Vibration band gaps of two-dimensional improved phononic crystals

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ABSTRACT

This paper proposes a kind of two-dimensional improved phononic composed of three parts: scatterer, matrix and additional mass, and study its bandgap structure based on the finite element method.Through the study we find that if we change the number , the material and arrangement of additional mass in a single cell,the propagation of elastic wave will be theoretically restrained and then achieve the purpose of vibration isolation and vibration reduction.This paper chose a representative cell as the research object and study the influence of material parameters and geometrical parameters on the band structure of two-dimensional phononic crystal.The results show that the band gap of the improved two-dimensional phononic crystal can be affected by changing the number of the mass blocks, the arrangement and the physical parameters of the additional mass.According to this phenomenon, we can control the propagation of elastic wave in the structure by changing the parameters of the additional mass.This research can be used in the high frequency vibration insulation of plate structures.

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1 INTRODUCTION

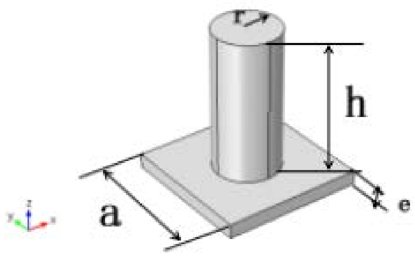
Phononic crystal were proposed for the first time by M.S. Kushwaha et al when they study on two dimensional solid periodic composite of Ni / Al in the year of 1993.At the same time, they pointed out that the band gap characteristics of phononic crystals will have a good application in high precision and non vibration environment.In 1995,R. Martínez-Sala et al confirmed the existence of acoustic band gap in the experimental by testing the Sculpture named "flowing melody" with a history of 200 years..Since then, the study of phononic crystals attract considerable attention.Phononic crystal is a periodic composite material with elastic wave band gaps consisting of two or more than two kinds of elastic medium .When the elastic wave propagates in the phononic crystal, it will form a special dispersion relation by the impact of the internal periodic structure, and the frequency range without the dispersion relation curve is called band gap.In theory,when the elastic wave propagation in the band gap frequency,it will be suppressed,but it will propagate without loss in the dispersion relation.

The energy band structure is mainly effected by material parameters, geometric parameters and so on . Material parameters mainly affect the band gap by the mass density and elastic constants of the material.Kmhwaha et al studied the band gap of two-dimensional phononic crystals under different shear modulus and density.Sigalas and Economou studied the variation of the relative band gap width with the scattering matrix and the density of the matrix. It was found that when the density mismatch is large, it is easier to produce the band gap.The main geometric parameters what affect the band gap include periodic arrangement form structure and cell topology etc.For two dimensional solid / solid system, triangular lattice is easier to produce band gap than tetragonal lattice.Changing the length-width ratio of the square lattice have little effect on the high frequency band gap of the iron / air system, but changing the depth-width ratio of triangular lattice can produce bandgap in the lower frequency .The cell topology is diverse, including the shape of the scatterer, the size (filling rate) and other factors.It is clear that the filling rate have large effect on band diagram and there is always an optimal value which makes the band gap reach maximum..Although many researcher discuss the impact of the shape of the scatterer on the bandgap, but unfortunately the ever-changing scatter shape make it difficult to get a regular knowledge.

This paper proposes a kind of two-dimensional improved phononic composed of three parts: scatterer, matrix and additional mass, and study its bandgap structure based on the finite element method.(COMSOL Multiphysics). and we optimize the structure of the crystal cells to improve it vibration - proof performance.By changing the number and arrangement of the mass blocks in a single cell, the propagation of elastic waves in two-dimensional phononic crystal plates can be suppressed theoretically, and the purpose of vibration isolation and vibration reduction can be achieved..In this paper, we take a representative cell as the research object, and mainly study the influence of the related parameters on the band structure of two-dimensional phononic crystals.

2.MODEL AND METHOD

The model we proposed composes of three parts, the scattering, the matrix and the additional mass. The shape of the scatterer is a cylinder with a height of h=10mm and a radius of r=2.35mm. The matrix shape cuboid with square bottom whose length is a=10mm, e=1mm. Additional mass shape cuboid with square bottom, As shown in FIG. 1 ,it is a model contains only one mass, its length is b=4mm, e=1mm. In this paper, we mainly study the influence of mass parameters on the band structure of phononic crystals. The material of the scattering body is steel, and the material of the substrate is epoxy resin. Its specific parameters are shown in Table 1.



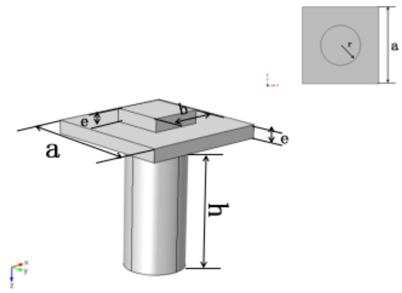
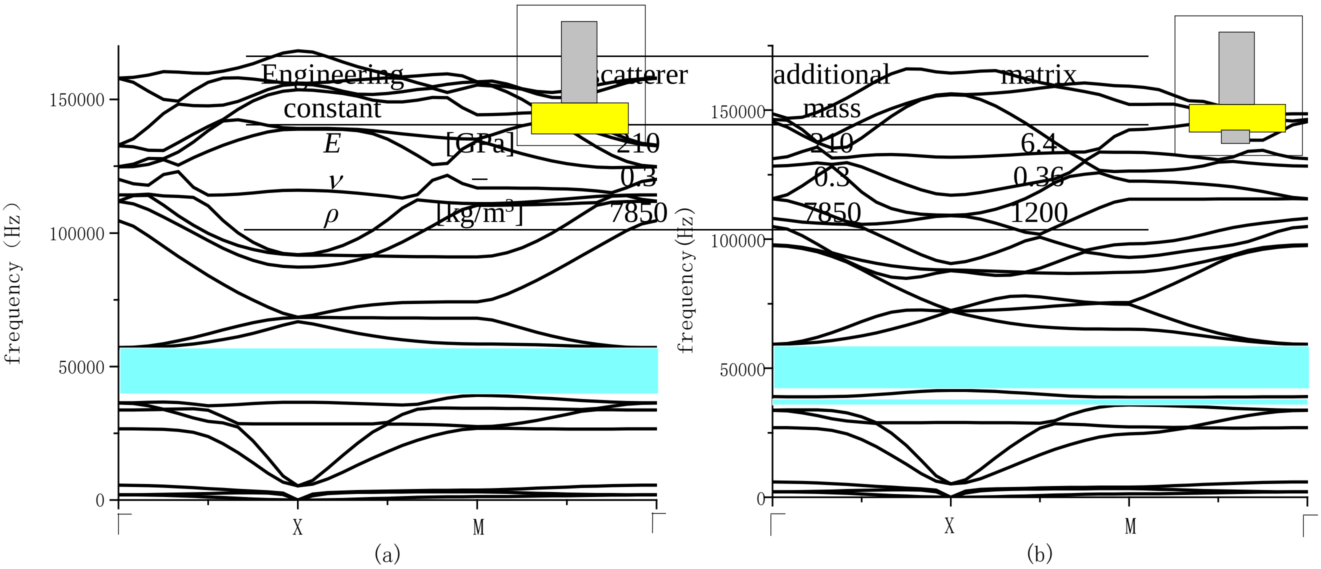


FIG. 1 Schematic view of a unit-cell of the investigated structures. (a) the structural element without additional mass (b) the structural element with one mass



Engineering constant		scatterer	additional mass	matrix
E	[GPa]	210	210	6.4
ν	–	0.3	0.3	0.36
ρ	[kg/m^3]	7850	7850	1200

Table 1: Physical properties of scatterer additional mass and matrix

We simulate the structure through the finite element software COMSOL Multiphysics, setting for periodic Bloch boundary condition, scanning the first Brillouin zone(Since the bandgap is calculated, only the boundary of the irreducible Brillouin zone be scanned.) and get the band structure diagram.The two-dimensional phononic crystal model with no additional mass and the two-dimensional phononic crystal model with only one additional mass are simulated and analyzed, the band structure we get is shown in Fig.2.

FIG. 2.Band structures of the studied structures a)band structures of the structural element without additional mass b) band structures of the structural element with one mass

It can be seen in FIG. 2 that the two structures aslo can produce obvious band gap, but the band gap width increases obviously when the mass block is added : from the 20.64KHz to 22.74KHz ,which mean the improved two-dimensional phononic crystal can increase the width of the band gap in a certain extent . This phenomenon is because the scattering structure , the additional mass and the matrix in the cell structure couple each other, making the cell structure in the band gap does not have a corresponding vibration mode.Therefore, the elastic wave in the band gap can not propagate in the phononic crystal plate.

3 MODEL IMPROVEMENT

We modify the material parameters and structural geometrical parameters of the mass block to observe the influence of the band structure on the band structure and hope to find the rule of the energy band structure change . If we find that we could select or change the parameters of different mass blocks to achieve the desired purpose.

3.1 INFLUENCE OF MATERIAL PARAMETERS

Firstly,we study the influence of material parameters on the band structure.The structure we studied is a two-dimensional phononic crystal model with four additional mass blocks.The geometric parameters and material of the scatterer and matrix are as same as that we used above. As shown in FIG. 3,the shape of the four additional mass is both shape cuboid with square bottom whose length is a = 2mm, height is h = 1mm, the four mass blocks remain equidistant spacing e = 2mm.The additional mass blocks are respectively made of steel, aluminum and rubber, and the material parameters of three kinds of materials with different parameters are simulated .Three energy band structures are obtained by simulation. In order to the observe of the band gap carefully, we sorted out the result(Table 3).

According to Table 3, with the density ratio between the mass and the matrix decrease,the number of the band gap decrease,and the total bandwidth also decrease.The result shows that the density ratio of the mass and the matrix has a great influence on the formation of the band gap. To a certain extent, the larger the band gap is, the larger the total bandwidth is. In this regard, we can use the appropriate materials to obtain the desired band structure.

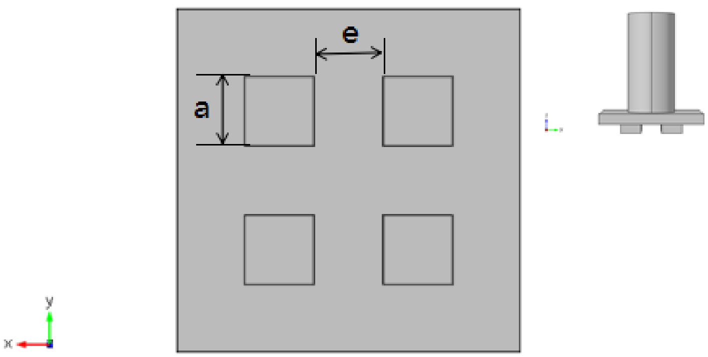


FIG. 3.modle with four additional mass ,the high of mass is h=1mm

Engineering constant		steel	aluminum	rubber
E	[GPa]	210	70	2.15
ν	–	0.3	0.33	0.4998
ρ	[kg/m^3]	7850	2700	1300

Table 2: Physical properties of steel aluminum and rubber

	第一带隙起止频率（KHz）		第二带隙起止频率（KHz）		第二带隙起止频率（KHz）		总带宽（KHz）
steel	40.98	52.81	57.60	69.38	92.28	109.31	41.19
aluminum	42.69	61.03	69.79	79.70	–	–	28.25

rubber	39. 25	58. 14	–	–	–	–	18. 89

Table 3：The band gap of three different materials

3.2 INFLUENCE OF GEOMETRY PARAMETERS

In addition, we also analyze the influence of the geometric parameters of the structure on the energy band structure.

In this paper, we study the model with four additional mass blocks. Still use the shape of the four additional mass is both shape cuboid with square bottom whose length is a = 2mm, height were taken 1mm, 2mm, 3mm, 4mm, 5mm these five cases.The material of the additional mass is steel, arranged as FIG. 3, where e = 2mm. The energy band structure of these five different cases is calculated and the vibration pattern is observed. shown as FIG. 4.

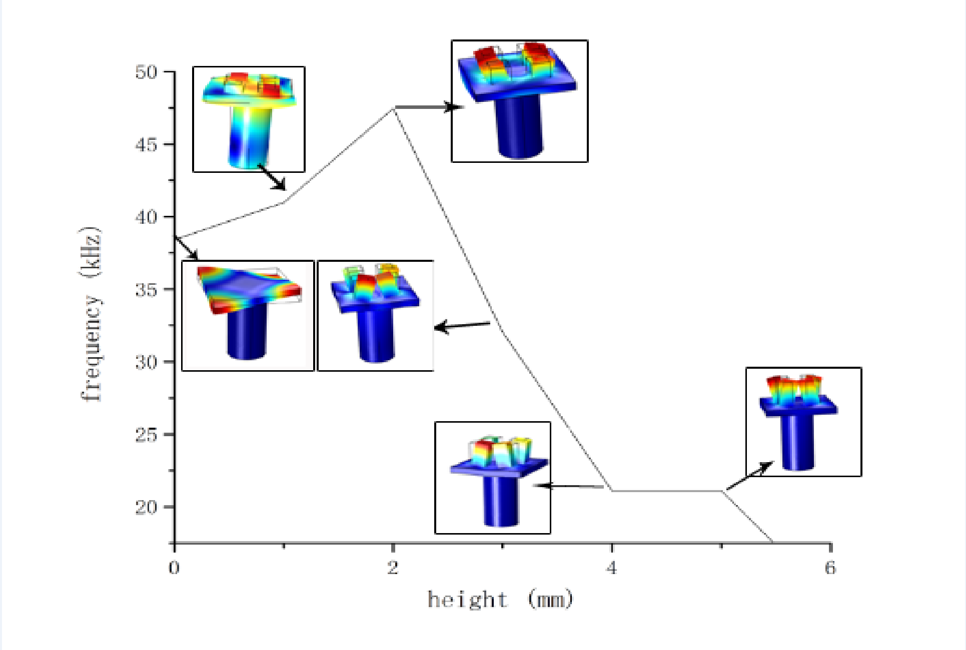


FIG. 4 With the increase of the weight of the additional mass, the initial frequency of the first bandgap decrese

It can be seen from FIG. 4 that the height of the mass block has a great influence on the starting frequency of the forbidden band. The higher the overall mass of the additional mass is, the lower the starting frequency is. So the initial frequency of the forbidden band can be controlled by changing the height of the mass block.

We also analyzed the effect of the height of the addition mass change on the bandwidth of the bandgap. The results are shown in Fig.5

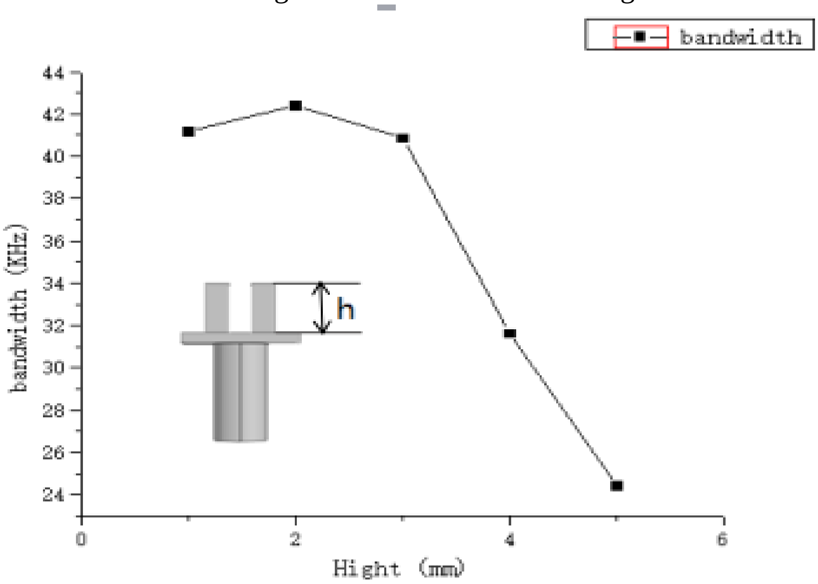


FIG. 5 With the increase of the weight of the additional mass ,the bandwidth increase

It can be seen from FIG. 5 that the height of the mass block have an great affect on the bandwidth of forbidden band, the higher height is, the less forbidden band width is, when the height of the addition mass is 2mm, the forbidden band get mostly width. Therefore, the width of the band gap in the band structure can be affected by changing the height of the mass.

We also analyze the effect of the number of mass blocks on the band structure,In order to comply with the principle of a single variable, this paper maintains the total mass of the addition mass block unchanged, using 1, 4, 9, and 16 additional mass blocks tespectively. An additional mass can be split into a number of small mass, when the additional mass number is 1 and the structure is as same as FIG. 1, additional mass number is 4, the quality gap between the blocks of 2mm, additional mass number is 9, the quality gap between blocks is 1mm. The additional mass number is 16, the quality gap between the blocks of 1mm . The structures are simulated and analyzed, the band structure we get is shown in FIG. 6.

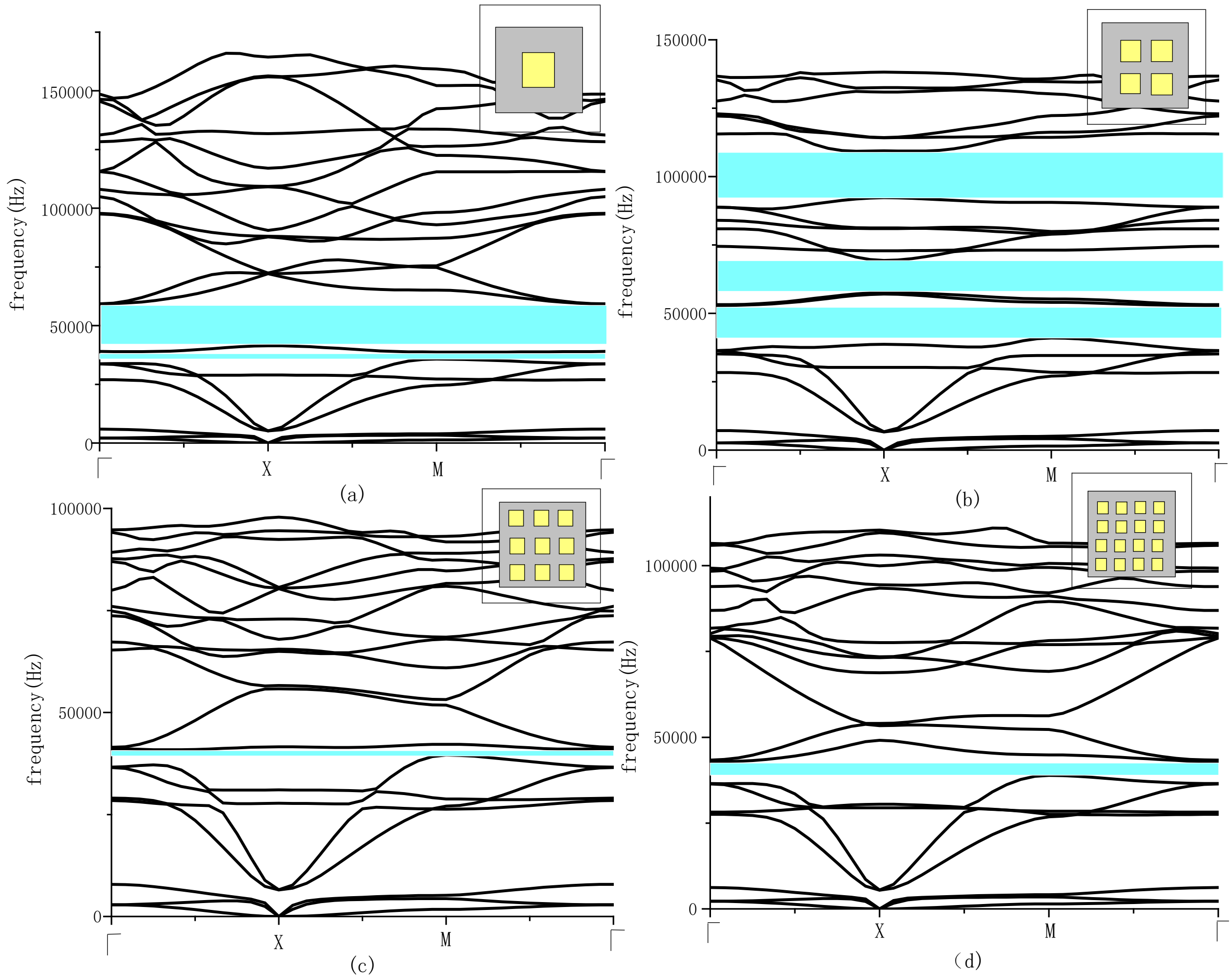


FIG. 6 Band structure of 1, 4, 9, and 16 additional mass

The graph shows that the structure with only one additional mass, there are two obvious gap, the initial frequency of the first band gap is 33.78KHz and the terminated frequency is 38.75KHz. The initial frequency of the second band gap is 41.45KHz band gap, the termination frequency is 59.22KHz . The total bandwidth is 22.74KHz.When the number of additional mass is four , there are three obvious band gap .tThe initial frequency of the first band gap is 40.98KHz and the terminated frequency is 52.81KHz. The initial frequency of the second band gap is 57.60KHz band gap, the termination frequency is 69.38KHz . The initial frequency of the third band gap is 92.28KHz band gap, the termination frequency is 109.31KHz .The total bandwidth is 41.19KHz.When the number of additional mass is nine, there is one obvious gap from 39.54KHz to 40.85KHz,which the band width is1.31KHz.When the number of additional mass is sixteen, there is one obvious gap from 38.91KHz to 42.82KHz,which the band width is 3.91 KHz.The results show that when the number of mass blocks increase, the bandgap increase first and then decrease. The structure with four additional mass blocks can get the maximum band gap

4.CONCLUSION

This paper shows that compared with the ordinary two-dimensional phononic crystals with only scatterer and matrix,the improved two-dimensional phononic crystals can expand the band gap width.We can contol the band gap width by changing the number , the arrangement and the material parameters of the addition mass. In this paper, the influence of material parameters and geometrical parameters on the bandgap generation is mainly simulated.

For material parameters, we take addition mass with three different material and find that with the density ratio of the additional mass to the matrix larger, the starting frequency of the band gap smaller, but the total gap width increases obviously.

For geometrical parameters,we study the the influence of the height and the number of the mass block on the energy band structure.When the height of the additional mass incease, the initial frequency of the first band gap will be reduced, and the total bandwidth will be reduced..When the number of the additional mass increase, the total bandwidth will first increase and then decrease. The best band gap will get when there are four additional mass,which the total bandwidth is 41.19KHz. We can take the additional mass as an another scatterer, it will interact with the matrix, the elastic wave of a frequency cannot propagate in them..

we can control the propagation of elastic wave in the structure by changing the parameters of the additional mass.This research can be used in the high frequency vibration insulation of plate structures.

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