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Vibration Reduction Assessment of Layered Acoustic Metamaterial

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Abstract Acoustic meta-materials offer an approach to reducing the vibration and noise transmission through layered panels. In this paper, the investigation of constructed meta-material for reduction of low-frequency vibration and noise is a major concern. The key concept underlying this approach is to construct the metamaterial as a highly-distributed system of tuned point masses that introduce instead of low resonance frequency one or more bands of higher frequency. They can be then successfully damped with passive methods. Using the modes method, a metamaterial system with distributed point masses integrated into the honeycomb core was designed to be a representative layered panel. To determine the dynamic response of the global sandwich panel, the metamaterial system was tested for 70 Hz and 120 Hz excitation. The obtained results confirm the possibility of tuning the considered layered meta-material to the excitation frequency and shifting low frequencies towards higher frequencies.

Keywords: reduction of vibration, layered plate, acoustic metamaterial, point masse, distributed model.

1. Introduction

Lowering the noise level is a long-lasting and still unsolved problem, both for industry and for the protection of the environment and the human surroundings [1]. Reduction of low-frequency vibration and noise is a major concern. The passive damping method promises high effective and reliability in the higher frequency band, i.e. above approximately 500 Hz [2]. At the lower frequency band active methods of noise and vibration reduction are usually applied; however, this approach requires additional power sources [3, 4].

There are known solutions in which the phase shift effect of reflection is used to suppress the sound wave. For waves of a certain frequency and falling at certain angles, attenuation can be achieved due to interference with the reflected wave [5].

The introduction of admixtures into homogeneous materials can also affect the acoustic properties. The frequency-dependent sound absorption coefficient can be modeled and its value improved in the low frequency range by using appropriately selected types and amounts of admixtures for "clean" materials used in sound-absorbing systems [6].

In systems for recovering energy from vibrations and noise, systems of resonators tuned to specific frequencies are used. The energy they capture is converted into another type of energy, such as electricity. Thus, the energy of the acoustic wave is reduced [7]. While the vibration energy is typically converted into a different type of energy, it is also possible to convert mechanical energy into mechanical energy, but with a different frequency, preferably higher.

Acoustic metamaterials offer an approach to reducing the dynamic response of and noise transmission through layered panels of special construction [8]. In this paper, we examine a sample of such structure. Using the assumed-modes method, a metamaterial system was designed to be integrated into the honeycomb core of a representative layered panel.

This metamaterial system was modelled as an effective distributed set of point masses. The key concept underlying this approach is to consider the metamaterials as a highly-distributed system of tuned point masses located inside the honeycomb structure. The resonance frequencies of the system may be tuned to match one of the higher resonance frequencies. In this way, the structure can change the low frequency vibration into higher ones.

Further research is necessary to improve and optimize the applied structure, as well as to manufacture and experimentally verify the operation of the resulting forms in practice.

2. Description of the phenomenon

A typical method of noise reduction is the use of passive sound absorbing and sound-insulating partitions. Passive methods allow one to obtain a satisfactory noise reduction coefficient for high frequencies, but are not sufficiently effective in the low frequency range. The presented solution enables the construction of hybrid soundproofing systems that combine the advantages of passive and active methods. This will allow effective reduction of low-frequency sounds in selected bands.

The hybrid sound insulation system is in the form of a multilayer sound absorbing and sound-insulating barrier that contains a passively damping layer, at least one air gap and an active damping layer between them.

The actively damping layer is made in the form of a thin plate of elastic material on which profiled incisions are formed, dividing the plate into sectors. The shape, size, and organization of the individual sectors of the actively damping layer plate determine the frequency for which damping is to occur.

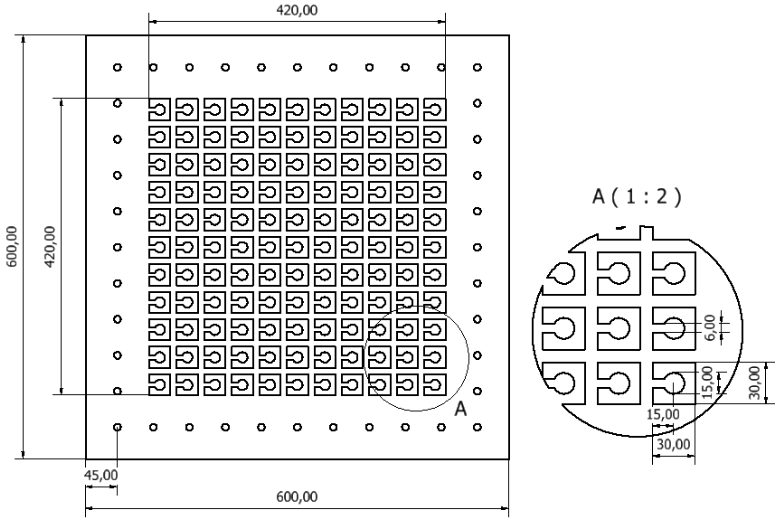

Figure 1. Dimensions of the plate with the spaces cut-out.

The profiled incisions of the sectors constitute vibrating resonators arranged on the plate in an orderly manner, their size and arrangement being adapted to capture the acoustic wave energy in a given frequency range. The energy of the captured wave stimulates the resonators to vibrate at higher frequencies, which can be suppressed more effectively by passive methods.

3. Measurement setup and instruments

The object tested was a steel square plate with dimensions of 600 × 600 mm and a thickness of 1 mm. Periodically repeating square spaces with a contoured shape constituting an elastic mass system in the form of protruding circular projections in the shape of a circle with a radius of 3 mm and a leg connecting the tongue with the edge of the plate were cut out on the plate. The dimensions of the plate with cut-out spaces are shown in Figure 1.

The plate was mounted with forty bolts to a closed steel structure. Each bolt was tightened with a torque of 30 Nm. The source of vibrations was the loudspeaker placed inside the structure at a distance of 60 cm from the tested plate. The distance between the slab and the floor of the room where measurements were made was 91 cm. The measuring stand is shown in Figure 2. The design of the test stand ensures uniformly distributed excitation.

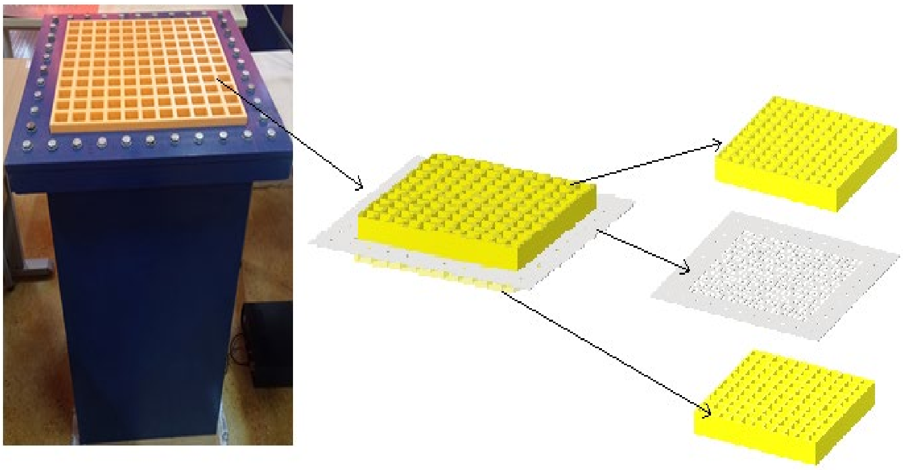

Figure 2. Measuring station with a layered structure.

The velocity and amplitude of the plate vibrations were tested using a Polytec PDV-400 vibrometer. PSV Acquisition and PSV Presentation software was used for data measurements and analysis. The laser was placed 105 cm above the tested plate.

Measurements were carried out successively with the frequency of 70 Hz and 120 Hz. Additionally, a chirp signal with a frequency varying from 20 to 500 Hz was generated, by means of which it was possible to analyze the resonance frequencies of the plate in this range. Measurements were carried out using a rectangular grid generated in such a way that measurements were made at the centers of each of the vibrating elements loaded with mass.

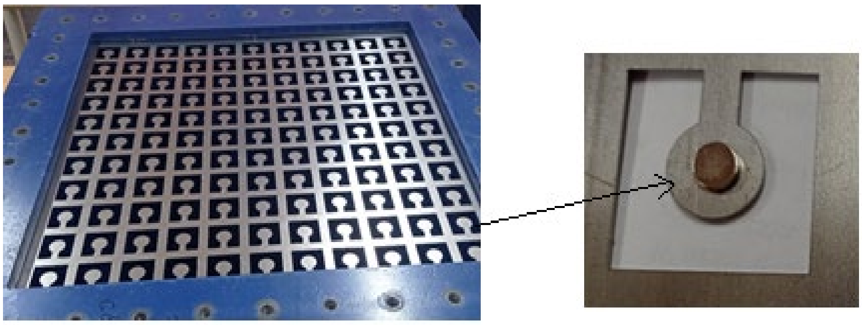

Figure 3. The tested plate with an elastic-mass system.

Measurements were carried out in the following stages:

a. Examination of the plate without additional layers and without load (Figure 3). Performed for several types of vibration excitation 70 Hz, 120 Hz and chirp signal.

b. Test with applied scattered point masses placed in the centers of protruding bars with circular ends with the above frequencies excitation values (Figure 3). At this stage, the value of the point mass was estimated by experimentally selecting different masses and simulating.

c. Examination of the stratified structure:
   - c.1. Examination of a plate with a layer structure attached to the upper source side.
   - c.2. Examination of a plate with a layer structure attached to both sides of the source.
   - c.3. Examination of a plate with a layer structure attached to both sides of the plate with a cover.

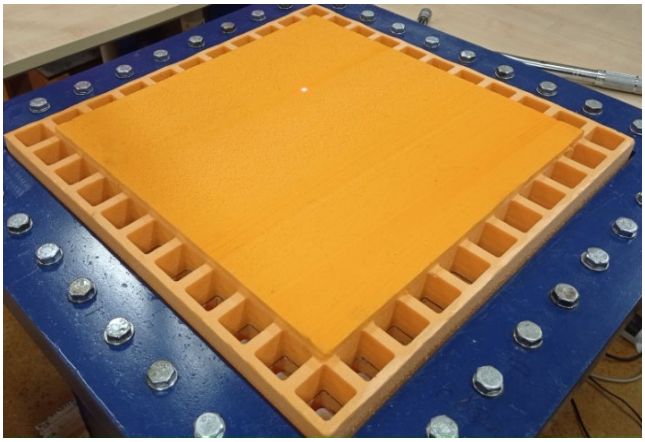

Figure 4. Layer structure with cover on both sides of the plate

4. Results and discussion

The next part of the article presents the result for one construction variant and two excitation frequencies. In their case, the experimental results showed that the structure of the metamaterial can alter the dynamic response of the plate in the low frequency range, thus offering promising results in terms of low band attenuation.

4.1. Identification of object parameters

The research was carried out in several series of measurements. First, the object was examined using a chirp signal in the range of 20-500 Hz. Measurements were made using a PSV-400 laser vibrometer for non-contact measurement in simital way as decribed in [10, 11]. This device made it possible to determine the vibration velocity and displacement of individual points on the surface of the considered object. The surface of the plate is scanned automatically with the use of an interactive and flexible grid of measurement points controlled and configured using the software supplied with the device. In this way, the resonance frequencies were determined. The plot of the frequency response of the object is shown in Figure 5.

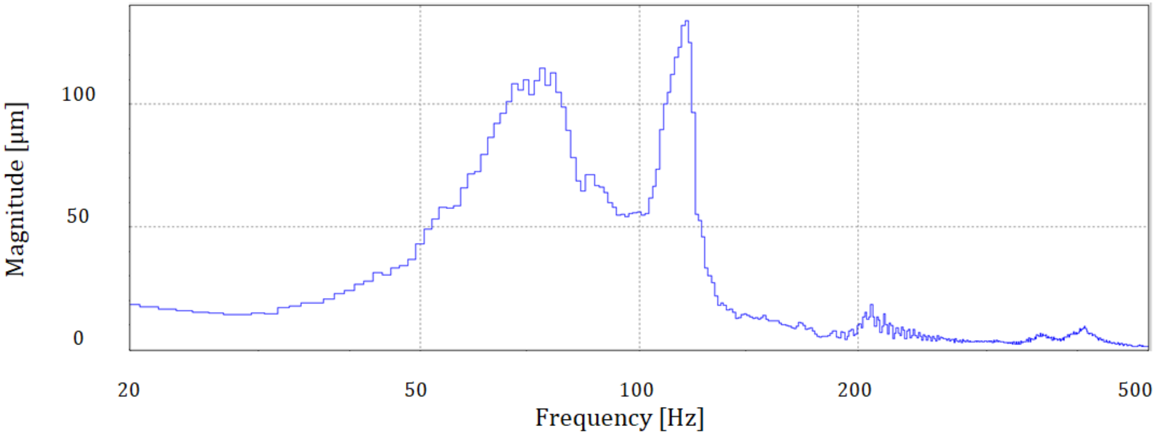

Figure 5. Object response to excitation with chirp signal.

The object responded to an excitation ranging from about 50 Hz to about 500 Hz. A stronger response was observed around 70 Hz, 120 Hz, and 210 Hz. The width of the response area is slightly wider around 70 Hz. Between 80 and 105 Hz the object reacted with less intensity. At 120 Hz, a distinct peak amplitude was noticeable. For this reason, for further research, excitation with signals of frequencies 70 Hz and 120 Hz was used.

4.2. Excitation with a signal with a frequency of 70 Hz

The object excited by a signal with a frequency of 70 Hz showed the expected properties, but to a small extent.

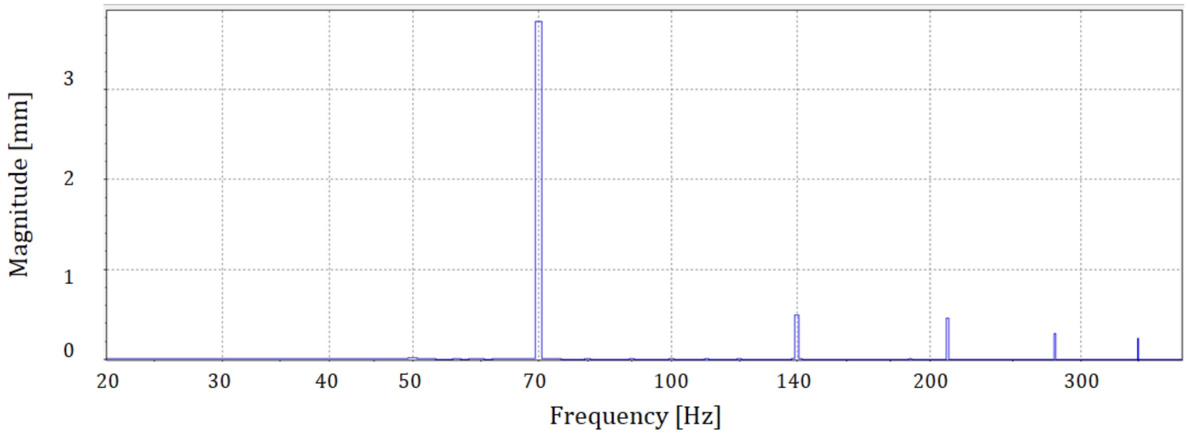

Figure 6. Object response to excitation at a frequency of 70 Hz.

In the frequency response shown in Figure 6, not only the excitation frequency band, i.e., 70 Hz, can be observed. There are also visible bands with frequencies of 140 Hz, 210 Hz, 280 Hz and 350 Hz, i.e. successive harmonics, although their amplitude is not large. These frequencies are not present in the target excitation signal. This means that some of the energy of the 70 Hz signal was absorbed by the plate and emitted, but in the higher frequency bands.

4.3. Excitation with a signal of frequency of 120 Hz

The object excited by the signal with a frequency of 120 Hz showed the expected properties to a slightly greater extent. In the frequency response shown in Figure 7, one can observe a frequency equal to the excitation frequency, i.e. 120 Hz, and additional frequencies at which the plate re-emits energy. In addition to the harmonic frequency of 240 Hz, you can also notice the band for 400 Hz. The vibration amplitude for this frequency is relatively large in relation to the vibration amplitude for the excitation frequency. An undesirable effect is low-frequency vibrations with frequencies 50 and 60 Hz, i.e. lower than the excitation frequency, but their amplitude is relatively small.

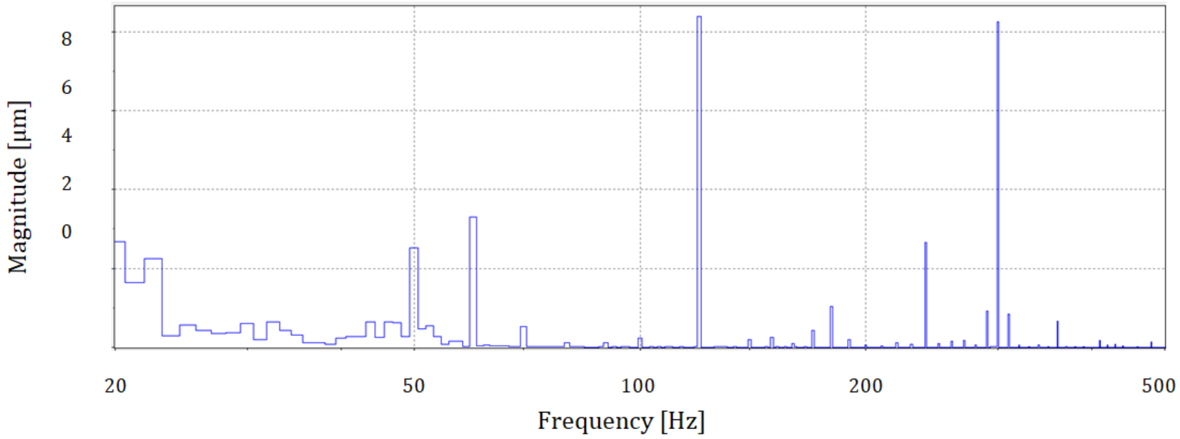

Figure 7. Object response to excitation at a frequency of 120 Hz.

5. Conclusions

This research addressed the investigation of an acoustic metamaterial for reducing the noise transmission through sandwich panels in low frequency ranges. As a result of the conducted works, the facility enabling the construction of a hybrid soundproofing and insulating system was developed and tested. Vibration tests of the sandwich panel prototype were performed with two different excitations. For the 70 Hz excitation, the model shows the properties as expected, but the amplitude values of the higher harmonics are not high. This is probably the result of adding too small point masses to the structure at this frequency. For the other excitation of 120 Hz the meta-plate shows a similar trend, namely that the peak responses above the local natural frequencies 120 Hz appear and their amplitude was comparable to the excitation. In conclusion, the experimental results demonstrated that the object with distributed point masses selected experimentally shows very promising properties supporting the assumption of a shift of low resonance frequencies towards higher ones.

Since this paper represents initial research on this topic, two major research directions could evolve from the present work. The first one involves creating the appropriate dynamic model for better simulation of this phenomenon, and the second will focus on the identification of factors influencing the effectiveness of transforming energy into vibrations of higher frequencies and the study of complete systems equipped with the described object and passive sound absorbing layers.

Additional information

The solution described in the article is covered by legal protection under the patent application No. P.439013.

References

1. L. Lu, K.L. Yin, R.C. de Lamare, Z. Zheng, Y. Yu, X. Yang, B. Chen; A survey on active noise control in the past decade - Part I: Linear systems; Signal Processing, 2021, 183, 108039.
2. C.H. Hansen, K.L. Hansen; Noise control: from concept to application. CRC Press, 2021.
3. P. Shivashankar, S. Gopalakrishnan; Review on the use of piezoelectric materials for active vibration, noise, and flow control; Smart Materials and Structures, 2020, 29(5), 053001.
4. J.A.B. Gripp, D.A. Rade; Vibration and noise control using shunted piezoelectric transducers: A review; Mechanical Systems and Signal Processing, 2018, 112, 359-383.
5. J. Guo, X. Zhang, Y. Fang, R. Fattah; Manipulating reflected acoustic wave via Helmholtz resonators with varying-length extended necks; Journal of Applied Physics, 2018, 124(10), 104902.
6. S. Amares, E. Sujatmika, T.W. Hong, R. Durairaj, H.S.H.B. Hamid; A review: characteristics of noise absorption material; Journal of Physics: Conference Series, 2017, 908(1), 012005.
7. M. Yuan, Z. Cao, J. Luo, R. Ohayon; Acoustic metastructure for effective low-frequency acoustic energy harvesting; Journal of Low Frequency Noise, Vibration and Active Control, 2018, 37(4), 1015-1029.
8. J. Guo, X. Zhang, Y. Fang, Z. Jiang; Wideband low-frequency sound absorption by inhomogeneous multi-layer resonators with extended necks; Composite Structures, 2021, 260, 113538.
9. R. Zhu, X.N. Liu, G.K. Hu, F.G. Yuan, G.L. Huang; Microstructural designs of plate-type elastic metamaterial and their potential applications: a review; International Journal of Smart and Nano Materials, 2015, 6(1), 14-40.
10. L. Leniowska, M. Grochowina, M. Sierżęga , B. Hołota; An Adaptive Method for Reducing Vibrations of Circular Plates with Recursive Identification; Appl. Sci., 2022, 12(5), 2723. DOI: 10.3390/app12052723
11. L. Leniowska, M.Sierżęga; The vibration control of a circular plate by the use of a parametric controller with phase shift adjustment; Mechatronics, 2019, 58, 39-46.