Speed of Sound in metal

The principles outlined above can be applied, also, to determine the speed of sound in a metal. Suitable apparatus for this purpose is illustrated in Figure 1. Longitudinal standing waves are formed in the metal bar, by striking one end of the bar with a mallet.

With the bar clamped at its mid-point a node forms there while antinodes form at the free ends, as indicated in Figure 1. If the bar is vibrating in its fundamental mode, then the wavelength of the wave in the metal is equal to twice the length of the bar, \( \lambda = 2L \). If the frequency of the waves can be determined, equation [2] can be used to calculate the speed of the sound wave in the metal.

The vibrating end of the bar produces sound waves in air with a frequency identical to that, at which the bar is vibrating, i.e.,

\[
f_m = f_a \tag{1}
\]

where \( f_a \) is the frequency of the sound waves in air. Thus, by measuring \( f_a \) one can determine \( f_m \) and, thus, calculate the speed of the sound wave in the metal bar from equation [2].

\[
v_m = \frac{\lambda}{f_m} \tag{2}
\]

where \( v_m, \lambda_m, \) and \( f_m \) are the speed, wavelength and frequency of the sound waves in the metal.

For the experiment, a sound sensor is used to collect the sound waves at the end of the metal bar. The computer uses a Fast Fourier Transform technique (FFT) to convert the sound waves to a spectrum of amplitude vs. frequency. With the rod or bar is clamped in the center and struck along its end it will produce a fundamental frequency and this frequency will be displayed along with some of it harmonics in the spectrum window, the largest peak amplitude is the fundamental frequency of the rod or bar. Using this frequency in conjunction with the wavelength (twice the length of the bar/rod) and equation [3] the speed of sound in the bar or rod can be determine. Theoretically, the speed of sound in metal can be calculated from the equation

\[
v_{\text{Theory}} = \sqrt{\frac{Y}{\rho}} \tag{3}
\]

where \( Y \) is the Young’s elastic modulus of the metal and \( \rho \) is the density of the metal.
Procedure

Speed of Sound in Metal

1. □ Close the current file and open the file speed of sound in metal.

Bar/rod Measurements
   You are to perform the experiment with both the metal rod and metal bar.
2. □ Acquire a metal bar or rod and measure its mass.
   □ Use the meter stick and measure and record the length in meters.
   □ Use the vernier calipers and measure the other dimension(s).
   □ Calculate and record the volume. It will be a small value use scientific notation and 3 decimal places.
   □ Calculate and record the density, \( \rho \).

A practice run
3. □ Locate where along the bar or rod length is the midway point. Firmly grasp the bar/rod at this point with your thumb and index finger.
   □ Holding it thusly use the metal striker to strike the end longitudinally sending a compression wave down the length of the bar/rod. A clear ringing tone should be heard.
   □ Grasping the bar to in your hand will cease the ringing.

Measuring the frequency of the tone
4. □ Located on the table is a sound sensor this will be held near the end of the bar/rod to acquire the tone emitted from the end of the bar/rod. Assign a lab partner to this task.
   □ As in step 3 hold the bar/rod between your thumb and index finger.
   □ Have a lab partner select Start from the experiment ToolBar. And the partner assigned to the sound sensor will hold it near the bar/rod end.
   □ Strike the bar/rod as you did in the practice run. A sharp pulse will appear in the graph display on the computer screen. Select Stop when this pulse appears.

5. □ From the Graph ToolBar Select the Smart Tool.
   □ Position the Smart tool so that the vertical line bisects the pulse. The \((x,y)\) values displayed relates to \((frequency, intensity)\).
   □ Record the frequency as \(f_m\) into the data table.

6. Determine the measured velocity and its uncertainty from the equations below.

\[
v_m = \lambda_m f_m
\]

7. Use equation [3] and the calculated value for density of the metal, \( \rho \), to determine the theoretical value of velocity \( v_T \) and also its uncertainty.
8. Repeat the experiment using the other form.
### Data Sheet 1

#### Table 1

<table>
<thead>
<tr>
<th>Bar</th>
<th>Material</th>
<th>Volume, $V = lwh$</th>
<th>Rod</th>
<th>Material</th>
<th>Volume, $V = \pi r^2 l$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length, $l$</td>
<td></td>
<td></td>
<td>Length, $l$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width, $w$</td>
<td></td>
<td></td>
<td>Diameter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height, $h$</td>
<td></td>
<td></td>
<td>Radius, $r$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume, $V$</td>
<td></td>
<td></td>
<td>Volume, $V$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass, $m$ in kg</td>
<td></td>
<td></td>
<td>Mass, $m$ in kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density $\rho = m/V$</td>
<td></td>
<td></td>
<td>Density $\rho = m/V$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\lambda_m = 2 \times$ Length</td>
<td></td>
<td></td>
<td>$\lambda_m = 2 \times$ Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency $f_m$</td>
<td></td>
<td></td>
<td>Frequency $f_m$</td>
<td></td>
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</tr>
<tr>
<td>Velocity $v_m$</td>
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<td>Velocity $v_m$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Youngs Modulus $Y$</td>
<td></td>
<td>$7.1 \times 10^9$</td>
<td>Youngs Modulus $Y$</td>
<td></td>
<td>$7.5 \times 10^9$</td>
</tr>
<tr>
<td>Velocity $v_c$</td>
<td></td>
<td></td>
<td>Velocity $v_c$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Determine the percent difference for the calculated value for the speed of sound in the metal to the measured value?