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FINITE PERIODIC STRUCTURE OF BEAM FOR LOW FREQUENCY STRUCTURE-BORNE SOUND ATTENUATION

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Abstract

Unwanted vibration in ships, aircraft and buildings is often caused by the operation of machinery and transmitted into the structure through connected beams. The attenuation of vibrational power transmission in low frequencies has been a difficult problem for a long time.

Recently, a series of studies about the elastic wave propagation in locally resonant sonic materials have found that phonon-like acoustic structures can have even better sound attenuation performances than before in a lower range of frequencies due to phonon resonance and Bragg interference phenomena. It is also supposed to effectively attenuate low-frequency vibrational waves in a beam-type one dimensional system by using the periodic phonon structure, the decay and transform of flexural waves in a beam with ternary locally resonant elements attached is studied in this paper.

1. INTRODUCTION

In practice, equipments of building services are often hung up on or mounted with load beam as shown in Fig.1. Sometimes the estimation of structure-borne sound insulation is not accurate enough because the characteristic of load beam as a bending-wave guide may be oversimplified. Yet there have been few studies about the general method which can make use of the independent characteristics of source, beam and receiving structure to predict the structure-borne sound transmission in a certain condition. The further theoretical and experimental research works will be done focusing on the estimation method with the measurement of bending beam.

Can the insulation for structure-borne sound through beam be improved by suitable methods in a general condition? To investigate the basic relation of the transmitted vibratory power into the mounting structure with the load beam, an approach analytically derived, in which electric circuit analogy is proposed for the physically helpful conception and convenient simulation. Though the mobility method commonly can provide a mathematically complete approach for the calculation of transmitted force and power, the problem is complex as the multi-degree mobility at a contact point of beam depends greatly on the position and boundary condition of the beam. The new estimating method based on the modal parameters of beam is to be comprehensively studied, which can make use of the independent characteristics of source, load beam, receiver structure, and isolator to predict the vibration of combined system the structure-borne sound transmission.

For the energy of vibration transmitted by bending waves, the attenuation of vibrational power in low frequencies has been a difficult problem for long time. Since the relevant studies [3,4] about the elastic wave propagation in so-called locally resonant sonic materials have found that the acoustic structure can be even better sound attenuation performances on a larger range of frequencies due to Bragg interference phenomena, it is supposed to effectively attenuate mechanic waves in the one-dimensional system.

In the research of this paper, the periodic element of beam, as shown in Fig.3, is designed to consist of two parts, one is the normal steel beam, and the other is made of local mass connected with elastic cantilever mounted on the beam, which can be treated as a sub-bending system. As the wave impedance and wavelengths of alternating elements are different, multi reflection and transmission will occur at the interfaces, which can result in a special band structure of bending wave-guide.

2. METHODOLOGY AND THEORETICAL WORK

In modern buildings, equipments of building services are normally hung up or mounted on loading beam with elastic isolator to attenuate the vibrational power transmitted into building structure. The scheme diagram of a simple setting case is shown in Fig.1. Yet for industrial application, there have been few studies about the general method which can make use of the independent characteristics of source, beam and receiving structure to predict the structure-borne sound transmission in a certain condition.

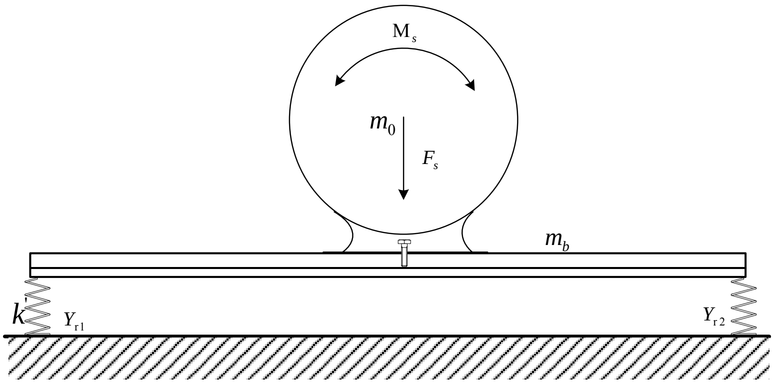


Fig.1 simple model of a source elastically mounted with supporting beam.

Based on the mobility method and the modal testing, an innovative analogy model of 8-port network is developed for a resiliently supported system with load beam, such as shown in Fig.2. By this way the structure-borne sound transmission can be predicted from separating parameters, which make use the 2-DOF mobilities of the input-port and output-port of the vibratory system mounted with beam.

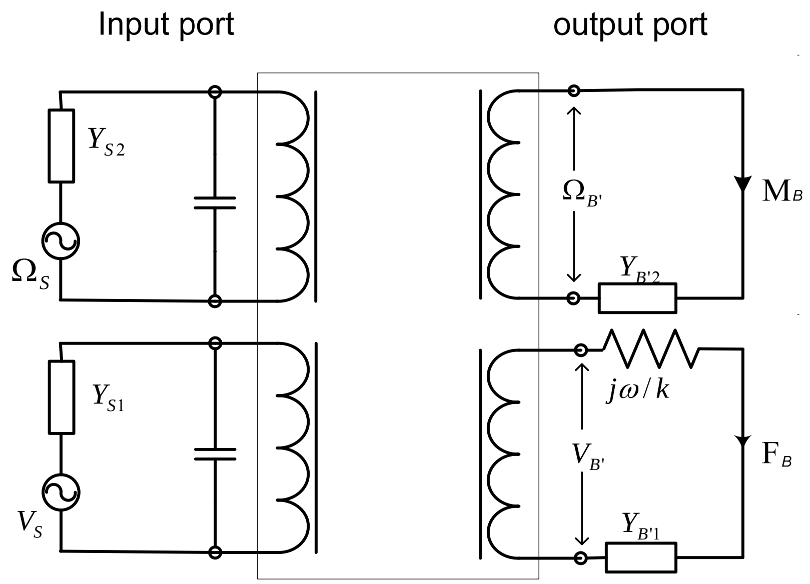


Fig.2 Equivalent circuit diagram to the model of a simple source mounted on load beam with isolators such as Fig. 1, based on an analogy model of 8-port network.

As far as known, periodic phonon structures can effectively absorb/ attenuate the waves propagating in the media, so in the research we design the periodic beam structure attached with locally resonant cell.

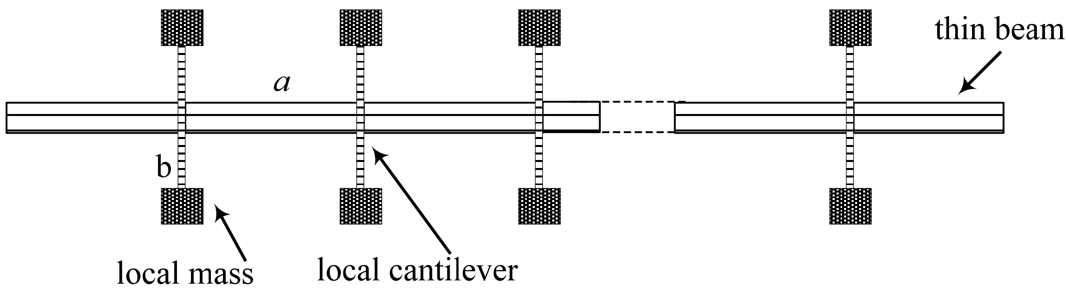


Fig.3 the periodic structure: beam attached with local cantilever-mass phonon structure

From the Bloch theorem, the formulation of a linear wave field in ideal periodic media can be written as $\xi(x+d)=\xi(x)e^{jKd}$, where $\xi(x)$ is a periodic function satisfying $\xi(x)=\xi(x+a)$, a is the length of periodic element, and ***K*** is the Bloch wave number in the media. According to the transfer matrix method, it implies that e^{jKd} is an eigen-value of periodic transfer matrix M_a, so the dispersion relation can be decided by the physicality of ***K***. From real solution of ***K*** it can be deduced as the frequency within pass bands, and from the complex solution of ***K*** it can be deduced that the frequency falls in the band gap.

3. COMPUTATION AND ANALYSIS

In the case as shown in Fig. 1, a simple source driven by inherent force is mounted on the center of a steel beam which is supported by two springs and symmetrically placed on a floor. It is assumed that the mass of source= 100 kg, length of beam=1 m, the spring is selected to result in a natural frequency= 12.5Hz. In the conditions of different flexure degrees of a beam, the transmitted powers are calculated as shown in Fig. 4.

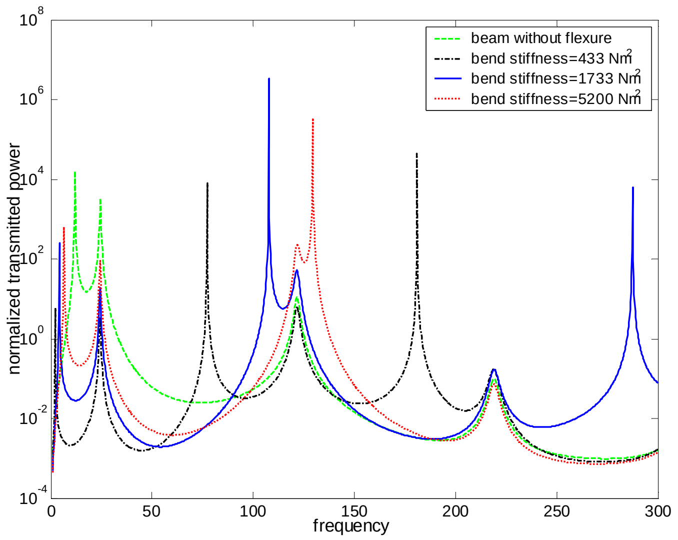
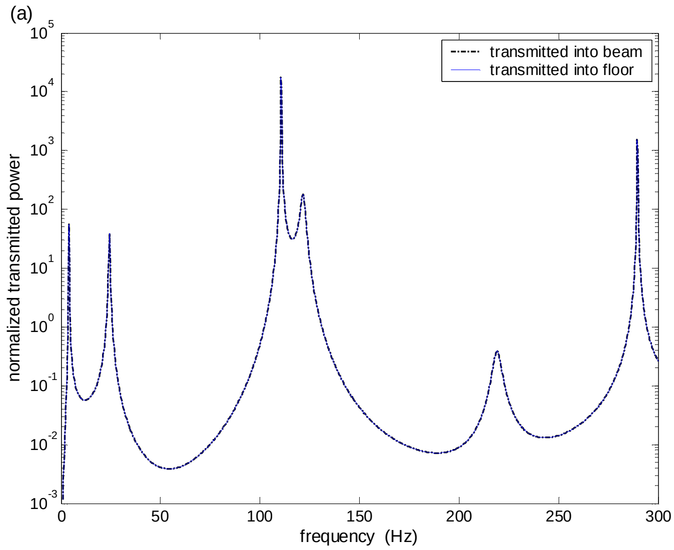


Fig. 4 The transmitted vibratory power from the elastically mounted simple source on the load beam of various bend stiffness.

While considering damping effect of the isolators, and the bend stiffness of beam is 1800 (N·m^2), the transmitted powers from the source into beam and from the beam into receiver are calculated as shown in Fig. 5:



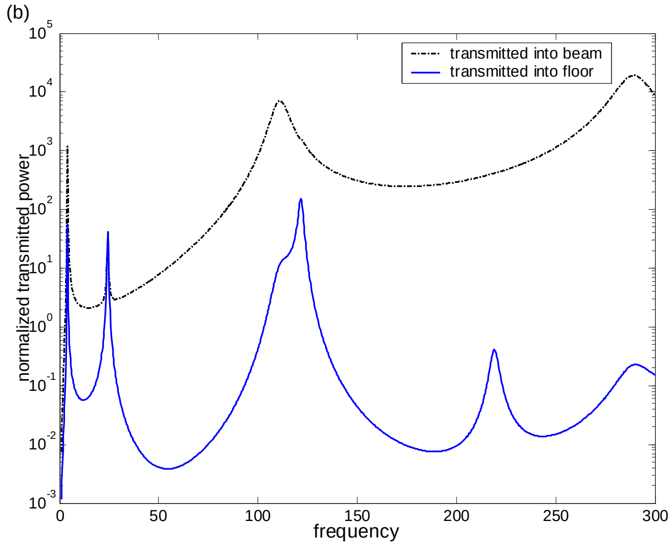
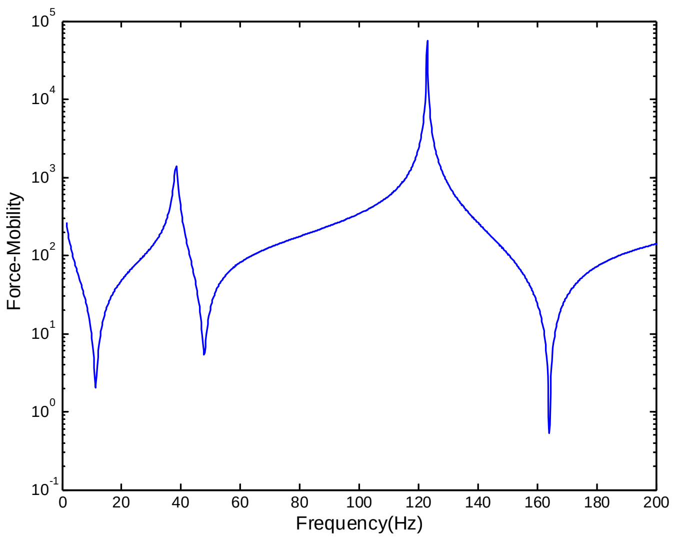


Fig. 5 The transmitted vibratory power from the elastically mounted simple source on load beam. (a) damping coefficient of isolator ή=0. (b) damping coefficient of isolator ή =0.005.

As shown in Fig. 5(a), when there is no damping effect of the beam, the transmitted power from source into the input-port equals to the power transmitted from the output ports supported by springs on the floor. While the damping coefficient increasing, as shown in Fig. 5(b), the transmitted power input into beam is going to be larger than the transmitted power output from beam, the fluctuation of 'input' power is becoming smaller, and the fluctuation of 'output' power is going to close with the transmitted power without bending wave, of which the peaks are correspondingly decreasing. It is revealed by the computed curves of Fig.(4) and (5) that in the low frequency region, the structure-borne power transmitted through a beam is obviously influenced by the bending effect of beam, and the low-frequency transmitted power cannot be effectively attenuated by simple elastic isolators as the bend stiffness is considerable.

To attenuate the low-frequency structure-borne sound through a flexural beam, a new type of locally resonant element is designed for the one-dimensional periodic structure shown as Fig.3. The local resonance cells are periodically attached on a loading beam, of which the contact points are in the middle. The force and moment mobility of phonon cell are plotted as Fig.6:



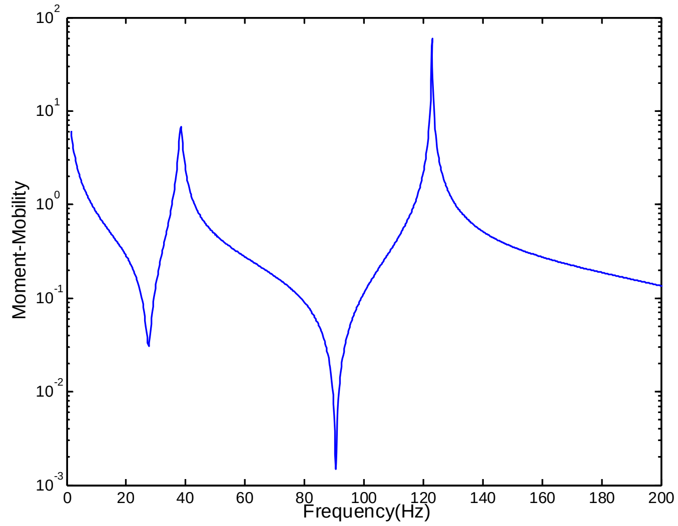


Fig. 6 (a) Force mobility of phonon cell, (b) Moment mobility of phonon cell.

In simulation, the attenuation degrees of the bending waves propagating through the semi-periodic structure attached with 4 phonon elements are plotted in Fig.7:

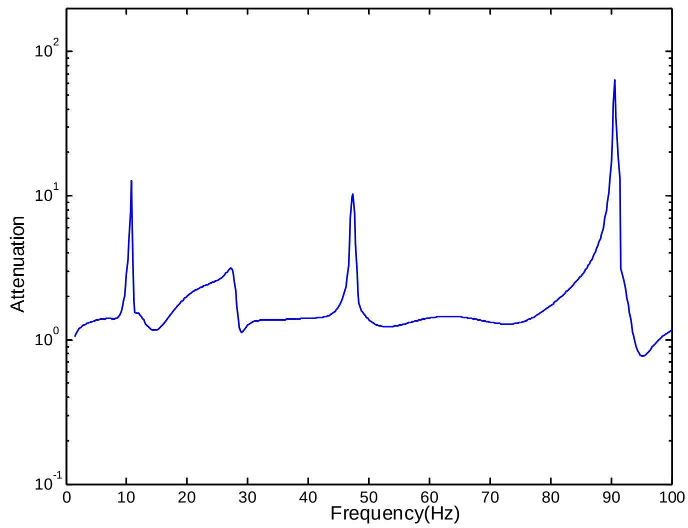


Fig. 7 Attenuation of bending wave propagating in a 4-cell periodic structure

From the curve plotted in Fig.7, it can been seen that the flexural waves transmitted through a bending beam can be significantly attenuated by the semi-periodic structure in some low-frequency regions. In engineering, the frequency regions can be adjusted by the parameters of locally resonant elements, such as the length, radius and stiffness of cantilevers and attached mass. Moreover, the attenuating effect can be enhanced by increasing the number of phonon-like cells.

4. CONCLUSIONS

By the analytical research about the structure-borne sound transmission in the system with flexible beam, it has been found that the bending waves in the beam obviously take effect on the transmitted power input from source and output into receiver. When the flexure vibration of beam is strong (bend stiffness is relatively small), the transmitted power is mainly dominated by the modes of bending beam. It is found from the analysis that in the region of low frequency, the transmitted power of bending waves normally cannot be effectively attenuated by isolators.

While the beam is periodically attached with phonon-like cells, due to the local resonance frequencies of phonon cell, the transmission of bending wave can be obviously attenuated in some low frequencies of resonant region. The attenuating method is adjustable with the main parameters of phonon elements, which may enlighten new studies and applications in the field of low-frequency structure-borne sound attenuation.

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