PHYS 311 Advanced Experimental Physics

Sonic Band Gap

Purpose

In this experiment, you will study the sound transmittance and sonic band gap.

Equipment and components

Oscilloscope, function generator, speaker, two microphones, two Aluminum pipes with stands and connector, four connectable Aluminum periodically structured pipes with microphone holder, two PVC periodic structure pipes with different diameters.

Background

Soundproofing techniques can be found easily in our everyday's life, such as band room or theatre. It is any means of reducing the intensity of sound with respect to a specified source and receptor. There are several basic approaches to reducing the amplitude of sound: increasing the distance between source and receiver or using noise barriers to block or absorb the energy of the sound waves. Everything can be noise barriers, but with different soundproof abilities. Therefore, in our experiment we are going to study the soundproofing performance of common object: paper.

Propagation of elastic waves in a periodic inhomogeneous medium leads to a number of novel and fascinating phenomena. Under appropriate conditions, multiple scattering of waves may give rise to the appearance of gaps in the phononic band structure of the medium. As a result, elastic waves with frequencies within the gap will be completely forbidden from propagation. Such materials are called phononic crystals or phononic band-gap materials. They play the same role for elastic waves as semiconductors do for electron waves and photonic crystals do for electro-magnetic waves. The existence of phononic gaps is in itself a very interesting phenomenon with many practical applications, for example for vibration isolation devices, acoustic mirrors and waveguides. This time this phenomenon is not studied with phononic crystals nor materials, instead a periodically structured pipe.

In optics and spectroscopy, transmittance is the fraction of incident light at a specified wavelength that passes through a sample.

$$T = \frac{I}{I_0} \tag{1}$$

where I_0 is the intensity of the incident light and I is the intensity of the light coming out of the sample. The transmittance of a sample is usually given as a percentage, defined as

$$T\% = \frac{I}{I_0} \cdot 100\% \tag{2}$$

When considering plane wave propagation along a linear elastic homogeneous isotropic periodic lattice, a phenomenon termed Bragg scattering can be observed. This phenomenon describes the behavior of a plane wave propagating at a particular frequency and becoming standing in the periodic lattice.

As shown in Fig.1, the periodical structured pipe can be decomposed into number of Bragg planes.

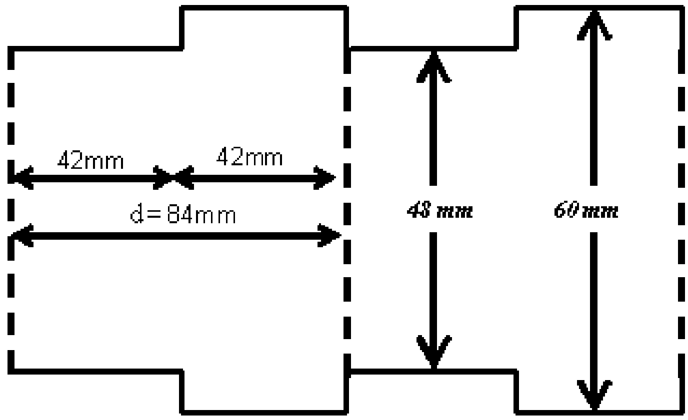

Figure 1. Big Pipe Dimension

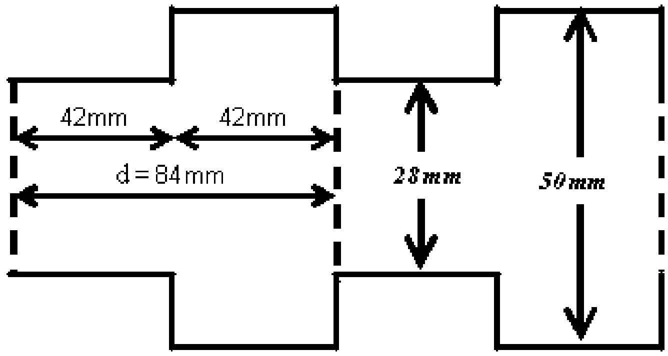

Figure 2. Small Pipe Dimension

As the sonic wave enters the pipe, some portion of it will be reflected by the first layer, while the rest will continue through to the second layer, where the process continues. The wave having the wavelength which is the double of planar separation may travel back or be reflected by the previous layer, so a path of one wavelength has been traveled, returning to the beginning situation. Due to periodicity, this wave is scattered in this periodical structure, thus being incapable of passing through the pipe. The scattered wave satisfies the following equation,

$$2d = \frac{v}{f} \tag{3}$$

where d is the planar separation, v is the speed of airborne sound wave and f is the frequency of the scattered wave.

Procedure

Part 1. Sound Transmission

(1) Set up the apparatus as shown in Fig. 3.

(2) Generate 1 kHz tone with the functional generator connected to the speaker.

(3) Record the peak to peak voltage of the incident and transmitted wave with the oscilloscope. Repeat the experiment for the frequency range from 1 kHz to 3 kHz with 0.1 kHz interval. Calculate the transmittance with Equation (1).

(4) Plot the transmittance T versus frequency.

(5) Cut out circular pieces of paper having exact same size of the pipe.
(6) Fix one piece of paper between two pipes and seal the connection gap with the connector to prevent sound leakage.
(7) Repeat steps 2 to 4 with the paper.
(8) Fix the frequency at 2kHz, fix one piece of paper between two pipes and record the transmittance.
(9) Repeat Step (8) with increasing number of pieces of number one by one and up to five pieces of paper.
(10) Find out the speed of the sound with the Oscilloscope.

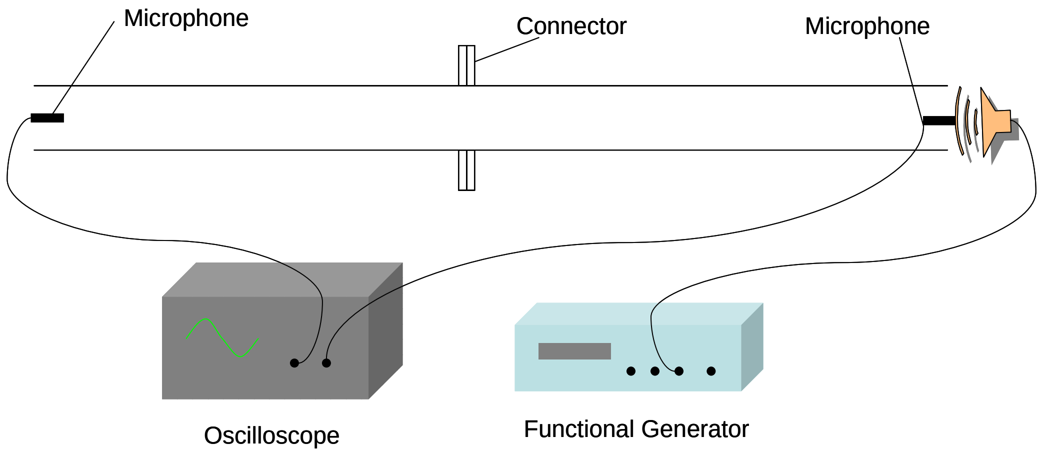

Figure 3. Schematic diagram of the two-tube, two-microphone test apparatus

Part 2 Sonic Band Gap

2.1 Length dependence

(1) Connect 2 units of Aluminum periodically structured pipes.
(2) Set up the apparatus as shown in Fig. 4.
(3) Generate 1 kHz tone with the functional generator connected to the speaker.
(4) Record the peak to peak voltage of the incident and transmitted wave with the oscilloscope. Repeat the experiment for the frequency range from 1 kHz to 3 kHz with 0.1 kHz interval. Calculate the transmittance with Equation (1).
(5) Plot the transmittance T versus frequency.
(6) Repeat steps 1 to 5 by connecting 3 units and 4 units of Aluminum periodically structured pipes.

2.2 Diameter dependence

(1) Setup the apparatus as shown in Fig. 4 using PVC periodically structured pipes with smaller diameter.
(2) Generate 1 kHz tone with the functional generator connected to the speaker.
(3) Record the peak to peak voltage of the incident and transmitted wave with the Oscilloscope. Repeat the experiment for the frequency range from 1 kHz to 3 kHz with 0.1 kHz interval. Calculate the transmittance with Equation (1).
(4) Plot the transmittance T versus frequency.

(5) Repeat Step 1 to 4 with PVC periodically structured pipes with larger diameter.

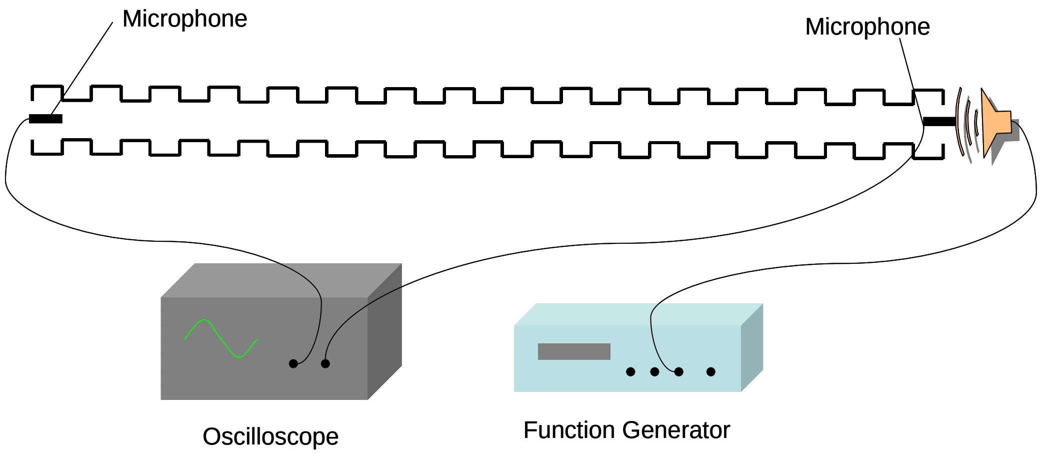

Figure 4. Schematic diagram of the periodically structured pipes

2.3 Defect modes

(1) Connect 2 units of Aluminum periodically structured pipes.

(2) Set up the apparatus as shown in Fig. 4.

(3) Place an Aluminum block in the middle of the pipes.

(4) Record the peak to peak voltage of the incident and transmitted wave with the oscilloscope. Repeat the experiment for the frequency range from 1 kHz to 3 kHz with 0.1 kHz interval. Calculate the transmittance with Equation (1).

(5) Within the band gap frequency range, increase the frequency finely and locate the sudden change of the peak to peak voltage in the oscilloscope.

(6) Plot the transmittance T versus frequency.

Analysis and Questions

1) Go through the theories of the one-dimensional sonic band gap with Ref. [1].
2) a) Calculate the band gap frequency of the periodically structured pipe with equation (3).
   b) What would you do to shift the band gap to a high (low) frequency?
   c) What would you do to increase/ decrease the width of the band gap?
3) Discuss the length dependence of the periodically structured pipe for the frequency range inside and outside the band gap frequencies. Go through the Fabry-Perot theory.
4) Compare and discuss the results of step (9) in part 1 and that of step (6) in part 2.1(with 4 units of Aluminum periodically structured pipes).
5) Discuss the diameter dependence of the periodically structured pipe for the frequency range inside and outside the band gap frequencies.
6) Discuss the defect mode in the periodically structured pipe.
7) Do you expect similar phenomena in light?

References (* denotes availability in the lab):

[1] *C.E. Bradley, Time harmonic acoustic Bloch wave propagation in periodic waveguides Part I and Part II, 96(3) 1994.

[2] *Eugene Hecht, Optics (3rd Edition).

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[4] *Amnon Yariv and Pocki Yeh, Optical waves in Crystals, Chapter 6 , Wiley Interscience.

[5] *Thomas D. Rossing, Neville H. Fletcher, Principles of Vibration and sound (2nd Edition).

[6] David Halliday , Fundamentals of Physics(6th Edition), John Wiley.

[7] *Xinhau Hu, C.T. Chan, Anomalous Doppler effects in phononic band gaps, Physical Review E 73, 0156002 (2006).