Sonometer

Aim:

To study the vibrational modes of a stretched string/wire using sonometer.

Student learning objectives:

- ➢ To determine the dependence of the fundamental frequency on tension in the string/wire and on length of the wire
- ➢ To verify the frequency of AC mains

Apparatus Required:
- ➢ Sonometer
- ➢ A non-magnetic wire e.g. stainless steel wire
- ➢ An electromagnetic coil
- ➢ An AC source of known frequency (6-8 V, 1 A)
- ➢ A set of weights

Theory:

The standing or stationary transverse waves can be formed in a stretched string or wire with both the ends fixed as shown in figure 1. If the length of the wire is L and both the ends of the wire are fixed then only vibrational modes are allowed where an integer number of half-wavelengths equals to the string length:

$$n\frac{\lambda}{2} = L \Rightarrow \lambda = \frac{2L}{n} \qquad\qquad ....(1)$$

Where n =1, 2, 3, 4, 5, 6……..

n = 1, the fundamental mode

n = 2, 1st overtone/2nd harmonic

n = 3, 2nd overtone/3rd harmonic

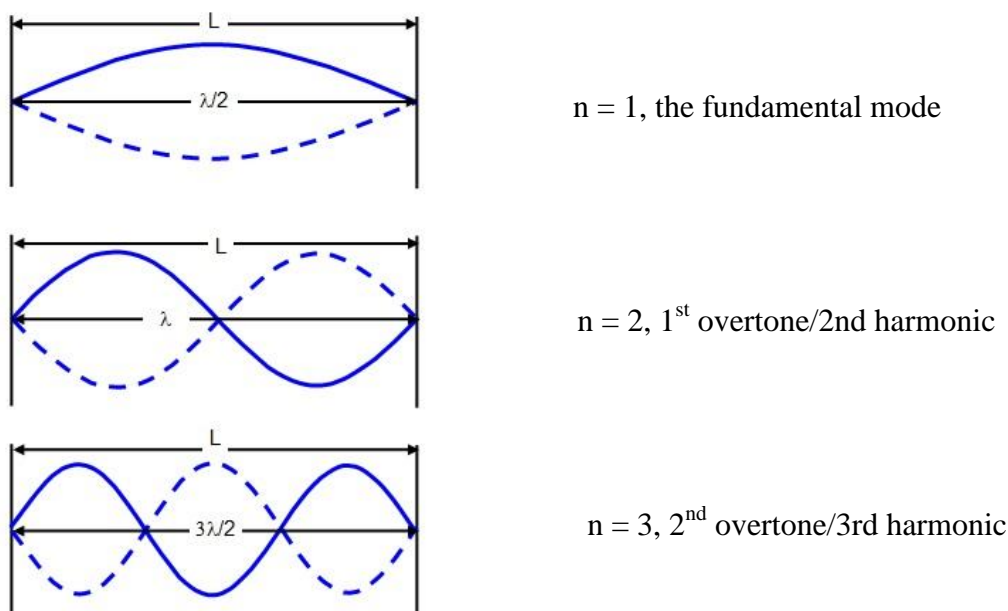**Figure 1: Vibrational modes of a stretched string**

n = 1 corresponds to fundamental mode of vibration while n =2, 3, 4….. correspond to, second, third, fourth harmonics respectively.

For a flexible and elastic wire, the velocity of wave propagation (v) in the wire is given by

$$v = \sqrt{\frac{T}{\mu}} \qquad\qquad \text{............(2)}$$

Where, T is the tension in the wire and μ is the mass per unit length or linear density of the wire.

The wave propagation velocity, v of the wave is related to the wavelength, λ and frequency, f as:

$$v = \lambda f \qquad\qquad \text{..............(3)}$$

By combining equations (1), (2) and (3), the frequencies of the fundamental mode (n =1) and harmonics (n > 1) for a given combination of T, μ and L can be found as

$$\boldsymbol{f} = \frac{n}{2L}\sqrt{\frac{T}{\mu}} \qquad\qquad \text{...............(4)}$$

Methodology:

The sonometer allows precise variation of the tension in the wire, by hanging a series of masses from one end, and also in the length of the wire by moving the knife edges as shown in Figure 2. Mass per unit length, μ may also be varied by using wires of different diameters. An electromagnetic coil connected to an AC power supply (6-8 V, 1 A) is used to excite the transverse waves in the stretched wire.
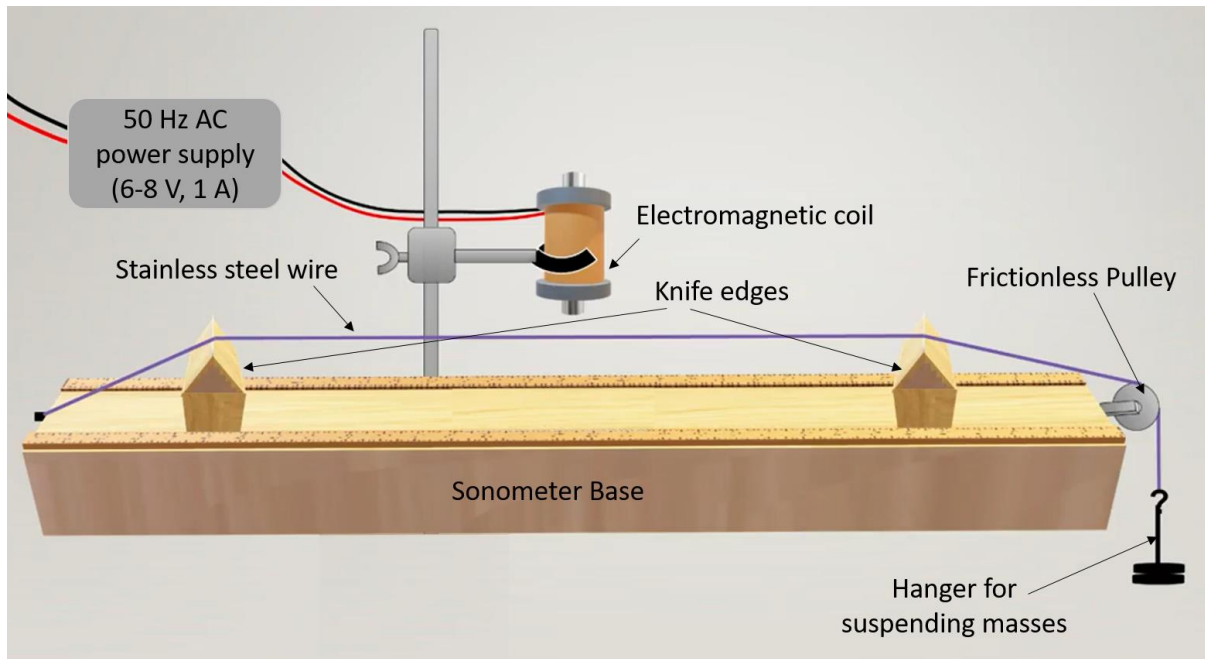

Figure 2: Schematic of sonometer experiment

1. To determine dependence of the fundamental frequency (n = 1) on tension in the wire, two knife edges are placed at equal distances from the coil.
2. For variation of tension in the wire, the mass suspended through hook is increased using the set of weights provided.
3. Tension in the wire is product of the mass suspended from the wire and acceleration due to gravity, $g = 9.8$ ms^{-2} and is given by $T = mg$.
4. Hang a mass, m = 500 g from one end of the wire and adjust the distance (L) between two knife edges symmetrically with respect to electromagnet till the wire appears to be vibrating with the maximum amplitude.
5. This is the resonance condition where wire is vibrating with a frequency equal to the excitation frequency of AC which is 50 Hz.
6. Note the distance (L) between the two knife edges using meter scale. This is the resonating length of the wire for the applied tension
7. By increasing the tension in the wire, repeat the step 4 for at least 5 different values of tension.
8. Linear density, μ of the wire can be found by weighing a piece of the known length of the wire.
9. Plot a graph between L vs $\sqrt{T}$. Join all the data points with a best fit straight line and calculate the slope.
10. Equate the obtained slope value with $2f\sqrt{\mu}$. Substitute the value of μ and calculate the fundamental frequency of vibration f.
11. Also find the value of f using the equation (4) for different tension values and corresponding resonating lengths. Calculate the mean value of f.
12. Compare the obtained values of f with the standard value which is 50 Hz and find out the percentage error.
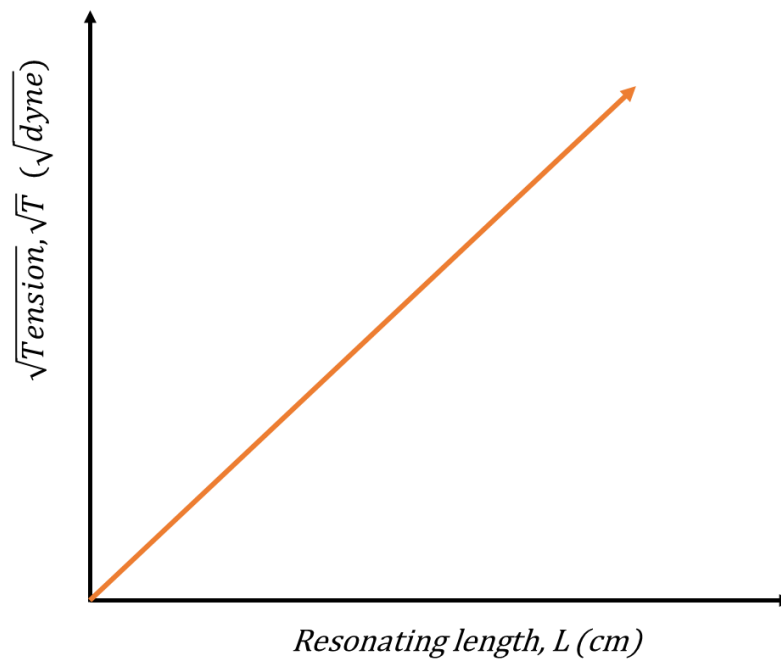

Observation table:

Mass per unit length of the wire, μ = ………….g cm^{-1}

Sl. No.	Mass suspended from the hanger, m (g)	Tension in the wire, T (dyne)	Resonating length, L (cm)	Fundamental frequency of vibration of the wire, f (Hz)
1				
2				
3				
4				
5				
6				
7				

Average value of frequency calculated using formula, f = ……………

Model Graph:

Calculations:

From equation (4), we can write $\sqrt{T} = 2f\sqrt{\mu}L$

Comparing above equation with the equation of a straight line passing through the origin i.e. $y = mx$ where m is slope of the line.

We have, $m = 2f\sqrt{\mu}$

On substituting the value of the slope obtained from the graph and μ, we get the value of fundamental frequency.

Calculate the value of f for each set of T and L using the equation (4) and also find the mean value of f.

Finally calculate percentage error in the value of f.

Result and Inferences:

Precautions:

1. There should not be any kinks in the sonometer wire.
2. Pulley should be frictionless
3. Electromagnetic coil should be placed in the middle to avoid higher harmonics and also to have sharper resonance.
4. Mass of the hanger should be included while calculating T.
5. The distance between the two knife edges should be altered very slowly otherwise resonance point would be missed.