Lab partners: Jared Fowler Team #:

Chikheang Soeng Day of Lab: Thursday

Date: Jan. 17, 2019

Melde's Experiment

Purpose:

To measure the linear mass density of two strings by using standing waves.

Required Equipment:

Pasco PI-9887C Digital Function Generator - Amplifier, Pasco SF-9324 Mechanical Vibrator, two table clamps and 1/2" diameter rod, 50 gram hooked weight hanger, eight 100 gram slotted weights or equivalent, approximately 3 meters of string of two different linear mass densities, pulley, connecting cables, analytical balance, meter stick.

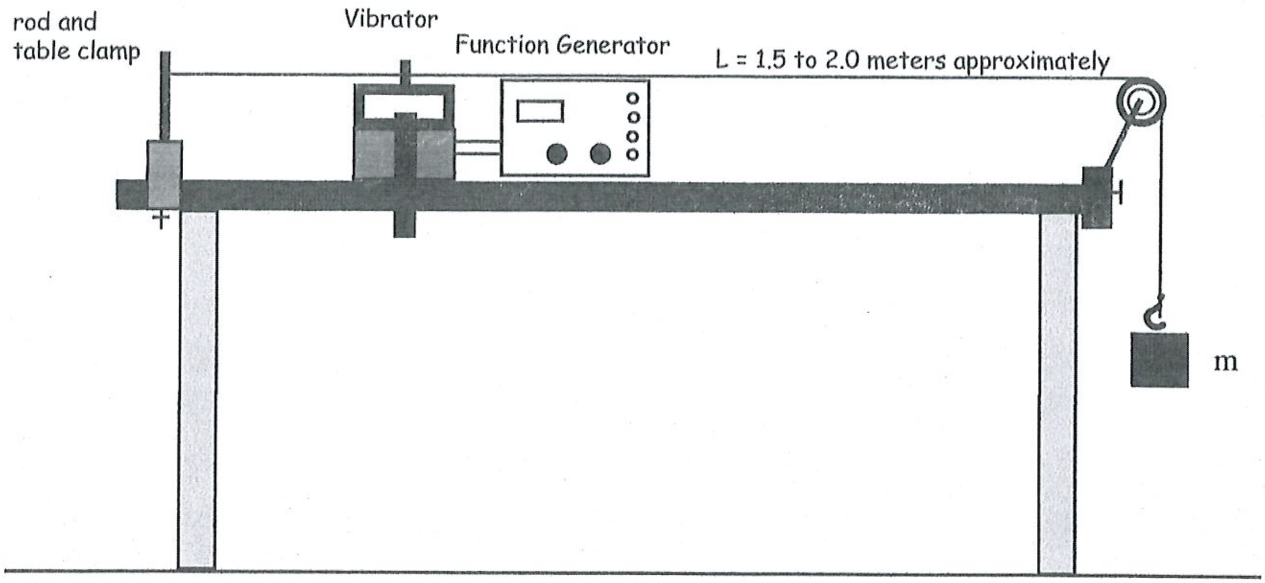
Discussion:

It has been shown in lecture that, for small amplitude vibrations, the speed of a transverse wave on a uniform string is given by,

$$v = f\lambda = \sqrt{\frac{T}{\mu}} \qquad (1)$$

where T is the tension in the string and μ is the string's linear mass density. Solving for the linear mass density we get,

$$\mu = \frac{mg}{(f\lambda)^2} \qquad (2)$$



Procedure:

Measuring the linear mass density of two strings.

1. Assemble the apparatus as shown in the picture above. Initially start with a single 100 gram slotted weight on the hanger (150 grams total) and adjust the frequency from the function generator until a standing wave pattern for the second, third or higher harmonic is produced. Using a meter stick, measure the distance d for a half-wavelength or multiple of half wavelengths. It is best to not use the half-wavelength closest to the vibrator as the node is usually not well defined.

2. Successively add 100 gram masses and repeat the procedure until eight runs have been made. Fill in the data in the tables on the following page. Note that n is the number of antinodes you measured, for example if you only measured a single half wavelength n = 1, if you measured a full wavelength n= 2, etc.

3. With the string under a moderate amount of tension (perhaps 4 slotted weights) carefully mark off a known length (say 150 cm) with a marking pen. Cut the string at the marks and weigh it on an analytical balance. This will give you a "known" value for μ.

4. Repeat the entire procedure for a second string of different linear mass density.

Jared Fowler

18

String #1

80-lb-test

n (# antinodes)	d (meters)	f (Hz)	m (kg)
2	1.135	40.610	0.150
2	1.135	52.150	0.250
2	1.130	61.805	0.350
2	1.135	70.102	0.450
2	1.135	77.650	0.550
2	1.135	84.230	0.650
2	1.135	90.340	0.750
2	1.135	96.170	0.850

Direct measurement of μ_1 L_1 = 1.500 ± 0.001 m M_1 = 1.0591×10^{-3} kg

$\mu_1 = M_1 / L_1$ = 7.06×10^{-4} kg/m

String #2

50-lb-test

n (# antinodes)	d (meters)	f (Hz)	m (kg)
2	1.135	48.820	0.150
2	1.135	66.680	0.250
2	1.135	77.760	0.350
2	1.135	87.545	0.450
2	1.135	96.302	0.550
2	1.135	104.60	0.650
2	1.135	112.20	0.750
2	1.135	119.20	0.850

Direct measurement of μ_2 L_2 = 1.500 ± 0.001 m M_2 = 0.7005×10^{-3} kg

$\mu_2 = M_2 / L_2$ = 4.67×10^{-4} kg/m

Calculations & Analysis

1. Using the data that you collected for Melde's Experiment, compute the linear mass density μ for each mass that you put on the hanger. You now have multiple measurements of the same quantity so you can compute the average and standard deviation. It's recommended that you Excel or another spreadsheet since you will be using this software for additional activities in this course.

2. Make a plot of μ versus hanging mass, m. Use the build-in Exel function LINEST to fit a line to the data and retrieve the slope, y-intercept, and other statistical information. There is a step by step guide to using LINEST as part of the introductory material from the 20AL manual that is posted on your course web site. Plot the best fit line on the figure. Note that data should consist of points and the best-fit should be a line. Make sure that you include axis labels, complete with units, and a figure legend. Attach both of your graphs and your tables of output from LINEST to your report. Perform this analysis for both strings.

3. Show one representative sample calculation of either μ in the box below.

sample calculation, not done using Excel (Example for μ_1, 80-lb-test line with 0.150kg)

$$\mu = \frac{mg}{(f\lambda)^2} = \frac{(0.150\,kg)(9.80\,m/s^2)}{\left[\left(40.610\,\frac{rads}{s}\right)(1.135m)\right]^2} = 6.92\times10^{-4}\,\frac{(kg)(s^2)(m)}{(s^2)(m^2)}$$

$$= 6.92\times10^{-4}\ kg/m$$

Results

80-lb-test	μ_1 = (6.98×10^{-4} +/- 0.03×10^{-4})kg/m % error = 1% σ_1 = +/- 3.41×10^{-6} kg/m
50-lb-test	μ_2 = (4.51×10^{-4} +/- 0.10×10^{-4})kg/m % error = 3% σ_2 = +/- 1.35×10^{-5} kg/m

Discussion of Results and Errors

In the box below, discuss the potential sources of error in this experiment. Estimate the +/- uncertainty in each of the types of measurments you made. Regarding your two graphs ("charts"), answer the following questions:

- Is the slope of the line consistent with a horizontal line to within the uncertainties?
- Is the y-intercept consistent with the average value to within the uncertainties?

Can you suggest any modifications to the experiment to improve the results? Mention one or more practical applications for the techniques used in this lab.

Overall, the experiment went as expected, yielding final experimental results which were relatively close to the theoretical values. The estimated uncertainties of mass 'm', frequency 'F', and wavelength 'λ' are ±0.001 kg, ±0.001 Hz, and ±0.001 meters respectively. The percent descrepancy, calculated as follows: $\% = \left|\frac{\mu_{accept} - \mu_{exp.}}{\mu_{accept}}\right|$ yields a 2% descrepancy for μ_1 (80-lb-test line), and 4% descrepancy for μ_2 (50-lb-test line). Unfortunately, these descrepancies are greater than their respective calculated percent errors by a factor of 1% each. This disagreement most likely comes from slight variations of error which were either not taken into account or underestimated. These potential sources of error include incorrect frequency while trying to find the wave's max amplitude, poor measurement of wavelength based upon a suspended, vibrating string, any movement from the mass which would vary tension, and any additional friction from within the system such as the pulley.

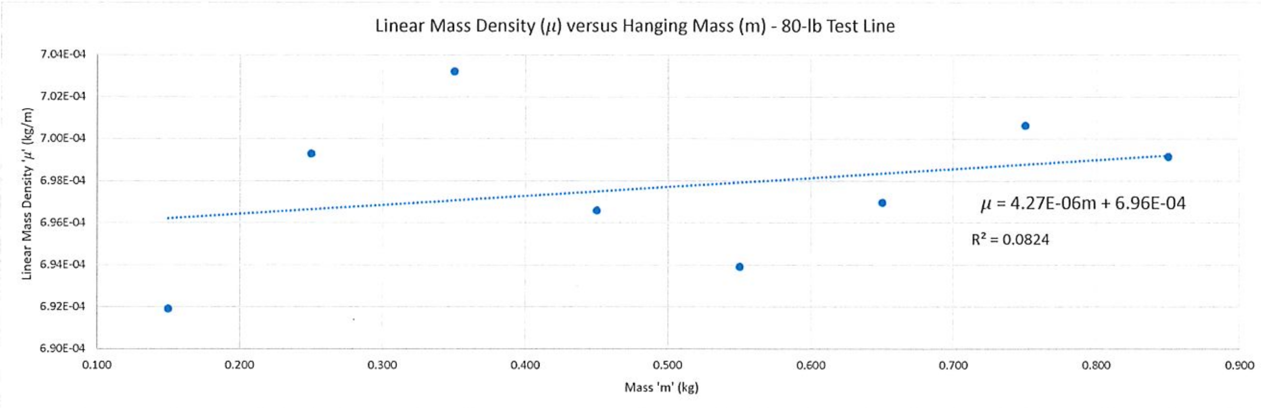
Comparing the graphical equations with the experimental results, the y-intercept for both μ_1 and μ_2 are consistent with the calculated averages each being off by a factor no greater than 1% for μ_1 and μ_2. The graphical slopes are overall consistent, μ_2's slope being within uncertainty range. μ_1's slope is out of its uncertainty range by 33%! This is likely due to the few data points which are outliers and the already mentioned sources of error.

Improvements could be made to the experiment to help better pinpoint maximum amplitude, thus giving better frequency results. Perhaps this could be done by using a light to cast a shadow of the vibrating string onto a white surface, thus enabling easier recognition of amplitude growth.

Melde's experiment can be used to find the linear mass density of various objects and their fundamental frequencies. Knowing this frequency, devices such as noise cancelers can be created.

String Type	Mass 'm' (kg)	Frequency 'f' (Hz)	Wavelength 'λ' (meters)	Linear Mass Density 'μ' (kg/m) $\mu = \frac{mg}{(f\lambda)^2}$
80-lb test	0.150	40.610	1.135	6.92E-04
	0.250	52.150	1.135	6.99E-04
	0.350	61.805	1.130	7.03E-04
	0.450	70.102	1.135	6.97E-04
	0.550	77.650	1.135	6.94E-04
	0.650	84.230	1.135	6.97E-04
	0.750	90.240	1.135	7.01E-04
	0.850	96.170	1.135	6.99E-04

"=AVERAGE(E2:E9)"	Average:	**6.98E-04**
"=AVEDEV(E2:E9)"	Average Deviation:	**2.86E-06**
"=STDEV.P(E2:E9)"	Standard Deviation:	**3.41E-06**
	LINEST	
"=LINEST(E2:E9,B2:B9)"	(Best Fit Line Slope):	**4.27E-06**
	(Best Fit line Y-Intercept):	**6.96E-04**



String Type	Mass 'm' (kg)	Frequency 'f' (Hz)	Wavelength 'λ' (meters)	Linear Mass Density 'μ' (kg/m) $\mu = \frac{mg}{(f\lambda)^2}$
50-lb test	0.150	48.820	1.135	4.79E-04
	0.250	66.680	1.135	4.28E-04
	0.350	77.760	1.135	4.40E-04
	0.450	87.545	1.135	4.47E-04
	0.550	96.302	1.135	4.51E-04
	0.650	104.60	1.135	4.52E-04
	0.750	112.20	1.135	4.53E-04
	0.850	119.20	1.135	4.55E-04

"=AVERAGE(E47:E54)"	Average:	**4.51E-04**
"=AVEDEV(E47:E54)"	Average Deviation:	**9.28E-06**
"=STDEV.P(E47:E54)"	Standard Deviation:	**1.35E-05**
	LINEST	
"=LINEST(E47:E54,B47:B54)"	(Best Fit Line Slope):	**1.10E-07**
	(Best Fit line Y-Intercept):	**4.51E-04**