Name: Antonio Perez Date: 02/11/2024

Experiment 9:

Mechanical Waves

Introduction

When matter is oscillating, it transfers energy through a medium and produces a wave that is called "Mechanical". While waves can move over long distances, the movement of the medium of transmission—the material—is limited. Therefore, oscillating material does not move far from its initial equilibrium position. A mechanical wave requires an initial energy input. Once this initial energy is added, the wave travels through the medium until all its energy is transferred.

Mechanical waves are classified mainly in longitudinal and transverse. A prime example of transverse waves is the propagation of energy in a string.

Transverse waves cause the medium to oscillate perpendicular to the direction of the wave or energy being carried by the medium. Transverse waves have two parts—the crest and the trough. The crest is the highest point of the wave and the trough is the lowest; these are called the antinodes in a standing wave. The distance between a crest and a trough is half of wavelength and is equal to the distance between nodes, which is called internodal distance. The wavelength, λ, is the distance from crest to crest or from trough to trough.

The frequency, f, of a wave is the number of waves generated per unit time and is usually expressed in vibrations (cycles) per second. The period, T, the time required for the generation of a single wave, is the reciprocal of the frequency.

$$T = \frac{1}{f} \qquad (1)$$

A simple relationship exists between frequency and wavelength. The wave pattern travels a distance λ over a time of one period T, that is, the speed of the wave v is given by $v = \lambda/T$. Since $f = 1/T$, we get:

$$v = f\lambda \qquad (2)$$

There is also a simple relationship between the physical properties of the wave and the velocity. These physical properties turn out to be the tension, F, in the string, and the mass, m, per unit length, l, also called linear density, ρ, of the string, where

$$\rho = \frac{m}{l} \qquad (3)$$

The equation relating the velocity of the wave with the tension on the string and its linear density is:

$$v = \sqrt{\frac{F}{\rho}} \qquad (4)$$

This experiment is designed to examine the relationship between wavelength, linear density, frequency, and tension of a vibrating string. Two strings with different density will be analyzed. Changing the frequency of the oscillations, it will be possible to find different harmonics, calculate the wavelength, and finally determine the velocity of the wave on each string.

Procedures

Part I: Constant Wave Velocity

1. Beginning with the thinnest string of the two, measure its mass and length. Note the strings in this experiment are very light so measure the mass with the more precise balance. Measure the string lengths with precision to a millimeter. Record the measurements on Table 1.
2. Tie one side of the first string to the post attached to the table and place the other side over the pulley.
3. Suspend the mass hanger with a 20 gram mass added on the loose end of the string over the pulley.
4. Open the corresponding data collection program and have your professor give you instructions about the oscillator and the function generator.
5. Adjust the frequency of the function generator until the string oscillates with a standing wave of one loop. Record the oscillation frequency, the number of loops, and the internodal distance.
6. Repeat step 5 for standing waves of 2, 3, 4 and 5 loops. Record all of the information on Table 1.
7. Remove the string.
8. Repeat steps 1 thru 7 for the second string recording the information on Table 2.

Part IIa: Constant Wavelength

9. Use third string, the thickest one, for the remaining experimental trials. Start with 30 grams on the mass hanger, and the oscillation frequency set at 50Hz.
10. Adjust the oscillation frequency until the string oscillates with a standing wave of three loops having the maximum amplitude.
11. Determine the internodal distance.
12. Record the total hanging mass, the number of loops, the frequency and the internodal distance in Table 3.
13. Add 10 grams to the mass hanger and measure. Repeat steps 10 thru 13.

Part IIb: Constant Frequency

14. Keep the setup the same as the last trial you completed: use the same frequency and start with the same total mass.
15. Adjust the mass on the mass hanger until four loops are obtained having the maximum amplitude. This will require gradually reducing the mass.
16. Determine the internodal distance.
17. Measure the total mass hanging from the string, including the mass hanger as well.
18. Record the total hanging mass, the number of loops, the frequency and the internodal distance in Table 3.
19. Adjust the mass until five loops are obtained, repeating steps 16 thru 18.

Analysis

Part I: Constant Wave Velocity

1. For Table 1.
2. Calculate the linear density of the string in units of (kg/m), Equation (3).
3. Calculate the wavelength of the standing wave using the internodal distance.
4. Graph the frequency of the wave as a function of the wavelength using Excel.
5. Choose the appropriate trendline fit in Excel for the data. Next use the equation of the fit to determine the experimental wave velocity when comparing with equation (2).
6. Calculate the value of the velocity of the wave using Equation (4).
7. Calculate the percent difference between the wave velocities.
8. Repeat these steps 2 thru 7 for data collected in Table 2.

Part II: Constant Wavelength and Constant Frequency

1. Calculate the wavelength for each trial using the internodal distance.
2. Calculate the wave velocity for each trial using Equation (2).
3. Calculate the tension in the string for each trial due to the hanging mass.
4. Calculate the linear density for each trial solving Equation (4).
5. Calculate the mean and standard deviation for the linear density.
6. Calculate the percent difference between the linear density found in Part I for string #2, and the mean linear density found in Part II.

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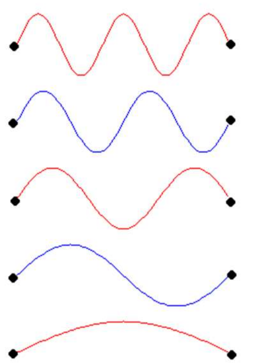
Data sheet: Standing Waves on a String

Table 1: Constant Wave Velocity - String #1 - Red

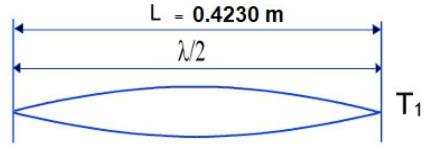
Hanging Mass: _0.0249822 Kg_____ Tension $\boldsymbol{F}$: _0.24482556 N
String Mass: _0.0001841 Kg _____ String Length: _1.779 m__
Linear Density $\boldsymbol{\rho}$: __1.034851 x 10^{-4} Km/m

Frequency	# Loops	Internodal Distance	Wavelength
29 Hz	1	0.8460 m	1.6920 m
58 Hz	2	0.4230 m	0.8460 m
87 Hz	3	0.2820 m	0.5640 m
116 Hz	4	0.2115 m	0.4230 m
145 Hz	5	0.1692 m	0.3384 m

Linear Density $\frac{kg}{m} = \frac{String\ Mass\ Kg}{String\ Length\ m}$	**Linear Density** $\frac{kg}{m} = \frac{0.0001841\ \text{kg}}{1.779\ \text{m}} = \mathbf{0.000103485}\ \frac{\boldsymbol{kg}}{\boldsymbol{m}}$
Tension $\boldsymbol{N} = Hanging\ Mass\ Kg * Gravity\ \frac{m}{s^2}$	**Tension** $\boldsymbol{N} = 0.0249822\ Kg * 9.8\ \frac{m}{s^2} = \mathbf{0.24482556}\ \boldsymbol{N}$



$\lambda_n \frac{2L}{n}$ $\quad n = 1,2,3 ....$



$L = Internodal\ Distance = \mathbf{0.4230}\ m$

$\lambda_2 = \frac{2 * 0.4230\ m}{2} = \mathbf{0.4230}\ \boldsymbol{m}$	$Wavelength\ m = \lambda_2 * 2 = \mathbf{0.846}\ \boldsymbol{m}$
$\lambda_3 = \frac{2 * 0.4230\ m}{3} = \mathbf{0.2820}\ \boldsymbol{m}$	$Wavelength\ m = \lambda_3 * 2 = \mathbf{0.5640}\ \boldsymbol{m}$
$\lambda_4 = \frac{2 * 0.4230\ m}{4} = \mathbf{0.2115}\ \boldsymbol{m}$	$Wavelength\ m = \lambda_4 * 2 = \mathbf{0.4230}\ \boldsymbol{m}$
$\lambda_5 = \frac{2 * 0.4230\ m}{5} = \mathbf{0.1692}\ \boldsymbol{m}$	$Wavelength\ m = \lambda_5 * 2 = \mathbf{0.3384}\ \boldsymbol{m}$

Wave Velocity From Calculation:

$$v = \sqrt{\frac{F}{\rho}}$$

$$v = \sqrt{\frac{0.24482556\ N}{0.000103485\ \frac{kg}{m}}} = 48.63954\ \frac{\boldsymbol{m}}{\boldsymbol{s}}$$

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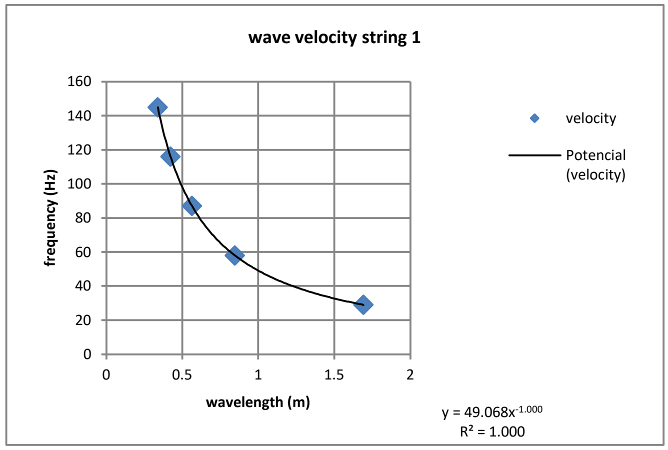
Description String 1			
Hanging Mass:	0.0249822	Tension:	0.24482556
String Mass:	0.0001841	String Length:	1.779
Linear Density:	0.000103485		
Frequency (Hz)	# of loops	Internodal Distance (m)	Wavelength (m)
29	1	0.846	1.7
58	2	0.423	0.8
87	3	0.282	0.6
116	4	0.2115	0.4
145	5	0.1692	0.3
	Wave Velocity From Graph:		49.068
	Wave Velocity From Calculation:		48.6
	Porcentage Diference:		0.877025676



Wave Velocity from graph =__49.068 m/s__

Wave Velocity = $v = \sqrt{\frac{F}{\rho}}$ = ___48.63 m/s_______

% Difference:_0.877025676_________

Table 2: Constant Wave Velocity - String #2_ White

Hanging Mass: __0.0249822 Kg___ Tension $\boldsymbol{F}$: __0.24482556 N
String Mass: _0.0002826 Kg_____ String Length: _1.601 m__
Linear Density $\boldsymbol{\rho}$: _0.0001765146 Kg/m__

Frequency	# Loops	Internodal Distance	Wavelength
23 Hz	1	0.8460 m	1.6920 m
45 Hz	2	0.4230 m	0.8460 m
67 Hz	3	0.2820 m	0.5640 m
90 Hz	4	0.2115 m	0.4230 m
122 Hz	5	0.1692 m	0.3384 m

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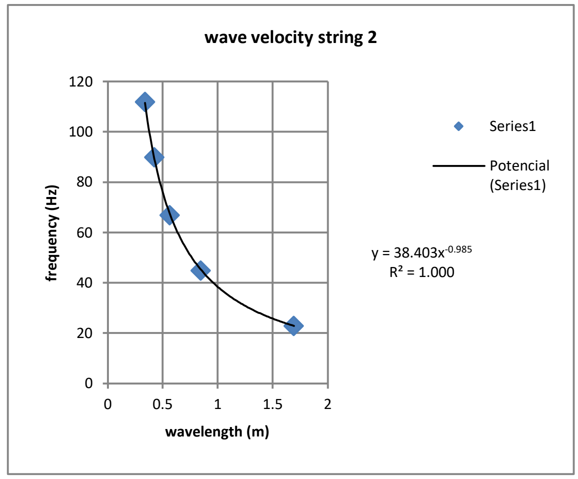
Description String 2			
Hanging Mass:	0.0249822	Tension:	0.24482556
String Mass:	0.0002826	String Length:	1.601
Linear Density:	0.000176515		
Frequency (Hz)	# of loops	Internodal Distance (m)	Wavelength (m)
23	1	0.846	1.7
45	2	0.423	0.8
67	3	0.282	0.6
90	4	0.2115	0.4
112	5	0.1692	0.3
	Wave Velocity From Graph:		38.403
	Wave Velocity From Calculation:		37.2
	Porcentage Diference:		3.068457378



Wave Velocity from graph =__38.403 m/s__

Wave Velocity = $v = \sqrt{\frac{F}{\rho}}$ = __37.44 m/s_

% Difference:__3.068457378_

Table 3: Constant Wavelength and Constant Frequency - String #2 _White

# of loops	Internodal Distance (m)	Frequency (Hz)	Mass (kg)
3	0.282 m	80 Hz	0.0349622 kg
3	0.282 m	92 Hz	0.0449414 kg
4	0.2115 m	92 Hz	0.0259762 kg
5	0.1692 m	92 Hz	0.0164352 kg

Table 4: Constant Wavelength and Constant Frequency - String #2 - Calculations_White

Wavelength (m)	Velocity (m/s)	Tension (N)	Linear Density (kg/m)
0.5640 m	45.12 m/s	0.3426295 N	1.683009×10^{-4}
0.564 m	51.88 m/s	0.4404257 N	1.6363368×10^{-4}
0.4230 m	38.91 m/s	0.2545667 N	1.681431×10^{-4}

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Table 4				Table 5			
# of loops	Internodal Distance λ (m)	Frequency (Hz)	Mass (kg)	Wavelength (m)	Velocity (m/s)	Tension F (N)	Linear Density (kg/m)
3	0.2820	80	0.0349622	0.564	45.12	0.34262956	0.000168301
3	0.2820	92	0.0449414	0.564	51.888	0.44042572	0.000163583
4	0.2115	92	0.0259762	0.423	38.916	0.25456676	0.000168091
5	0.1692	92	0.0164352	0.3384	31.1328	0.16106496	0.000166175
					Mean Linear Density		1.67E-04
					Standard Deviation		2.18964E-06
					Porcentage Difference		-5.82E+00

0.3384 m	**31.13 m/s**	**0.1610649 N**	**1.6620445 x 10^{-4}**

$Wavelength\ m = \lambda_3 * 2 = \mathbf{0.5640\ m}$
$Wavelength\ m = \lambda_3 * 2 = \mathbf{0.5640\ m}$
$Wavelength\ m = \lambda_4 * 2 = \mathbf{0.4230\ m}$
$Wavelength\ m = \lambda_5 * 2 = \mathbf{0.3384\ m}$

Velocity (m/s): $v = f\lambda$

$$v_3 = 80\text{ Hz} * 0.5640\text{ m} = 45.12\text{ m/s}$$
$$v_3 = 92\text{ Hz} * 0.5640\text{ m} = 51.88\text{ m/s}$$
$$v_4 = 92\text{ Hz} * 0.4230\text{ m} = 38.91\text{ m/s}$$
$$v_5 = 92\text{ Hz} * 0.3384\text{ m} = 31.13\text{ m/s}$$

$\textbf{Tension}\ N = \ Hanging\ Mass\ Kg\ *\ Gravity\ \frac{m}{s^2}$
$\textbf{Tension}\ N = 0.0349622\ Kg\ *\ 9.8\ \frac{m}{s^2} = \mathbf{0.34262956\ N}$
$\textbf{Tension}\ N = 0.0449414\ Kg\ *\ 9.8\ \frac{m}{s^2} = \mathbf{0.44042572\ N}$
$\textbf{Tension}\ N = 0.0259762\ Kg\ *\ 9.8\ \frac{m}{s^2} = \mathbf{0.25456676\ N}$
$\textbf{Tension}\ N = 0.0164352\ Kg\ *\ 9.8\ \frac{m}{s^2} = \mathbf{0.16106496\ N}$

Linear Density (kg/m) : $\rho = \frac{F}{v^2}$
$\rho_3 = \frac{0.34262956}{45.12^2} = 0.000168301\ Kg/m$
$\rho_3 = \frac{0.44042572}{51.888^2} = 0.000163583\ Kg/m$
$\rho_4 = \frac{0.25456676}{38.916^2} = 0.000168091\ Kg/m$
$\rho_5 = \frac{0.16106496}{31.1328^2} = 0.000166175\ Kg/m$

Mean Linear Density: 1.67 x 10^{-4} Kg/m

Standard Deviation: 2.18964 x10^{-6} Kg/m

Percent Difference: -5.82 %