis of the simulation results, the transversal setting of the phononic crystal plate is infinite period, and the number of its original cell is changed in the longitudinal direction. From the transfer characteristics of each plate, the number of primary cells in the longitudinal direction of the phonon crystal plate is less than 8, and there are some differences between the vibration transfer characteristics and the band gap characteristics. So, when the number of primary cells is less than the number 8 there is a difference in the band gap characteristics. When the quantity is less than 8, the vibration transfer property of the system is not consistent with its band gap characteristics. When the number of cells is greater than or equal to 8, the vibration transfer characteristics are basically consistent with the band gap characteristics. Therefore, the number of original cells is guaranteed to be at least 8.

#### 4.2. Analysis of the band gap characteristics of the transverse periodic number

According to the simulation results of the band gap characteristics of the original cell number in the previous section, the number of the longitudinal primary cells of the phononic crystal plate is determined to be 8, and then the effect of the transverse periodic number on the band gap and vibration transfer characteristics of the phononic crystal structure plate is considered respectively. The simulation model shown in Figure 5 is established in COMSOL software. It has 8 vertical cell structures and 4 horizontal structures. The displacement excitation of a 1mm is given at the left end of the plate, and the displacement signal at the response is obtained through the calculation of the vibration transfer characteristic of the plate, and the transfer loss is obtained accordingly.

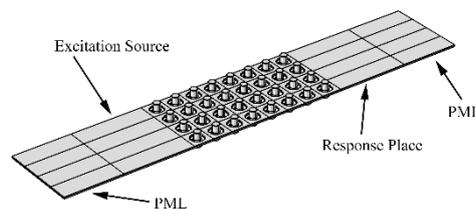


Fig.5 A simulation model of 4 cycles in the transverse direction of the plate

First, a phononic crystal plate with 8 primary cell structures is first determined, and then the effects of the structure of the phononic crystal on the vibration transfer characteristics of the phononic crystals with 1, 4 and infinite periods are studied. The transfer characteristics of the transverse period number to the phononic crystal plate can be obtained, as shown in Figure 6.

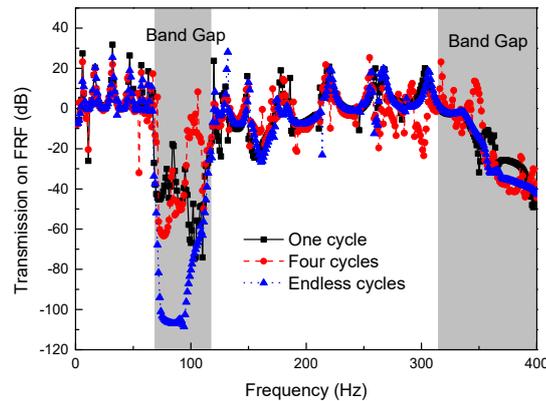


Fig.6 Vibration transfer characteristics of different periodic number of plates

It can be seen from the diagram that the vibration transfer characteristics of the different periodic number of the phononic crystal structure plate correspond to the band gap range of the calculated ideal phononic crystal, but there is also a deviation. In general, if the number of cycles in a finite periodic structure is increased, the vibration attenuation effect in the band gap will be better, and the band gap is more consistent with the transmission attenuation section.

## 5. Summary

In this paper, an acoustic metamaterial model is first presented, and the energy band diagram is obtained. Then, by changing the cycle number of acoustic metamaterials, we can get the following conclusions:

(1) The band gap of the acoustic metamaterial model designed in this paper is 71Hz~120Hz and 315Hz~400Hz.

(2) In order to ensure the band gap characteristics of acoustic metamaterials, the number of longitudinal cells is at least 8.

(3) The transfer rate in the band gap decreases with the increase of the number of periodicity, that is, in practical applications, the number of periodic structures of the finite periodic structure can be increased, and more attenuating elastic band gaps can be obtained.

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