Experiment 1
Normal Modes in Vibrating Strings

Objectives of the Experiment:
- Study and understand the normal modes in vibrating strings.
- Use statistical tools to estimate the wave propagation velocity.

I. Introduction to the experiment

I.1 Introduction and Theoretical Framework

Recall that a vibrating string fixed at both ends experiences standing waves with very specific frequencies and wavelengths; these are known as **normal modes**, resonant modes, or harmonics. These modes are characterized by covering the string with multiples of half a wavelength. For example, the first mode, or fundamental harmonic, $n = 1$, corresponds to a standing wave that occupies half a wavelength along the string, $L = \lambda/2$. This implies that its wavelength is twice the length of the string, $\lambda = 2L$, and since the relationship between frequency, wavelength, and propagation speed is $v = f\lambda$, the frequency of the fundamental mode is

$$f_1 = \frac{v}{2L} \qquad [1]$$

Where L is the length of the string and v is the propagation speed of the waves in the medium, which in this case is the material of the string. The frequencies of the following resonant modes, $n = 2, 3, 4, \ldots$, are given as **multiples of the fundamental frequency**, calculated using the following expression:

$$f_n = nf_1 \qquad [2]$$

Lastly, these standing waves have very special points called **nodes** and **antinodes**. At a node, the wave's amplitude is always zero, meaning that point does not vibrate. On the other hand, the vibration at an antinode is at its maximum. Figure 1 illustrates the position of a node and an antinode for the resonant modes $n = 1, 2$ and 3.

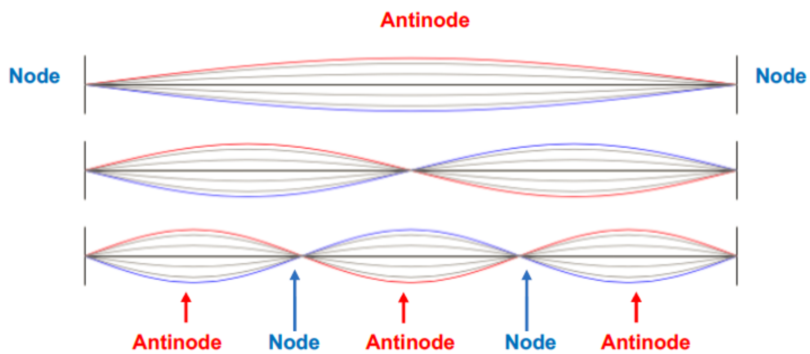

Figura 1. Nodes and antinodes of a standing wave on a vibrating string corresponding to the 1st, 2nd and 3rd resonant modes, $n = 1, 2$ and 3.

For a string stretched along a length L (in meters) and subjected to a tension T (in Newtons), the wave velocity can be calculated as:

$$v = \sqrt{T/\mu} \qquad [3]$$

Where T is the tension in the string and μ is the linear mass density of the string, measured in kilograms per meter. The linear mass density is calculated by dividing the total mass of the string by its total length:

$$\mu = \frac{m}{L} \qquad [4]$$

Question: *Do you need to consider any specific properties of the string?*

I.2 Experimental Setup

On a workbench, two supports are placed at a distance of one meter apart. One of the supports holds a wave generator, while the other has a pulley. A string is stretched between these two supports and tensioned using a weight attached to the end of the string, which passes over the pulley.

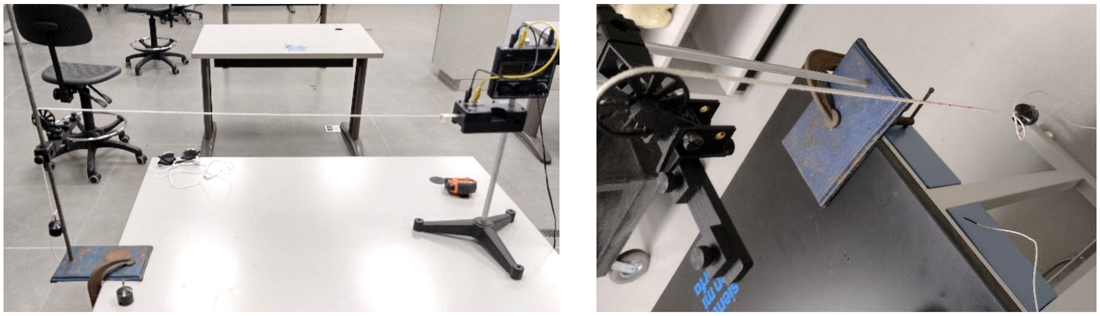

Figure 2. Experimental Setup.

The string must be as horizontal as possible, and the supports must be perfectly aligned to prevent the string from being at an angle when viewed from above.

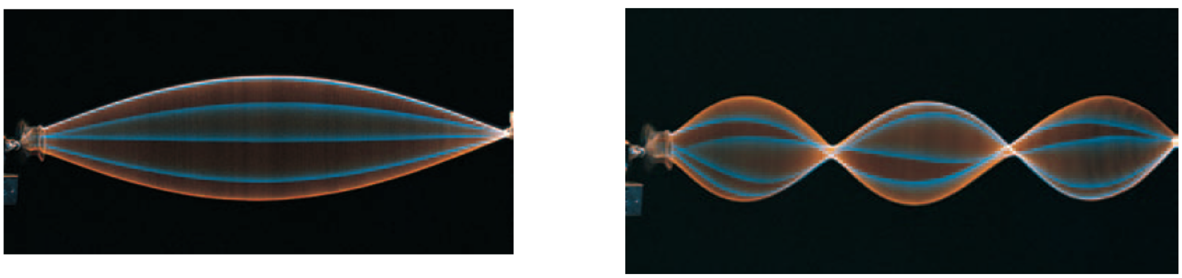

Figura 3. Fundamental (n=1) and 3rd (n=3) modes in a vibrating string.

II. Conducting the Experiment

To determine the wave propagation velocity using laboratory equipment, it is first necessary to take certain measurements. Utilizing these data and theoretical framework formulas, the speed of transverse waves in the string can be calculated, along with determination of any harmonic frequencies. The primary objective of this experiment is to produce at least the first modes (including the fundamental) for almost one tension application to the string.

II.1 Preliminary Measurements

Instructions: Using the provided scale, measure the mass of the weight that will be used to tension the string. Similarly, measure the mass of the string to be used. Then, using the measuring tape, measure the total length of the string without overstretching it, as well as the length of the string segment stretched between the wave generator and the pulley. Record your measurements in the tables provided below.

String		
Mass (kg)	Total Length (m)	Linear Density - μ (kg/m)

Table 1 String properties

Weight	
Mass (kg)	Tension (N)

Table 2 Weight properties

Using this data you could estimate an initial value of the theoretical velocity (v_{theo}), using the Equation [3], computing additionally the uncertainty using the propagation error rules.

II.2 Reproducing Normal Modes

Instructions: Stretch the string between the wave generator and the pulley, attaching the weight to the free end of the string. Set a frequency close to the fundamental mode on the wave generator and adjust the amplitude to the largest possible value without causing unwanted effects in the system. Now, vary the frequency of the generator to more accurately locate the fundamental mode. Remember that for each normal mode, resonance occurs, where the system dissipates the greatest amount of energy, and the amplitude of the standing wave reaches its maximum value.

Repeat this procedure to reproduce the other harmonics and report the experimentally determined frequencies in the table below. In each row compute the velocity as a function of the frequency and the wavelength, $v = f\lambda$.

Take photographs of the generated modes and record a short video.

Question: *What is the highest harmonic you can generate with this system? Try to reproduce it.*

n	f (Hz)	λ (m)	v_{exp} (m/s)
1			
2			
3			
…			

Table 3 Frequencies and wavelengths, velocity estimation.

Finally, using the multiple measurements of the velocity, compute and report the average experimental velocity v_{exp} and the error in the measurement, ***how far is your experimental velocity from the theoretical one?***

III. Connection to the Profession

The study of standing waves and wave propagation is fundamental for engineers, providing tools to analyze vibrations, resonance, and energy transfer. Accurate measurements and error analysis is key to advancing critical applications such as designing stable structures, enhancing signal transmission, and refining acoustic systems. This practice builds a strong foundation in precision and analytical thinking, helping engineers apply these principles to solve real-world challenges effectively.

IV. Conclusions

(Add a paragraph about the most important conclusions you take away from this practice. Emphasize the concepts and ideas that were unfamiliar before but are now clear and familiar after completing it.)