MODELING OF WAVE CHARACTERISTICS IN COMPOSITE MATERIALS

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Abstract - Studies of periodic structures find important applications in devices and applications for vibration control, noise and sound insulation, and other fields. One of the important tasks in the design of a composite material is to determine its future properties. Industrial production of composites is an expensive and complex technological process and every year not only the demand for composite materials is growing, but also the requirements for such properties as sound insulation and impact resistance, which are key questions in this study, are increasing. Phonon crystals, which are periodic structures, were taken as a basis. Software has been developed to search for properties and combinations of components. The article is devoted to methods of modeling wave processes in composite materials.

Keywords - Composite Materials, Numerical Methods, Phonon Crystals, Software.

I. INTRODUCTION

The modern period is characterized by the transition to sustainable development, conservation of natural resources and reduction of environmental pollution. Innovative technologies and composite solutions are replacing traditional materials and manufacturing, as well as demonstrating properties such as higher strength, light weight and reduced cost. The composite materials industry is increasingly integrating automation, electronics, 3D prINTING AND VARIOUS SENSORS [1].

The software is an integral part at different stages of development and production of composite materials. There are also software for modeling the composite structure, i.e. the shape and design are designed taking into account various types of components. This article presents software for calculating the pressure and velocities of wave propagation in heterogeneous media and provides some examples obtained as a result of these calculations. This software used an approach that takes into account the spatial features of the structure, such as periodicity. A feature of this approach is the development of numerical methods that take into account the polydispersity of components.

II. PHONON CRYSTALS AS AN OBJECT OF MODELING

In recent decades, significant progress has been made in applying the results of the theory of propagation of vibrations in media of different nature: molecular structures of various substances (thermal, sound and ultrasonic) and electromagnetic and gravitational fields. Modern physics makes it possible to control the processes of propagation of vibrations not only by influencing the source of these vibrations, but also by actively changing the properties of the propagation medium itself. This area of physical science is called phononics [2].

The term "phonon" is formed by analogy with the concept of a photon in quantum electronics. As in the case of classical and quantum mechanics, quantum effects in acoustics do not play a significant role in the study of macroscopic processes. However, in the transition to subtle acoustic phenomena, it becomes necessary to construct a quantum theory of these phenomena. The problem of propagation of acoustic waves in a heterogeneous medium is difficult to study due to the unlimited range of vibrations, as well as the formation of reflection, scattering and transmission waves, which in turn depend on the geometry of the composite structure.

Phonon crystals cover a wide range from periodic meter-sized structures for sound in the air to nanometer-sized structures for information processing or for protecting the surface of integrated circuits from heating [3, 4]. Thus, the tasks of photonics are to study the propagation of elastic vibrations in media with a complex periodic structure. Some examples of such problems and ways to solve them are presented in the review [5].

Phonon crystals are a new class of artificially structured materials, the peculiarity of which is to control the movements of atoms in their structure. Phonon crystals use fundamental properties of waves, such as scattering and interference, to form "band gaps", i.e. ranges of wavelengths or frequencies within which waves cannot propagate through the structure.

In this article, a two–component phonon crystal is considered, one of the components is water droplets, and the second is air bubbles. Calculations are performed both for a monodisperse medium (when the particles of both components have the same size) and

for a polydisperse medium (when the particles of both components have different sizes).

III. MATH METHODS FOR CALCULATING THE WAVE PROPAGATION VELOCITY IN PHONON TWO-COMPONENT CRYSTALS

There are early works in which the features of wave propagation in heterogeneous media were studied [6]. Modeling of heterogeneous media using phonon crystals is essentially one of the methods for studying wave propagation.

We consider a gas-water system consisting of two media with the parameters of water (ρ1, c1) and air (ρ2, c2) respectively, and the cell length L, where c is the speed of sound in the corresponding medium, and ρ is the density of the medium at rest. The periodic structure is shown in Figure 1 and corresponds to the following scheme: 1/2 water+1/4 air+1/8 water+1/8 air=1.

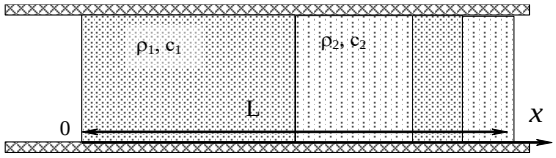


Figure 1: The geometry of the structure and notation

The media (ρ1, c1) – liquid is denser than the second media (ρ2, c2) – gas. In this structure, these media alternate and have different volumes or lengths.
Consider the regions:

$\Omega_1 = \{x: 0 \le x \le k_1\}$
$\Omega_2 = \{x: k_1 \le x \le k_2\}$
$\Omega_3 = \{x: k_2 \le x \le k_3\}$
$\Omega_4 = \{x: k_3 \le x \le 1\}$

where x – it is a spatial variable, and k – this is the immeasurable length of the area filled with the corresponding medium.

Sound waves are described by acoustic pressure disturbances, respectively, in these media. Helmholtz equations are used to solve the equations of elastic and acoustic waves.
During a series of calculations, we obtain an 8x8 matrix [7].
Then substituting the values of the gas-water parameters

$\rho_{air} = 1{,}204,\ c_{air} = 331,\ \rho_{water} = 999,\ c_{water} = 1500,$
$k_1 + k_3 = k_2 + k_4 = 0{,}5$

in the obtained matrix and, omitting the detailed mathematical transformations and calculations, we get the graph shown in Figure 2, which shows the dependence of the frequency bandwidth on the linear concentration k for fixed values of the parameters of two media (water - air).

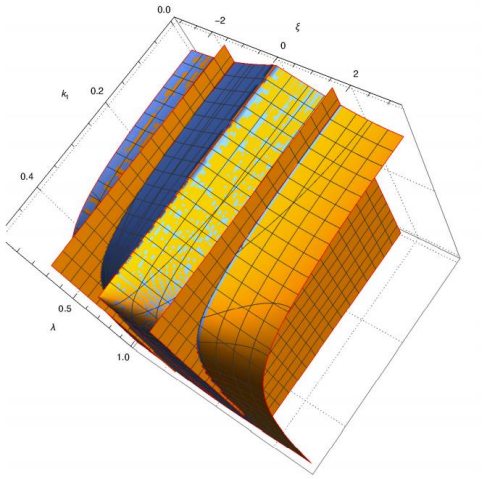


Figure 2: The dependence of the bandwidth on the concentration.

The following formula was used to calculate the phase velocity:

$$c_{ph}(\xi, k, \tau) = \lambda(\xi, k, \tau)/\xi \qquad (1)$$

where ξ is the wave number, λ is the cyclic oscillation frequency, k is the concentration of the medium and τ is the ratio of the density of air (gas) to the density of water (liquid), the graphs of which are shown in Figures 3, 4, and the phase velocity of waveguide modes in a polydisperse chain may be less than the speed of sound.

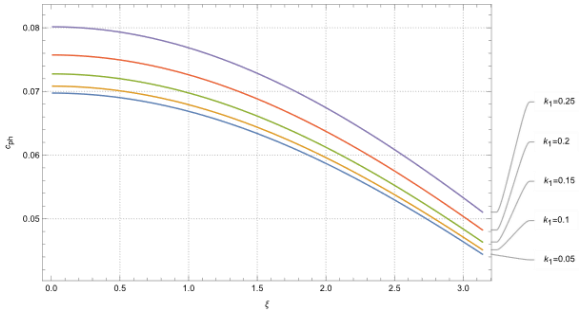


Figure 3: The dependence of the phase velocity on the wave number

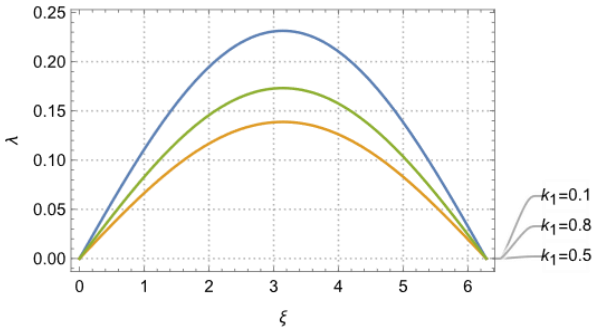


Figure 4: Frequency dependence on the wave number at different concentrations

The attenuation of a propagating wave is an energy loss in which the energy of the wave is conserved but redistributed into a deformed stress pulse. The loss of energy during dynamic motion in phonon crystals can be attributed to at least four phenomena:
- viscoelastic or inelastic effects of components;
- wave scattering;
- micro-destruction;
- friction between poorly connected components.
Phonon crystals contain air components in such a way that the speed of sound propagation is periodic.

IV. SOFTWARE DEVELOPMENT

Despite the huge number of engineering software and specialized libraries and modules developed for them, nevertheless, each task is unique and requires an individual approach. The uniqueness of our task lies in the development of methods and software for the study of wave processes in composite materials, taking into account the number of components and dispersion ratios in them. In the course of the study, a comparative analysis of the propagation of acoustic waves through mono- and polydisperse fundamental cells was carried out.

The developed program is intended for numerical calculations of wave characteristics in inhomogeneous media. This program is designed as a web application and allows you to study the properties of materials in their combination and combination, with the ability to adjust the concentration of the medium and its length. The program implements mathematical methods and algorithms for studying the wave properties of various materials. Calculations are accompanied by the output of graphs for visual analysis of the studied structure [9]. Methods and algorithms are implemented in the Java programming language, and the web application itself is implemented in html, javascript and css. An example of a working panel is shown in Figure 5.



Figure 5: A working panel

Wave propagation in periodic media is studied by many researchers. The interest in phonon crystals lies in the fact that the composite structure exhibits gaps (which leads to wave attenuation) and acoustic wave bandwidths (which can cause resonances), the regulation of which, as well as changes in the structure and composition, leads to the formation of new properties.

The results of the study are several provisions: firstly, these phonon crystals can serve as the basis for MEMS sensors, and secondly, the developed methods and software can be used to model the properties of phonon crystals, as well as an additional module to other programs.

V. CONCLUSION

Composite materials offer advantageous properties and characteristics, displacing metal from many structures. In addition, composites are resistant to loads, temperature changes, corrosion and wear, which increases the service life of this product or material. The main research interest is the study of such characteristics as vibration stability and noise absorption. Human hearing is a vital part of the body's defense mechanism [10]. However, the environment is filled with low-quality sounds. These are the sounds of cars, planes, trains, cooling systems, ventilation systems, various equipment and other sounds in a continuous mode, which leads to negative consequences for human health.

Phonon crystals by their properties best realize the above-mentioned characteristics. When creating phonon crystals, there are certain features. Within the framework of this task, a model for calculating some characteristics of wave processes that are applicable to solving inverse problems and problems of flaw detection was developed, and a program was created on their basis. The developed program allows you to analyze different systems of inhomogeneities and, accordingly, select such parameters at which the reflected wave is minimal. The results of numerical calculations appear on the graph in the form of various dependencies, which can be used to give a quick assessment of the selected system of materials. In addition to the fact that the program implements different algorithms for the dependence of the waveguide frequency λ on the coefficient characterizing the phase shift in neighboring cells ξ, it also provides for a study depending on the proportions of components in the fundamental cell. But the main feature of the program is an approach that takes into account the polydispersity of the components and the spatial feature of the geometry of the phonon crystal cell, such as periodicity.

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