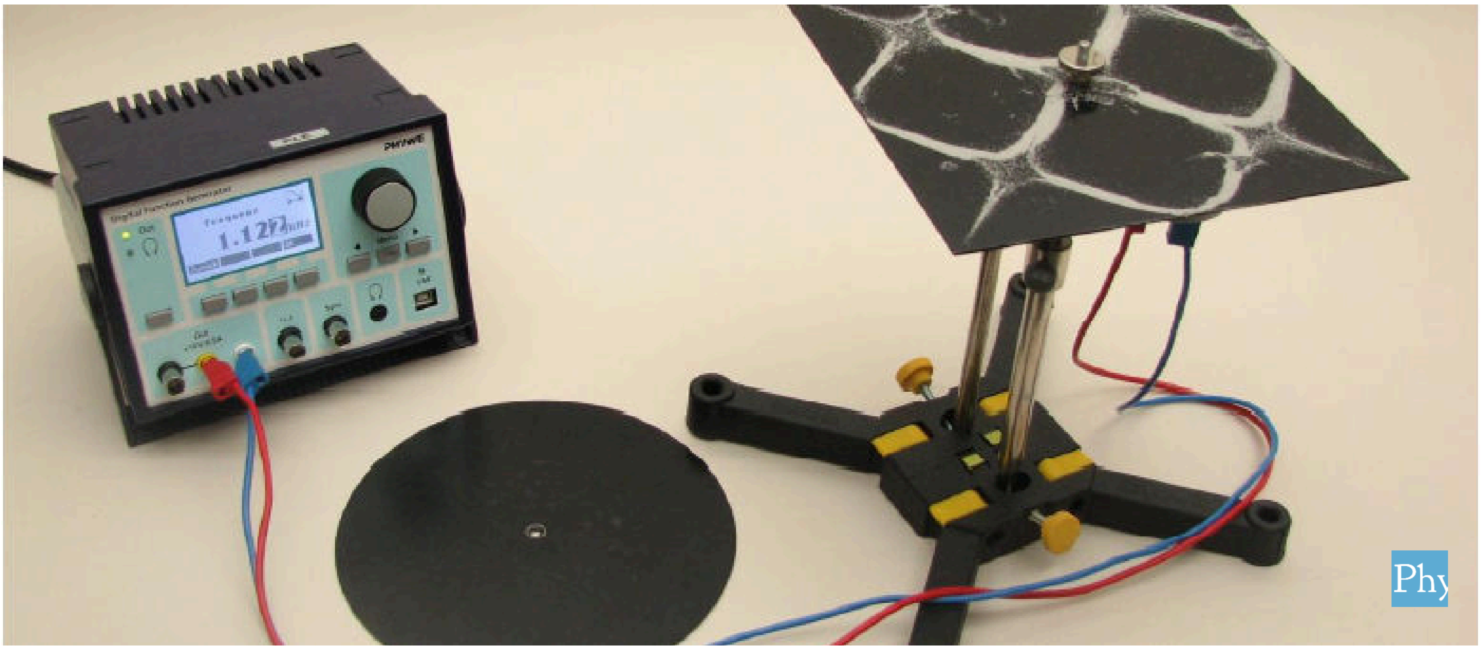
Chladni figures



P2150501

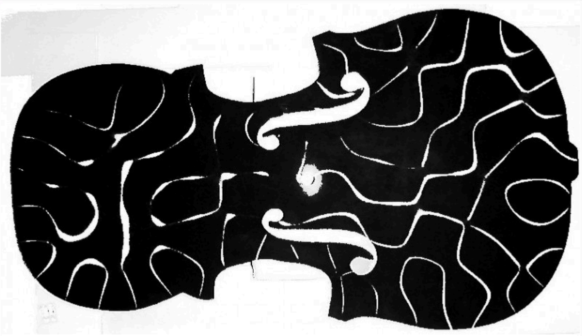
Physics > Acoustics > Sound generation & propagation

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

General information

Application



A violin-shaped aluminum Chladni plate showing a Chladni pattern.

Chladni plate is an early way to visualize the effects of vibrations on mechanical surfaces , which was introduced by the German scientist Ernst Chladni in the late 1700s . Principles of Chladni plate enable us to understand acoustic characterisations and advance in acoustic manipulations.

For example, Chladni patterns can be used during the making process of string instruments to provide feedback as the critical front and back plates of the instrument's resonance box are shaped.

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Other information (1/2)

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Prior knowledge

Natural frequency defines the frequency which a system tends to oscillate without the presence of any driving force. When a force is applied at the system's natural frequency, it goes into resonance, and a higher amplitude vibration response is created.

Scientific principle

Square and round metal plates are brought to vibrate through acoustic stimulations by a loudspeaker. When the driving frequency corresponds to a given eigen-frequency (natural vibration mode) of the plate, the nodal lines are made visible with sand. The sand is expelled from the vibrating regions of the plate and gathers in the lines because these are the only places where the amplitude of vibrations is close to zero.

Other information (2/2)

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Learning objective

Understanding the motions of vibrating Chladni plates.

Tasks

Determine the frequencies at which resonance occurs and drive the plate specifically at these frequencies.

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Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

For H- and P-phrases please consult the safety data sheet of the respective chemical.

Theory (1/4)

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The figures seen here result from flexural vibrations. The frequency of such a natural vibration is proportional to the plate's thickness and is dependent on Young's modulus, the density, and also, because of the two-dimensionality of the waves, on the transverse contraction coefficient of the plate's material as well. Here, with a thick plate and a freely vibrating rim, for circular plates the exact solutions are only to be found with advanced mathematics, and for rectangular plates only numerical solutions exist.

For thin plates with a fixed rim the two-dimensional wave equation

$$\delta_{xx} u(x,y,t) + \delta_{yy} u(x,y,t) = \frac{1}{c^2}\,\delta_{tt} u(x,y,t) \qquad (1)$$

yields solutions to the problem.

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Theory (2/4)

The solutions to Eq. (1) for a rectangle of width a and length b and boundary condition $u = 0$ for $x = 0$ and $y = 0$ are standing waves

$$u(x, y, t) = A\, sin(\frac{n\pi}{a}\, x)\, sin(\frac{m\pi}{b}\, y)\, cos(\omega t) \qquad (2)$$

with frequencies

$$\omega = \sqrt{(\frac{n}{a})^2 + (\frac{m}{b})^2} \qquad (3)$$

Theory (3/4)

The solutions to Eq. (1) for a rectangle of width a and length b and boundary condition $u = 0$ for $x = 0$ and $y = 0$ are standing waves

$$u(r. \theta, t) = A \cdot J_n(kr)\, cos(n\theta)\, sin(\omega t) \qquad (4)$$

where J_n is the n^{th} order Bessel function and kk is such that $a_k = z_{n,m}$, $z_{n,m}$ being the m^{th} root of the n^{th} order Bessel function (value where J_n is zero). A zero of the Bessel function must occur at the boundary $r = a$ and zeros occurring before the mthmth zero form ($m - 1$) concentric circular nodes.

The principle of standing waves can be illustrated by an example of a tube. Notice the different number of nodes as the eigen-frequencies increase, and how the form of the standing waves depends on the boundary conditions (closed tube in the left panel as opposed to open tube in the right one).

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Theory (4/4)

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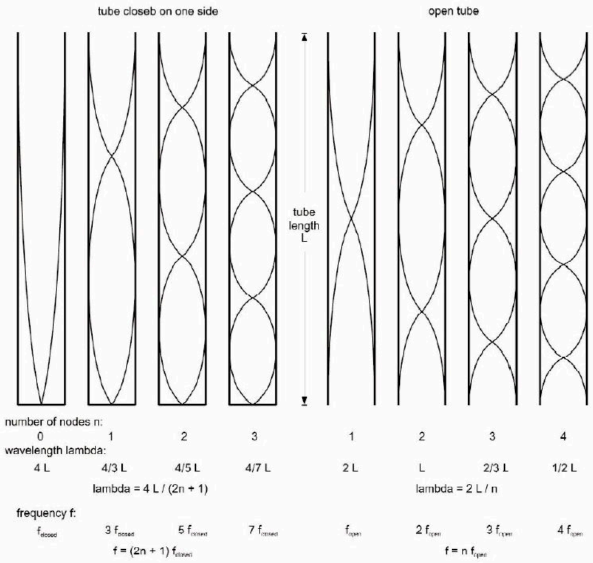

Schematic illustration of standing waves in a tube.

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Equipment

Position	Material	Item No.	Quantity
1	PHYWE Digital Function Generator, USB	13654-99	1
2	Loudspeaker / Sound head, 8 ohms	03524-01	1
3	Sound pattern plates	03478-00	1
4	Support base, variable	02001-00	1
5	Boss head	02043-00	1
6	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	1
7	Stand tube	02060-00	1
8	Connecting cord, 32 A, 500 mm, red	07361-01	1
9	Connecting cord, 32 A, 500 mm, blue	07361-04	1
10	Sea sand, purified 1000 g	30220-67	1

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Setup and procedure

Setup

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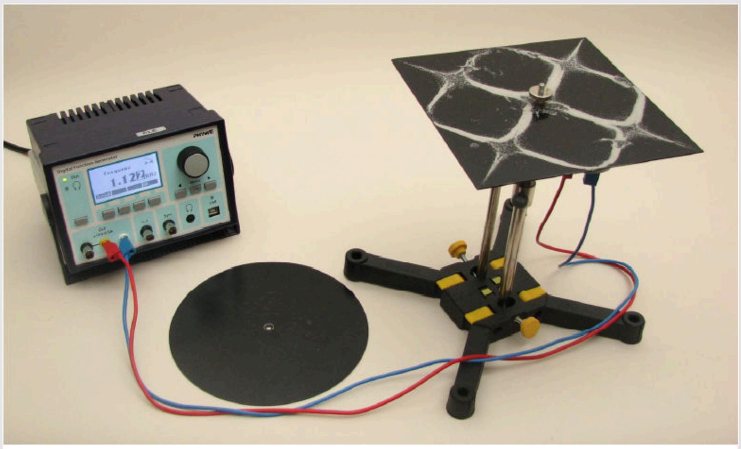

Experimental set-up

Set up the equipment as seen in the figure.

The speaker is mounted on the support rod through the boss head and is facing upwards. Make sure that the speaker is close to the plate but is not in contact with it. The only thing touching the plate should be the stand tube on which it is mounted!

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Procedure

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Set the generator signal to sine and the frequency to about 100 Hz. Adjust the signal amplitude so that the sound from the speaker is loud but still bearable. Distribute some sand over the plate and start changing the frequency slowly from 0.1 to 2 kHz.

At some frequencies, patterns should emerge. The specific frequencies may differ from the here given values because even smallest production variations significantly detune the modes of vibration.

When you notice the sand vibrating and a figure appearing on the plate, fine-tune the frequency to obtain the best result. You may occasionally add more sand as it is removed from the plate by vibrations.

Evaluation (1/2)

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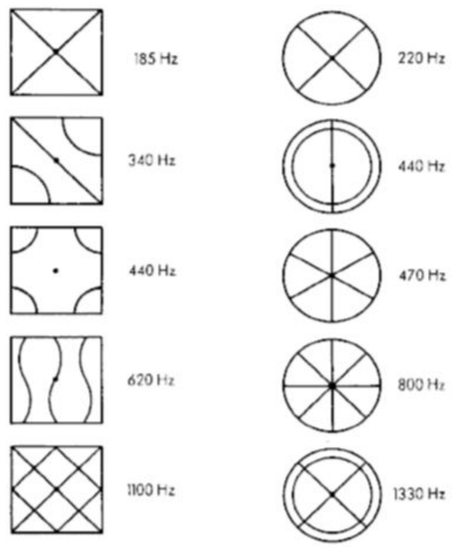

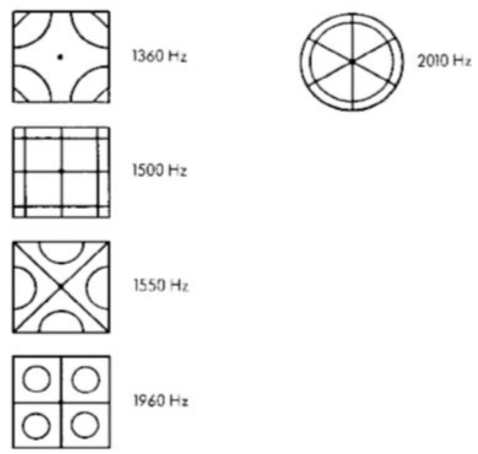

Some Chladni figures with corresponding frequencies.

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Evaluation (2/2)

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Fill in the blanks:

The pattern formed by the sea sand on the plate is the ______ pattern associated with the ______ of the Chladni plate. When an external frequency is exerted on the plate, some areas vibrates and some don't. The sea sand vibrates and moves away from the ______, where the amplitude of the standing wave is ______. It comes to rest along the ______ positions, where the amplitude is ______.

- maximum
- antinodes
- nodal
- natural frequencies
- standing wave
- minimum

Check

Slide	Score / Total
Slide 15: Summary Chladni figures	0/6

Total Score 0/6

Show solutions Retry

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