Experimental study on the application of metamaterials in low frequency vibration reduction of thin plates

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Abstract. In order to validate the damping effect of metamaterials, the low frequency damping effect of the spring oscillator metamaterials was used to test the vibration of thin plates. And the damping effect was compared with the viscoelastic damping materials. The results show that, with lighter additional weight, the low frequency damping effect of the spring oscillator metamaterials for plate was better than that of the viscoelastic damping materials.

1. Introduction

Low frequency vibration is a difficulty in vibration control because of its low frequency and slow attenuation. There are two main control methods for low frequency vibration: passive control and active control. Passive control, such as the application of damping materials or damping devices, has the characteristics of low cost and good reliability, but the energy attenuation of passive measures for low frequency vibration is slow, and the effect is not ideal. Active control has a good damping effect for low frequency vibration, but the problems of high cost, great difficulties and complexity also greatly limit its application scope.

Metamaterials are a kind of artificial materials developed recently. Through artificial design, metamaterials can have negative mass density, negative elastic modulus, negative Poisson's ratio and other special physical properties. These special physical properties bring new ideas and ways for the control of low frequency vibration, and show great application prospects in the field of low frequency vibration control.

Liu[1] first proposed the local resonance theory of metamaterials by studying the three-dimensional three-component cubic lattice structure, and realized the band gap of low frequency vibration with small-scale structure, which laid a foundation for the control of propagation of low frequency vibration of metamaterials. Since then, metamaterials have gradually become a research hotspot in the field of vibration reduction and noise reduction. The main method of using metamaterials to control the vibration of thin plates is to attach a local resonant micro structure to the thin plates. Through the interaction between the micro structure and the thin plates, the low frequency vibration can be controlled. Wu[2] and Pennic[3] have designed and analyzed a kind of local resonant type metamaterial plate structure which is composed of a cylinder with periodic arrangement on a homogeneous thin plate. Their research shows that the local resonant type complete band gap can be generated in this structure. Oudich[4] further studied the low frequency local resonance band gap characteristics and the defect state waveguide characteristics in a similar local resonance type super material plate structure, and designed and prepared samples for experimental testing, which confirmed that there is a complete band gap within the audible audio frequency range. Recently, Ma[5] further discussed the formation mechanism of band gap of local resonant phononic crystal plate structure with cylindrical resonance.
unit, explained the reason why it can not form full band gap in wide frequency range, and put forward an improved design scheme, so as to realize wider full band gap.

In the above research on the low frequency vibration of the metamaterial for plate, it is mainly about the theoretical research on the propagation control of the low frequency vibration in the thin plate. However, the actual damping effect of the metamaterial in the application of the low frequency vibration control of the thin plate is rarely involved, which can not reflect the superior performance of the metamaterial. In this paper, the experimental research on the damping performance of the metamaterial in the low frequency vibration of the thin plate is carried out, and the effectiveness of the metamaterial in the low frequency vibration control of the thin plate is verified by comparing with the traditional passive damping method.

2. The sample of the low frequency vibration damping metamaterial

In order to obtain the damping effect of low frequency and wide-band, this paper first designs a metamaterial sample of spring oscillator for low frequency vibration of thin plate, as shown in Figure 1. The vibration reduction principle of the spring oscillator is to transfer the vibration energy to the spring oscillator through the resonance of the spring oscillator on the thin plate, and to achieve the suppression of the vibration of the thin plate through the reaction of the force. In order to achieve the low frequency and wide-band vibration reduction effect of the spring oscillator, it is necessary to have a dense modal distribution in the low frequency range.

![Figure 1. Structure of spring oscillator](image)

The main structural parameters of spring are outer diameter, inner diameter, pitch and turns. Through these four parameters, the modal distribution of spring can be adjusted flexibly. The four parameters are simulated respectively, and the influence of the four parameters on the first 10 modes of spring is studied, as shown in Figure 2.

![Figure 2](image)

It can be seen from the figure that as the outer diameter of the spring increases from 8mm to 14mm, the first 10 modes range of the spring decreases from 40 ~ 453Hz to 22 ~ 171Hz; as the inner diameter increases from 0.6mm to 1.2mm, the first 10 modes range increases from 24 ~ 237Hz to 49 ~ 474Hz; as the pitch increases from 3mm to 6mm, the first 10 modes range decreases from 61 ~ 440Hz to 34 ~ 369Hz; as the number of turns increases from 8 to 10, the first 10 modes range The range is reduced from 90-552Hz to 45-359Hz. It can be seen from the calculation results that the influence on the first 10 modes of the spring is the outer diameter, the inner diameter, the number of turns and the pitch of the spring. According to this conclusion, the modal distribution of spring can be adjusted flexibly.
In order to control the low frequency vibration of 30 ~ 300Hz, the parameters of the spring oscillator are determined as the outer diameter of 10 mm, the inner diameter of 0.8 mm, the number of turns of 10, and the pitch of 5 mm. The first 10 natural frequencies when one end of the spring oscillator is fixed are shown in Table 1.

Through the analysis of the first 10 modes of spring oscillator, it is found that four modes can be used for vibration control, which are swing mode, tension compression mode, bending mode and sectional tension compression mode, as shown in Figure 3.

Through the left and right swing of the spring oscillator, the swing mode can implement torque on the additional structure and reduce the bending amplitude of the additional structure; through the extension and compression of the length direction of the spring oscillator, the tension or pressure on the additional structure can reduce the vibration amplitude of the additional structure; the bending mode also realizes the control of the bending vibration of the additional structure through the bending of the spring oscillator. The vibration control effect of segment tension compression mode is similar to that of tension compression mode. In the first 10 modes, the spring oscillator absorbs the vibration of the structure through these four modes and reduces the vibration amplitude of the structure.
3. Test process

The test system of metamaterial damping performance test is shown in Figure 4. The main test instruments include LMS SCADAS signal test and analysis system, MB modal 25 exciter system, PCB 208c force sensor and PCB 333B acceleration sensor.

According to the standard GB / T11349.2- 2006, the vibration characteristic test is carried out, the vibration acceleration sensor is arranged on the surface of the tested sample, the force sensor is installed on the lifter of the vibration exciter, and fixed on the surface of the tested sample, the vibration acceleration of each point of the tested sample is measured by applying wide-band random excitation to the tested sample through the vibration exciter, and the input excitation force of the vibration exciter is normalized. The vibration response of the tested sample is obtained.

In order to compare the damping effect of the spring oscillator type metamaterial with that of the traditional damping material, the DFM type viscoelastic damping material commonly used in ships is specially selected. The maximum loss factor of this type of damping material is greater than 1, which has excellent damping performance.

Three samples of 300mm×300mm×1.5mm steel plate, steel plate+spring oscillator type metamaterial and steel plate+DFM viscoelastic damping material were tested respectively, and the size...
of the three samples was identical. The steel plate+metamaterial sample is shown in Figure 5, and the test site is shown in Figure 6.

![Figure 5. Steel plate+metamaterial sample](image1)

![Figure 6. Test site](image2)

4. Test results

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It can be seen from table 2 that for 1.5mm thick steel sheet, the vibration reduction effect of spring oscillator type metamaterial is better than that of DFM rubber damping material in the frequency range of 10~300Hz under the condition that the additional weight (0.495kg) is less than DFM rubber damping material (0.715kg).

It can be seen from Fig. 7 that since the metamaterial of spring oscillator mode has dense modal distribution below 300Hz, the vibration peak value of thin steel plate has been effectively attenuated in the frequency range of 10~300Hz, and there is no new peak value at other frequencies. The damping material has a large weight and a certain modulus, which has a great influence on the modal frequency of the steel plate. The vibration peak value moves to the low frequency, and the vibration peak value attenuates, but the corresponding frequency changes greatly.

| Table 2. Test results of damping performance |
|---------------------------------------------|
|                                        | Steel plate | Steel plate + damping material | steel plate + metamaterial |
| Weight/kg                               | 1.042       | 1.757                           | 1.537                      |
| Acceleration response /dB               | 144.8       | 139.1                           | 138.8                      |
| Additional weight /kg                   | —           | 0.715                           | 0.495                      |
| Damping effect/dB                       | —           | 5.7                             | 6.5                        |
5. Conclusion

In order to verify the damping effect of the metamaterial in practical application, this paper designs the samples of the spring oscillator type low frequency broadband damping metamaterial, and applies them to the experimental study of the low frequency damping performance of the thin plate. In the frequency range of 10~300Hz, for 1.5mm thick steel plate, compared with the traditional viscoelastic damping material, under the condition of small additional weight, the damping effect of spring oscillator type metamaterial is better than the traditional viscoelastic damping material.

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