Standing Waves

1. Pipes

The sound in wind instruments is produced by *standing waves*. The musician has to make the air in the instrument oscillate in order to compensate for the energy emitted in form of sound energy.

For a standing wave we have to distinguish between the air's motion and periodic pressure variations. At places of maximum air motion (*motion antinode*) the pressure variations have a minimum (*pressure node*) and vice versa (*motion node* and *pressure antinode*). A microphone or our ear-drum are sensitive to pressure variations.

Goals: You know the possible frequencies for open and closed pipes. You realise that the theory has to be refined to accurately describe the results.

Setup:
- Plexiglass tube, rubber cork to close one end
- Frequency generator and loudspeaker
- Microphone (connected to oscilloscope)
- Tape-measure

Procedure:

a Measure the dimensions of the tube.

b Introduce the microphone into the tube. Starting from 50 Hz, increase the frequency and determine the values for maximum amplitude (*resonance frequencies*).

Hint: Regularly Vary the microphone's position in order to avoid nodes.

c Choose a resonance frequency between 1 kHz and 2 kHz. Measure the distances between the minima (pressure nodes) and the tube's upper end.

Analysis:

1. For thin tubes, all the resonance frequencies should be integer multiples of the fundamental frequency. Check this prediction using your measurements.
2. Using the distances measured in c, calculate the wavelength and the speed of sound.
3. The first pressure node is much closer to the tube's end than half a wavelength. How far from the tube's end is the next (fictive) pressure node outside the tube? A refined theory predicts a value of 60 % of the tube's radius. Can you confirm this theory? What is the effective tube length you should use for your calculations?

2. Bars

The ends of a bar are oscillation anti-nodes. Standing waves in the bar have to respect these constraints.

Goal: You investigate the properties of standing waves in an aluminium bar.

Setup:
- Aluminium bars of different length
- Tape-measure
- Computer with microphone and spectrum analysis software

Procedure:

a Make yourself familiar with the spectrum analysis software "Sounds".

b Hold the longest aluminium bar with two fingers and hit it with the hammer. There should be a long ringing sound.

c Record the sound and read the frequencies of the visible harmonics from the frequency spectrum.

d Measure the lengths of the five bars and their fundamental frequencies.

Analysis:

1. The theoretical values for the frequencies of bending waves in a bar with two free ends are given by the relation

$$f_n = \frac{\pi r}{16\,L^2}\, v_{\mathrm{S}} \cdot (2n+1)^2$$

where r is the radius, L the length of the rod and v_S the speed of waves propagating in the aluminium bar.

Discuss the qualitative differences between the harmonics in a bar and those in a pipe or on a string.

2. Verify if the frequencies for the harmonics of the longest bar have the correct ratio.
3. Using an appropriate graphical representation determine a value for the wave speed in the bar. Compare the result to the value found in "Formeln und Tafeln".

3. Strings

The ends of a stretched string are obviously oscillation nodes. Standing waves on the string have to respect these constraints.

Goal: You investigate the properties of standing waves on a stretched string in a systematic way.

Setup:

- Strings
- Set of masses to stretch the string
- Vibrator connected to frequency generator
- Tape-measure

Procedure:

a Lock the vibrator (position „lock“) and attach a string. Unlock the vibrator (position „unlock“). Remember to lock the vibrator whenever you change the string.

b Measure the length of the piece of string between hook and pulley (some 120 cm).

c Attach a 500 g mass to the string's free end stretch the string. Switch on the frequency generator and determine the lowest frequency for which you can observe an intense oscillation (at some 30 Hz). Find subsequent resonance frequencies.

d Carry out systematic measurements allowing you to investigate how the fundamental frequency depends on the string tension.

Analysis:

1. For every resonance frequency in c, calculate the wave speed. Find a relation for the ratio of fundamental frequency and harmonics.
2. Using an appropriate graphical representation investigate how the fundamental frequency of the string depends on the tension of the spring.
3. Using the formula for the speed of transversal waves on a string, calculate the theoretical values for the strings used in your measurements. Compare the theoretical to your experimental results.

Requirements: If you write a short report on this experiment, work on the analysis for one of the three experiments. The complete analysis for at least two experiments is required for a full report.

Hand in your report and the lab journal by Friday, 17 January 2011.