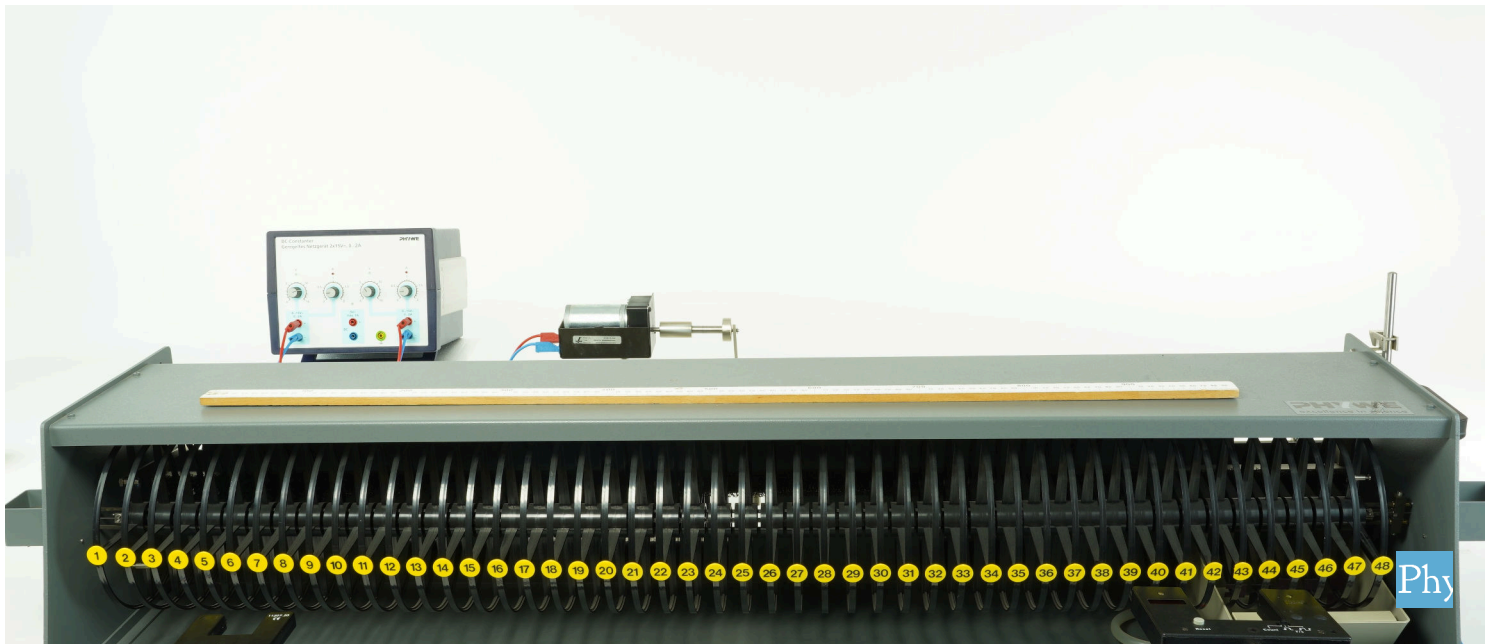


# Propagation of a periodically excited continuous transverse wave



The goal of this experiment is to investigate the propagation of a transverse wave with a wave machine.

Physics

Acoustics

Wave Motion



Difficulty level

medium



Group size

2



Preparation time

10 minutes



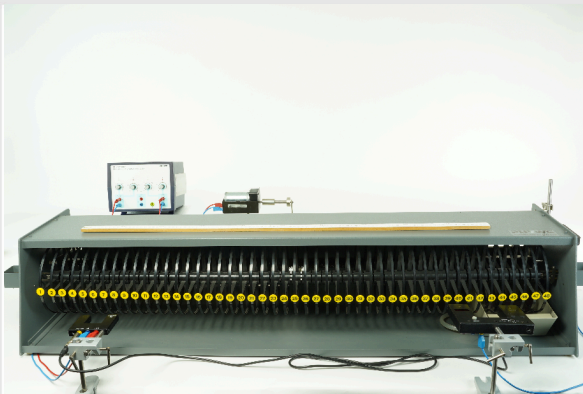
Execution time

10 minutes



# General information

## Application



Experimental setup

In physics, a transverse wave is a wave whose oscillations are perpendicular to the direction of the wave's advance. This is in contrast to a longitudinal wave which travels in the direction of its oscillations.

A simple example is given by the waves that can be created on a horizontal length of string by anchoring one end and moving the other end up and down.

Another example is the waves that are created on the membrane of a drum. The waves propagate in directions that are parallel to the membrane plane, but the membrane itself gets displaced up and down, perpendicular to that plane.

## Other information (1/3)

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### Prior knowledge



General knowledge about oscillators is required.

### Main principle



The periodicity of connected stationary oscillators is demonstrated on the example of a continuous, harmonic transverse wave generated by a wave machine. The number of oscillations carried out by different oscillators within a certain time is determined and the velocity of propagation is measured. A relation between frequency, wavelength and phase velocity is established. The formation of standing waves is demonstrated and studied.

## Other information (2/3)

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### Learning objective



The goal of this experiment is to investigate the propagation of a transverse wave with a wave machine.

## Other information (3/3)

### Tasks



1. The frequency of the oscillators 1, 10, 20, 30 and 40 is to be determined with the electronic counter of the light barrier and the stop-watch for a particular frequency of excitation.
2. By means of a path-time measurement the phase velocity of a transverse wave is to be determined.
3. For three different frequencies the corresponding wavelengths are to be measured and it is to be shown that the product of frequency and wavelength is a constant.
4. The four lowest natural frequencies with two ends of the oscillator system fixed are to be detected.
5. The four lowest natural frequencies with one end of the oscillator system fixed and the other one free are to be detected.

## Theory (1/3)

A harmonic transverse wave results from the propagation of a harmonic excitation along the system of coupled oscillators. If one observes the oscillator system at a fixed position  $x$  ( $x = 0, x_1, x_2, \dots$ ), then each oscillator carries out a periodic movement relative to time with the same frequency  $f$  respectively with the same period of oscillation  $T$  at its equilibrium position. Because  $\varphi_n = A \cdot f(t, x_n)$  holds, one obtains for the harmonic excitation:

$$\varphi_n = A \cdot \sin\left(2\pi f \left(t - \frac{x_n}{C_p}\right)\right) = A \cdot \sin\left(2\pi \left(f \cdot t - \frac{x_n}{\lambda}\right)\right)$$

with  $C_p = f \cdot \lambda$

$A$  = amplitude of oscillation,  $\lambda$  = wavelength, and  $C_p$  = phase velocity.

## Theory (2/3)

This equation includes both the spatial and the temporal periodicity of the wave, as at  $x = 0$ , the amplitude of the oscillation is given by

$$\varphi_1 = A \sin(2\pi ft) \text{ or } \varphi_1 = A \sin(\omega t) \text{ with } \omega = 2\pi f = \frac{2\pi}{T}$$

By superimposing of two waves it can be shown:

a. If both ends of the system are fixed, the condition

$$k \cdot \frac{\lambda}{2} = L$$

is valid for the occurrence of standing waves (internodal distance  $\lambda/2$ ), whereby  $L$  is the system length and  $k$  can assume the values  $1, 2, 3, \dots$ . For  $k = 1$  this yields the fundamental frequency with a wavelength of  $\lambda = 2 \cdot L$ .

## Theory (3/3)

b. If one end of the system is fixed and the other is free, the condition

$$(2k - 1) \cdot \frac{\lambda}{2} = L$$

holds for standing waves (internodal distance  $\lambda/2$ ). For  $k = 1$ , this yields the fundamental frequency with a wavelength of  $\lambda = 4L$ .

## Equipment

Position	Material	Item No.	Quantity
1	Wave machine	11211-00	1
2	PHYWE Power supply, 230 V, DC: 0...12 V, 2 A / AC: 6 V, 12 V, 5 A	13506-93	1
3	Light barrier with counter	11207-30	1
4	Light barrier, compact	11207-20	1
5	Motor with disk holder	11614-00	1
6	Digital stopwatch, 24 h, 1/100 s and 1 s	24025-00	1
7	Screened cable, BNC, l 1500 mm	07542-12	1
8	Connecting cord, 32 A, 1500 mm, blue	07364-04	1
9	Connecting cord, 32 A, 1500 mm, yellow	07364-02	1
10	Bench clamp expert	02011-00	3
11	Adapter, BNC male/4 mm female pair	07542-26	1
12	Meter scale, l = 1000 mm	03001-00	1
13	Right angle clamp expert	02054-00	2
14	Support rod, stainless steel, 500 mm	02032-00	2
15	Connecting cord, 32 A, 2000 mm, red	07365-01	2
16	Connecting cord, 32 A, 2000 mm, blue	07365-04	2
17	Adaptor, BNC socket/4 mm plug	07542-20	1
18	Collar adaptor w. connecting cord	07542-05	1
19	Connecting cord, 32 A, 1000 mm, red	07363-01	1
20	Connecting cord, 32 A, 1000 mm, black	07363-05	1
21	Power supply 5 V DC/2.4 A with 4 mm plugs	11077-99	1



# Setup and Procedure

## Setup and Procedure (1/3)

The wave machine is to be set up as shown in Fig. 1. The motor with disc holder is connected with the adapter for wave machine to the drive eccentric of the wave machine. The rotational speed determines the wave frequency and can be adjusted by the applied voltage. The connecting rod is used to couple the control shaft to the first oscillator of the system. For further details see the instruction manual of the wave machine.

The damping system must be used to dampen reflections at the free end of the oscillating system. To do this, the attenuation bath is placed beneath the last oscillator and filled with water.



Fig. 1: Experimental setup

## Setup and Procedure (2/3)

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A light stop is attached to the oscillator whose frequency is to be measured. To measure the frequency, the light barrier with digital counter should be arranged such that its optical path is crossed by the light stop at each zero passage of the oscillator. The digital counter is working as a pulse counter. For a particular number of pulses the measuring time  $\Delta t$  is determined with the stopwatch.

The determination of the phase velocity by means of a path-time- measurement in the wave machine is demonstrated on a continuous, harmonic transverse wave of length  $3/4\lambda$ . Two light stops are attached to oscillators 1 and 36 and the light barriers which are interconnected by a BNC cable are adjusted at a height such that, at maximum deflection of the oscillator the light stop just crosses the barrier. The first light barrier triggers the chronometer incorporated in the second light barrier. Finally the distance  $\Delta x$  between oscillator 1 and 36 is measured.

For the wavelength measurements the speed of the laboratory motor is set such that a continuous transverse wave of 3 to 4  $\lambda$  is generated. After the frequency has been measured as described above, the brake system of the wave machine is activated and the wave is "frozen". From the "frozen" wave wavelength  $\lambda$  can easily be found by using the meter scale.

## Setup and Procedure (3/3)

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For the detection of the natural frequencies the right end of the oscillator system is fixed, that means oscillator 48 is fixed to the wave machine case with the second connecting rod. Proceeding from a frequency of excitation  $f = 0$  Hz, one looks for those frequencies where standing waves with large amplitudes form. This is done by gradually increasing the speed of rotation of the motor and measuring the frequencies for which large amplitudes are observed.

Finally, the right end of the oscillator system is left free. A small amplitude is chosen and the damping system removed. For the fundamental frequency we can identify length  $L$  of the oscillating system with  $\lambda/4$ . The lowest frequency can thus be determined from a path-time measurement. Then, proceeding from the highest frequency of excitation, one looks for those frequencies which allow the formation of standing waves with large amplitudes by gradually decreasing the rate of rotation of the motor. These frequencies are determined experimentally with the aid of the digital counter and the stopwatch.



# Evaluation

## Evaluation 1 (1/2)

Place the light stop onto the first oscillator and align the light barrier accordingly. Then switch the laboratory motor on and select a speed of rotation which will produce a continuous transverse wave with a total length of  $4\lambda$  to  $5\lambda$ . Once a stable transverse wave has formed, start the digital counter and the stopwatch simultaneously and stop them when 280 pulses have been counted. Record measuring time  $\Delta t$  and the number of pulses.

Now repeat this measurement on different oscillators, whereby it is practical to convert the experimental arrangement with the oscillator system "frozen in place" and the drive still running. This ensures that all of the measurements are carried out at one speed of rotation of the motor (frequency of excitation).

The results obtained in one experiment are compiled in the following table:

whereby pulses = number of pulses within the measuring period,  $n$  = number of oscillations, and  $t$  = measuring time.

## Evaluation 1 (2/2)

All the oscillators of the system move at the same frequency  $f = n/\Delta t = \text{const} = 1.9 \text{ Hz}$  respectively with the same period of oscillation

$$T = \frac{1}{f} = \frac{1}{1.9} \text{ s} = 0.5 \text{ s}$$

Oscillator number	1	10	20	30	40
<b>Pulses</b>	280	280	280	280	280
<b>n</b>	140	140	140	140	140
<b><math>\Delta t</math> [s]</b>	73	73.4	72	73.2	73.6
<b><math>f = \frac{n}{\Delta t}</math> [1/s]</b>	1.9	1.9	1.9	1.9	1.9

## Evaluation 2

One determines phase velocity  $C_p$  of the wave from measured values  $\Delta x$  and  $\Delta t$  using the relation

$$C_p = \frac{\Delta x}{\Delta t}$$

When the first oscillator starts to move upwards from its maximum lower deflection, the reset key of the timer is activated. When the oscillator reaches its maximum upper deflection, the light gate triggers the timer. It stops when oscillator 36 assumes this state of oscillation. Note the indicated measured value and verify by repeating the measurement. Finally, determine the path  $A_x$  travelled by the phase by measuring the distance between the two oscillators.

The table contains test examples for 5 individual measurements:

	1	2	3	4	5	mean
<b><math>\Delta t</math> [s]</b>	1.04	1.02	1.03	1.04	1.04	1.03
<b><math>\Delta x</math> [cm]</b>	86.0	86.0	86.0	86.0	86.0	86.0

As mean value for  $C_p$  we find

$$C_p = 83.5 \frac{\text{cm}}{\text{s}}$$

## Evaluation 3 (1/2)

Switch the laboratory motor on and set the speed of rotation such that a continuous transverse wave of length  $3\lambda$  to  $4\lambda$  is generated.

Once the system has reached a steady state of Oscillation start both the digital counter and the stopwatch simultaneously and stop them both when measuring time  $\Delta t = 60\text{s}$  is completed.

Record the values for measuring time  $A_t$  and number of zero passages  $N$  of oscillator 1.

Now activate the breaking system to "freeze" the wave. Determine the characteristic wavelength  $\lambda$  for the frequency of the "frozen" waveform by linear measurement.

Release the breaking system and repeat the measurement at a low frequency of excitation (lower speed of rotation of the motor).

## Evaluation 3 (2/2)

The following table gives an experimental example for 3 different frequencies:

whereby  $N$  = number of pulses within measuring period  $\Delta t$ , and  $n = N/2$ . The mean value from the three individual measurements for phase velocity is

$$C_p = \frac{1}{3} \sum_{i=1}^3 \lambda_i \cdot f_i$$

$$C_p = 85.5 \frac{\text{cm}}{\text{s}}$$

This is in rather good agreement with the previous result from path-time measurement.

<b>N</b>	<b>n</b>	<b><math>\Delta t</math> [s]</b>	<b>f [1/s]</b>	<b><math>\lambda</math> [cm]</b>	<b><math>C_p</math> [cm/s]</b>
1308	154	60	2.57	33.0	84.8
2258	129	60	2.15	40.0	86.0
3158	79	60	1.32	65.0	85.8

## Evaluation 4

For both ends of the fixed oscillator system it can be observed that with an increasing speed of rotation of the laboratory motor, standing waves are first observed for a frequency of 0.38 Hz. This is the lowest natural frequency. The oscillation associated with this natural frequency is called the fundamental frequency. Its wavelength is  $\lambda = 2L$ .

All higher natural frequencies  $f_k$  are supposed to be integral multiples  $k$  of the lowest natural frequency  $f_g$ :

$$f_k = k \cdot f_g.$$

The resonance frequencies  $f_k$  are called "harmonics".

The resonance frequencies measured with increasing speed of rotation are listed in the following table:

$f_k$ [Hz]	$k$	$f_k/k$	$\lambda$
0.38	1	0.38	$2L/1$
0.74	2	0.37	$2L/2$
0.94	3	0.31	$2L/3$
1.43	4	0.36	$2L/4$

From the frequency ratio  $k$  and the number  $Z$  of nodes, one easily obtains the relation

$$Z = \frac{f_k}{f_g} + 1.$$

## Evaluation 5 (1/2)

From the relation  $(2k - 1)\frac{\lambda}{4} = L$  we obtain for  $k = 1$  a wavelength of  $\lambda = 4L$ . The corresponding frequency is the fundamental frequency. It can be found from a path-time measurement. If  $t$  is the time which a perturbation needs to pass through the oscillator system of length  $L$ , then  $4t$  is the time which corresponds to the period  $T$  and the fundamental frequency is thus given by the expression

$$f_g = \frac{1}{T} = \frac{1}{4t}.$$

From a path-time measurement,  $t$  was found to be 1.42 s.

Hence  $f_g = 0.18$  Hz.

The laboratory motor was then switched on and set to its highest speed of rotation. While slowly diminishing its speed those frequencies of excitation, which are the natural frequencies of the system and thus make the formation of standing waves at resonance possible were measured.

## Evaluation 5 (2/2)

The following table contains the results:

From the frequency ratio  $k$  one obtains the number of nodes  $Z$  from the relation

$$Z = \frac{1}{2} \cdot \frac{f_k}{f_g} + \frac{1}{2} = \frac{1}{2} \cdot (k + 1)$$

**Note:**

Please see instruction manual for complete description of the wave machine. The manual contains additional experiments specially in the field of demonstration of wave propagation.

$f_k$ [Hz]	$k$	$f_k/k$	$\lambda$
1.56	9	0.17	4L/9
1.18	7	0.17	4L/7
0.83	5	0.17	4L/5
0.55	3	0.18	4L/3
0.18	1	0.18	4L/1