Summative Lab

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Abstract

The aim of this experiement was to determine the Young's modulus of a "ruler shaped" material to decide if it would be a suitable replacement for an ambulance's suspension. The method was to use a microphone to record the sound from the oscillations of the ruler while it was overhung over a ledge and struck in order to find the fundamental frequency of the ruler for a given legth and use this to calculate the Young's modulus. As a result, the Young's modulus was found to be 175GPa and in conclusion, this was a suitable replacement.

1. Introduction

A material with a Young's modulus close to that of stainless steel was needed to replace a piece of an ambulance's suspension after it was damaged in a disaster relief situation. The aim of this experiment was to determine the Young's Modulus of a "ruler shaped piece of material" in order to repair its suspension. The motivation behind finding the Young's Modulus of a material is due to the fact that this will predict the behavior of the material when subjected to a force and how easily it stretches and deforms.(Univeristy of Birmingham, no date) Therefore, the Young's Modulus will determine whether or not the material is suitable replacement.

2. Methods

2.1. Circuit

Firstly, the circuit below (Fig 1) was built on a breadboard in order convert sounds received by a microphone to a signal which a RasberryPi Pico microcontroller converts to data output in a .csv file.

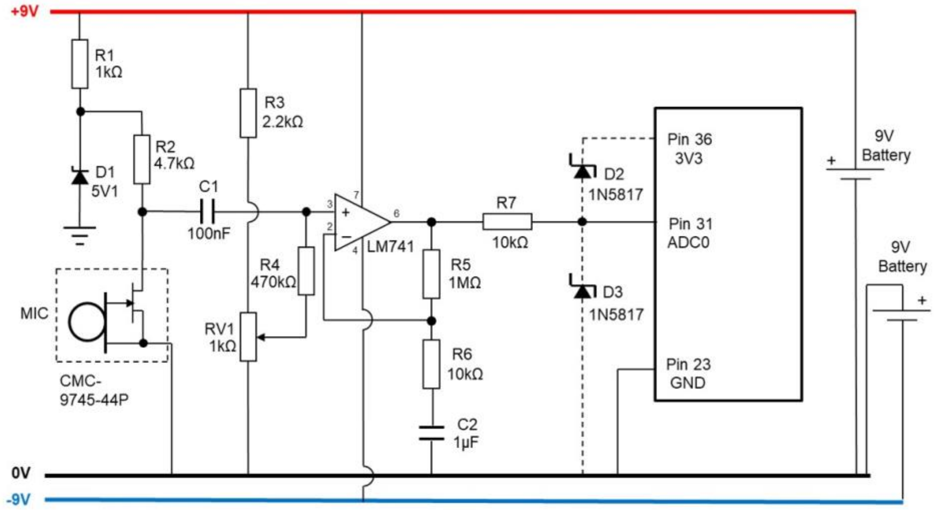

Figure 1, circuit design by Lindsay Clare, University of Bristol

2.2. Experiment Set up

Next, the below set up (Fig 2&3) was built consisting of the "ruler shaped material" with the desired free overhang length (measured with a ruler) overhung over the edge of the table. A book and a heavy object were placed on top of the ruler in order to ensure only the overhang end vibrated and taped down in order to ensure no movement occurred. The breadboard containing the circuit was placed on an elevated platform with the microphone directly below the ruler so that the microphone could pick up the sound.

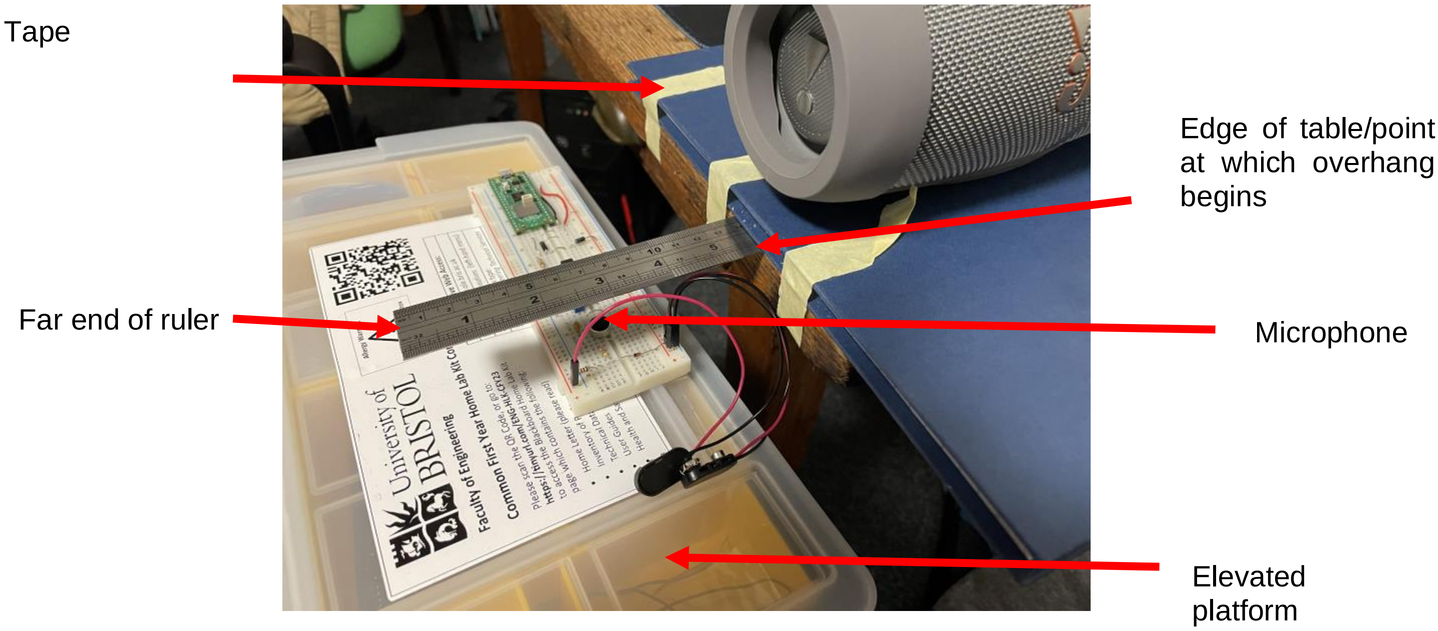

Figure 2, Experimental setup for a 14cm overhang

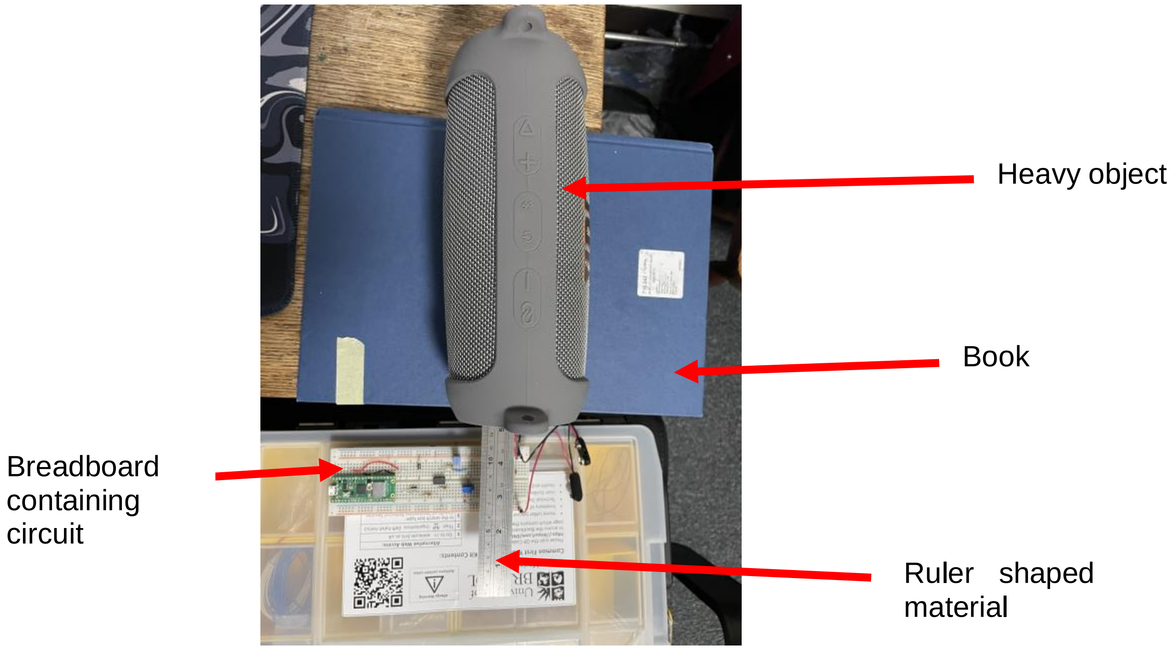

Figure 3, Top view of experimental setup

The batteries where then connected to the circuit to give it power and the microcontroller was connected to a laptop in order to record the data.

2.3. Data recording

The data.py code was ran on Thonny while the far end of the ruler was flicked down. This caused the ruler to “twang” and vibrate which produced a noise. This noise was recorded by the microphone and logged using the data.py code. Once the ruler finishd vibrating, this processed was repeated an additional 2 times. Once this was completed, the whole process was repeated for 2 other overhang lengths.

2.4. Additional Measurements

The height and base width of the ruler shaped material were measured using vernier calipers since these values were needed to determine the Young's Modulus.

3. Results

The following equation was rearranged and used to find the Young's Modulus:

$$f = 0.56\sqrt{\frac{EI}{qL^4}} \tag{1}$$

$$E = \left(\frac{f}{0.56}\right)^2 \frac{qL^4}{I} \tag{2}$$

where, f is the fundamental frequency, E is the Young's Modulus, I is the second moment of area, q is the mass per unit length, L the free overhang length of the "ruler shaped" material.

The mass per unit length (q) was found using the following equation:

$$q = \rho A \tag{3}$$

where ρ is the density of the material, taken to be approximately that of stainless steel so 8030kg/m^3 (Acestainless, no date) and A is the cross sectional area of the "ruler shaped" material which was calculated using equation 4 to be 17.57mm^2.

$$A = bh \tag{4}$$

where b is the base width of the ruler found to be 25.1mm and h is the height of the ruler found to be 0.7mm.

The second moment of area (I) was found to be 0.717mm^4 using the following equation:

$$I = \frac{bh^3}{12} \tag{5}$$

The fundamental frequency (f) was found using the data collected previously. The raw data of each test of each length was cropped starting at the highest recorded amplitude and ending after 0.5s since that is where sound from the ruler was significantly large. Then a low-pass Butterworth filter was applied to limit the effect of background noise on the signal. The cut-off frequency was selected by trial and error to line up smoothly over the unfiltered data. An oscillation was seen in the graph below (Fig 4) which meant the circuit was working as anticipated.

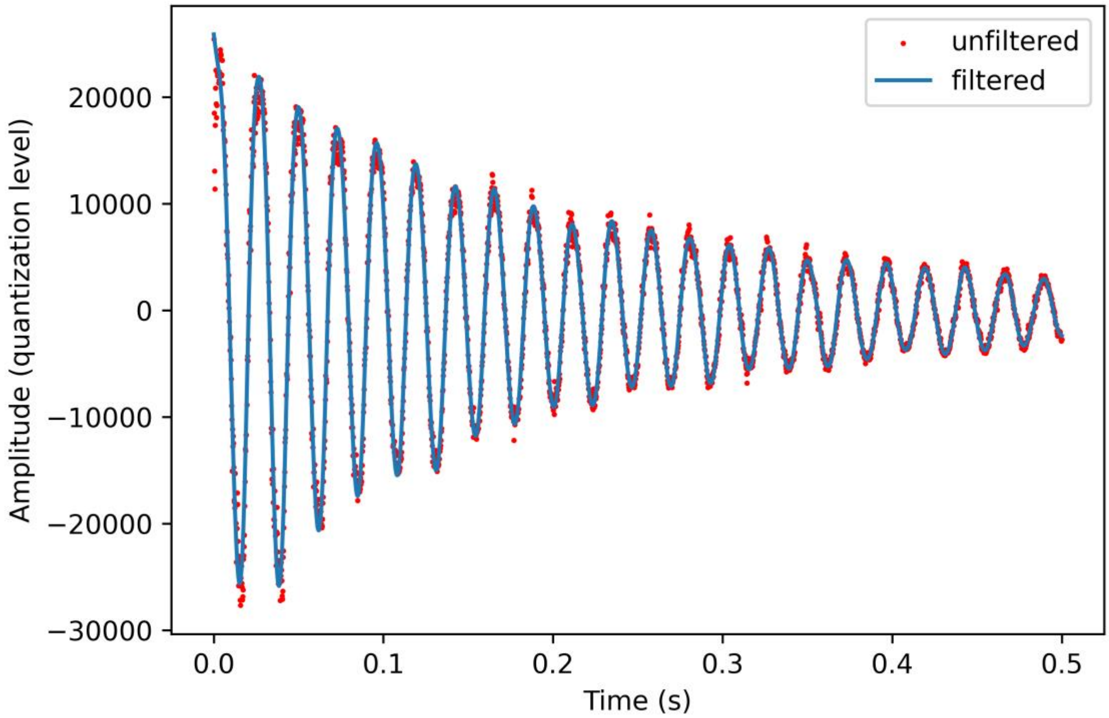

Figure 4, showing the unfiltered data (red) and filtered data (blue) for an 11cm overhang legth

The filtered data graph was the used to find the fundamental frequency (f) through the following equation:

$$f = \frac{n}{2t} \tag{6}$$

where n is the number of times the signal crosses the x-axis and t is the sampling period.

The Young's modulus was finally found by taking the average of each test of each length, the results of which were summarized in the table below (Table 1).

Table 1, the results found from the experiment

Overhang Length (L) [m]	Fundamental Frequency (F) [Hz]	Young's Modulus (E) [GPa]
0.11	43.0	170
0.11	43.0	170
0.11	43.0	170
0.13	31.0	172
0.13	31.0	172
0.13	31.0	172
0.15	24.0	183
0.15	24.0	183
0.15	24.0	183

The Young's modulus of the "ruler shaped" piece of material was found to be 175GPa.

4. Discussion

The Young's modulus of the "ruler shaped" piece of material was found to be 175GPa. The material needed a Young's modulus similar to that of stainless steel, which is 190GPa according to azo materials.(AZO materials, 2024) The value found experimentally was within 8% of the suitable value, hence it would be a suitable material. This slight error may have been the result of noise in the signal since not all the noise could be perfectly filtered. Another source of error could have been due to some small vibrations travelling all the way up the legth of the ruler, changing the frequency of the oscillation and causing different damping than expected. This could be minimized in later experiments by welding the ruler down and making sure the part not overhanging cannot move at all. Another source of error could be the assumption of taking the density of that of steel. This could have been an incorrect assumptions, hence giving an innacurate result. An additional experiement with the goal of finding the density of the ruler could be done in order to eliminate this potential error. Another potential source of error could have been air resistance affecting the frequency of the oscillation, slowing the ruler down as it twanged.

5. Conclusion

This experiment was conducted to determine the eligibility of a material as a replacement for an ambulance part. A series of recordings were taken in order to find the fundamental frequency of a "ruler shaped" piece of this material. The data was filtered and processed to finally give a value for the Young's modulus. A number of possible sources of error were identified and potential improvements were given. In conclusion, the Young's modulus of the "ruler shaped" piece of material was found to be 175GPa and this was deemed a suitable replacement for the ambulance's suspension as it is within 8% of the value for stainless steel.

References

University of Birmingham (no date) Physics A level revision resource: Introduction to young's modulus, University of Birmingham. Available at: https://www.birmingham.ac.uk/study/undergraduate/schools-and-colleges/post-16/a-level-stem-resources/youngs-modulus#:~:text=The%20Young's%20modulus%20of%20a%20material%20is%20a%20useful%20property,bridges%20to%20vehicles%20and%20more. (Accessed: 21 April 2024).

The Density of Stainless Steel: Everything You Must Know (no date) Acestainless.com. Available at: https://www.acestainless.com/blog-4-density-of-stainless-steel#:~:text=Depending%20on%20the%20specific%20alloy%2C%20the%20density%20of%20stainless%20steel,of%20its%20strong%20heat%20resistance (Accessed: 21 April 2024). Properties: Stainless steel - grade 304 (UNS S30400) (2024) AZoM. Available at: https://www.azom.com/properties.aspx?ArticleID=965 (Accessed: 21 April 2024).

Properties: Stainless steel - grade 304 (UNS S30400) (2024a) AZoM. Available at: https://www.azom.com/properties.aspx?ArticleID=965 (Accessed: 27 April 2024).