INTERNATIONAL BACCALAUREATE DIPLOMA PROGRAME
PHYSICS (HL) EXTENDED ESSAY

# Investigation of the effect of width of guitar string on the sound output frequency

MAY 2018

WORD COUNT: 2667

Aim of this experiment: Aim of this experiment is to find out that how does width of the string affects the frequency output of that string in hertz.

Background Info:

I play guitar as my hobby in my free times to release some stress or form enjoyment. On the guitar there are 6 strings in total (there might be more than that, but usually guitar have 6 strings). First three strings and last three strings are made of same material, but with different widths. So that all strings produce different amounts of frequency in hertz and I got curious about this as I played the guitar more and more. We can calculate a strings frequency by its vibration and standing wave(s) on it. On guitar there is only one standing wave as its both ends are closed and force is implied from only one point. Then I design an experiment about string and frequency output and I fixed one end of the string to my system and put weight to the other end.

What is standing waves?

Standing wave, also called stationary wave, combination of two waves moving in opposite directions, each having the same amplitude and frequency. The phenomenon is the result of interference—that is, when waves are superimposed, their energies are either added together or cancelled out. In the case of waves moving in the same direction, interference produces a travelling wave; for oppositely moving waves, interference produces an oscillating wave fixed in space.[1]

What is resonance?

Resonance, An object free to vibrate tends to do so at a specific rate called the object's natural, or resonant, frequency. (This frequency depends on the size, shape, and composition of the object.) Such an object will vibrate strongly when it is subjected to vibrations or regular impulses at a frequency equal to or very close to its natural frequency. This phenomenon is called resonance. Through resonance, a

1

comparatively weak vibration in one object can cause a strong vibration in another. By analogy, the term resonance is also used to describe the phenomenon by which an oscillating electric current is strengthened by an electric signal of a specific frequency.[2]

What is acoustic resonator?

Resonators help out to produce frequency. Acoustic resonators are found in musical instruments. A device consisting of a combination of elements having mass and compliance whose acoustical reactance s cancel at agiven frequency. Resonators are often used as a means of eliminating an undesirable frequenc y component in an acousticalsystem. In other instances resonators are used to produce an increase in the s ound pressure in an acoustic field at aparticular frequency.Resonators are useful most often in the control of low frequency sound. They are of particular value in reducing the noise from sources having constant frequency excitation.[3]

Lab Quest 2 and devices which are used in this experiment:

Vernier Lab Quest 2 is a standalone interface used to collect sensor data with its built-in graphing and analysis application. The large, high-resolution touch screen makes it easy and intuitive to collect, analyse, and share data from experiments. Its wireless connectivity encourages collaboration and personalized learning. You can also use Lab Quest 2 as a USB sensor interface using Logger Pro software or with our Graphical Analysis app for iOS, Android, or Chrome to stream data wirelessly to one or more mobile devices.[4]

2

3

4

Microphone:

- Frequency Range: approximately 100 Hz to 15 kHz
- Typical Maximum Frequency: 10,000 Hz
- Power: 1.45 mA @ 5 VDC[5]

Research Question: How does the width of the string affect its frequency output in hertz?

Hypothesis: As the width of the string increases, the frequency which is produced by string also increases.

Materials:

1. 12 strings which are made from same material and each string has a different width from each other. (I used steel strings with copper wiring around them.)
2. L shaped wooden system with a stationary pulled which is fixed to the end of the L shaped system.
3. 1.5 kilograms of weight to put to the each string so tension over the string will be same.
4. Lab Quest 2, Microphone and Dynamometer device of Lab Quest 2.
5. A pick to imply force upon the string.
6. A pulley (to fixate at the end of the L shaped system.)
7. A power drill (to open a hole on the L shaped wooden system.)

5

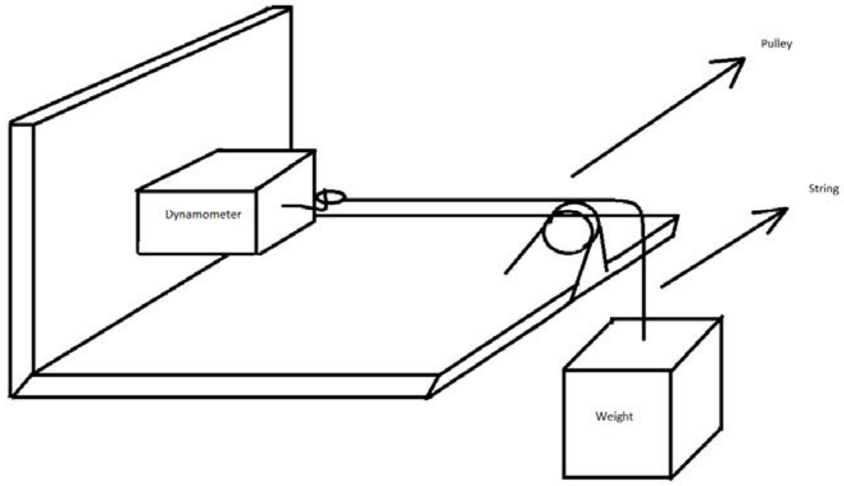



Figure 1: Experiment set up

Variables:

Independent Variable:

I changed the width of the steel string with copper wiring around and looked to the frequency output of the steel strings with copper wiring around with different widths

Dependent Variable:

Frequency output of the steel string with copper wiring around in hertz is change throughout the experiment as it is dependent of the width of the steel string with copper wiring around and it is changed during the experiment.

Controlled Variable:

Wind in the experiment room:

All doors and windows of the experiment room is closed so there is no wind or air circulation in the experiment room. If wind in the experiment room is not controlled, frequency output of the string might change.

Air friction applied to the steel string with copper wiring around:

Experiment is done in the same place and all doors and windows are closed so air friction applied to each string is equal. If the air friction is not controlled, frequency output of the steel string with copper wiring around might change as now all the strings have a different forces of air friction they need to resist while producing frequency.

Force implied on the steel string with copper wiring around:

Steel string with copper wiring around is always pulled to the same distance and released from that place so the force implied on the steel string with copper wiring around is always same. If the force implied on the steel string with copper, frequency output of the strings will change as they vibrate more or less.

Material of the steel string with copper wiring around:

All strings are made up from steel and wired around with copper. If strings with copper wiring around are made from different materials, their frequency output will change as its timbre will change.

Length of the steel string with copper wiring around:

All strings are cut to the same length before used in the experiment. If the length of the steel string with copper wiring around is not controlled, its frequency output will change as same amount of force is implied on a shorter or longer string.

The object which implied force over the steel string with copper wiring around:

I always used the same object (the pick) to pull the string throughout the experiment. If the object changed throughout the experiment, the frequency output of the string might change as everything has different elasticity and can transfer force differently.

Uncontrolled Variables:

Temperature of the surrounding:

As the temperature of the experiment room is changed accordingly to the weather conditions, it is not controlled during the experiment process.

Noise of the surrounding:

In the experiment area there is a fixed sound and it is not controlled as it dependent on the surroundings.

Method:

1. L shaped wooden system is made by a carpenter.
2. A puller is added to the end of the L shaped wooden system for hanging steel strings with copper wiring around down.
3. A hole is opened by a power drill on the L shaped wooden system for putting dynamometer which will hold the steel string with copper wiring around parallel to the L shaped wooden system's ground.
4. Dynamometer device is fixated in the hole which is opened by a power drill.
5. Dynamometer device is connected with Lab Quest 2.
6. Steel string with copper wiring around is tied to the dynamometer.
7. The steel string with copper wiring around is hanged down from the pulley.
8. 1.5 kilograms of weight is fixated to the other end of the steel string with copper wiring around.
9. 15 newton are measured by the Lab Quest 2 via dynamometer device.
10. Microphone device is connected to Lab Quest 2 for measuring frequency output of the steel string with copper wiring around.
11. Each string is hit with the pick 5 times and each hit's frequency output, which is measured by Lab Quest 2 via microphone device, is noted down to a paper.
12. String is changed with another unused string.
13. Process is repeated.
14. Average of these 5 frequency output value is used for the data.

Data Analysis:

In the table below, Table 5: Raw data table, you can see all my data which I got through out in the experiment. Average of 5 trials are used in the graph for the most accurate and precise graph.

Uncertainty of the frequency is calculated by;

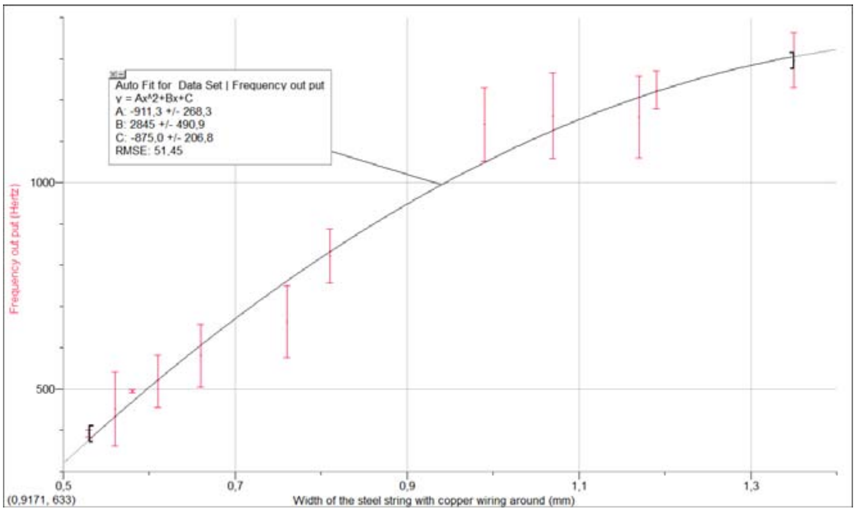
$$[\,Max(frequency) - Min(frequency)\,]/2$$

Maximum frequency and minimum frequency is taken from the 5 trials of the steel string with copper wiring around with the same width. Uncertainty for the steel strings copper wiring around were not given on their packaging, so I did not use any uncertainty for the width of the steel string with copper wiring around.

| Width of the steel string with copper wiring around | | 0.53 | 0. 56 | 0.58 | 0.61 | 0.66 | 0.76 | 0.81 | 0.99 | 1.07 | 1.17 | 1.19 | 1.35 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency output of the steel string with copper wiring around | Trial 1 | 394 | 464 | 496 | 459 | 480 | 595 | 780 | 1079 | 1135 | 1148 | 1195 | 1257 |
| | Trial 2 | 394 | 357 | 495 | 484 | 632 | 770 | 827 | 1169 | 1253 | 1259 | 1225 | 1249 |
| | Trial 3 | 381 | 463 | 492 | 585 | 631 | 662 | 899 | 1139 | 1275 | 1160 | 1225 | 1373 |
| | Trial 4 | 394 | 438 | 490 | 578 | 612 | 627 | 770 | 1072 | 1068 | 1168 | 1237 | 1241 |
| | Trial 5 | 398 | 536 | 498 | 489 | 548 | 663 | 836 | 1251 | 1078 | 1061 | 1240 | 1363 |
| | Average of 5 trials | 392.2 | 451.6 | 494.2 | 519.0 | 580.6 | 663.4 | 822.4 | 1142.0 | 1161.8 | 1159.2 | 1224.4 | 1296.6 |
| Uncertainty | | ±8.5 | ±89.5 | ±4 | ±63 | ±76 | ±87.5 | ±64.5 | ±89.5 | ±103.5 | ±99 | ±46 | ±66 |

Table 1: Raw data table. The variation of frequency output of the steel string with copper wiring around depending on its width.

In the graph below, Graph 1, averages of the 5 trials are used for most accurate and precise outcome.

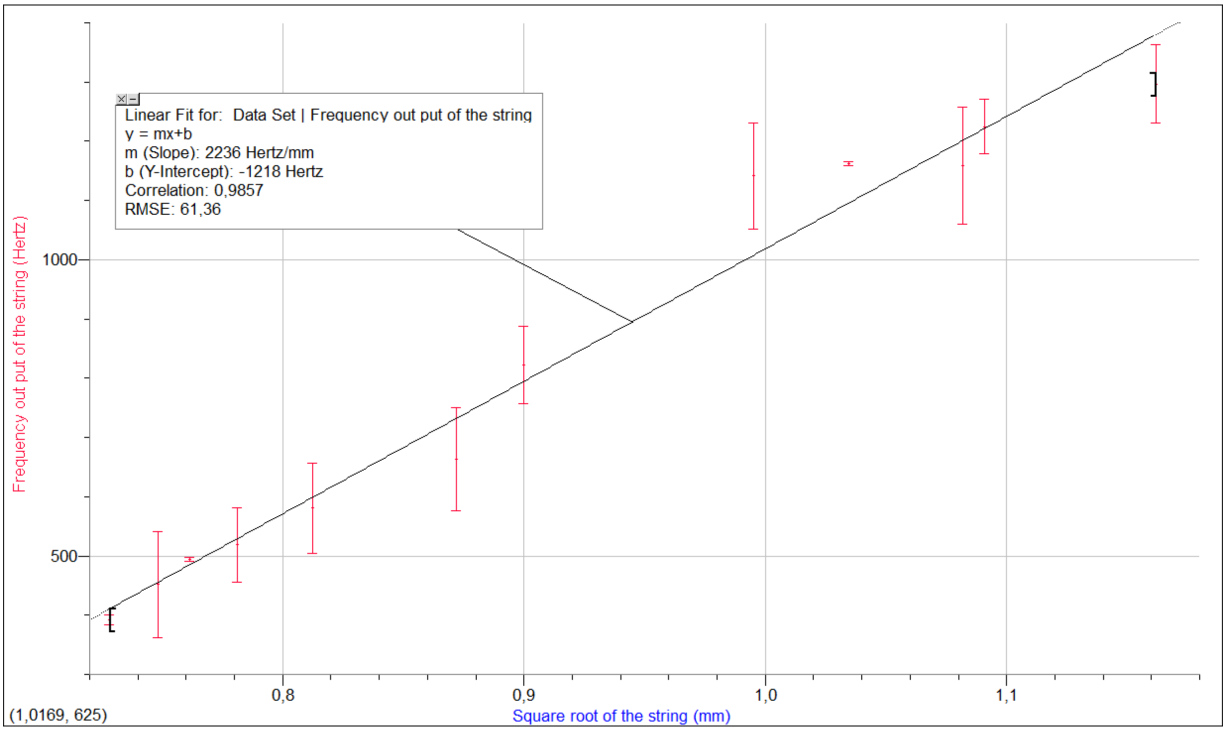



Graph 1: Graph of the variation of frequency output of the steel string with copper wiring around depending on its width.

In the graph above, Graph 1, frequency output of the steel string with copper wiring around increases while width of the steel string with copper wiring around increases. However increase speed of the frequency output of the steel string with copper wiring around decreases gradually. The rule of the frequency output of the steel string with copper wiring is connected to the square of the width of the steel string with copper wiring around. So for finding how the frequency output of the steel string with copper wiring around directly connected to the width of the steel string with copper wiring around, we should use square root of the width of the steel string with copper wiring around for the graph. And in the end we will find a linear graph.

| Square root of the width of the steel string with copper wiring around ( mm ) | Frequency output of the steel string with copper wiring around ( Hertz ) |
|---|---|
| 0.728 | 392.2 ± 8.5 |
| 0.748 | 451.6 ± 89.5 |
| 0.762 | 494.2 ± 4 |
| 0.781 | 519.0 ± 63 |
| 0.812 | 580.6 ± 76 |
| 0.872 | 663.4 ± 87.5 |
| 0.900 | 822.4 ± 64.5 |
| 0.995 | 1142.0 ± 89.5 |
| 1.034 | 1161.8 ± 103.5 |
| 1.082 | 1159.2 ± 99 |
| 1.091 | 1224.4 ± 46 |
| 1.162 | 1296.6 ± 66 |

Table 2: The variation of frequency output of the steel string with copper wiring around depending on its width's square root.




Graph 2: Graph of the variation of frequency output of the steel string with copper wiring around depending on its width's square root.

As I took square root of the X axis, width of the steel string with copper wiring around, the graph became linear. So that I can see how width and frequency output of the steel string with copper wiring around affects each other. The equation for the linear graph is;

$$y = mx + b$$

Y = Frequency output of the steel string with copper wiring around.

X = Square root of the width of the steel string with copper wiring around.

M = Slope of my graph. In this situation it is equal to 2236 ± 121.0 Hertz/mm.

B = Y – Intercept of the graph. In this situation it is equal to -1218 ± 112.0 Hertz.

So in the end my equation is;

$$f = 2236\sqrt[2]{d} - 1218$$

f = Frequency output of the steel string with copper wiring around.

d = Width of the steel string with copper wiring around.

Conclusion:

In the end of the experiment I learned that I could calculate the frequency output of the steel string with copper wiring around it according to its width's square root. As a result, I can now change my guitars strings according to the frequency needed for the best sound and experience for the song which I will play next because I can calculate the strings' frequency output. This experiment helped me to understand and learn how to do a proper experiment which includes using a lot of different devices, building some systems, doing a lot of trials for better accuracy and working hard for accomplish one thing. I also learned how to use Vernier Lab Quest 2, microphone and dynamometer device and setting up a quiet environment. Setting up a quiet environment form y experiment was very crucial as it could affect my experiment results and data completely.

In my experiment there is experimental error. The cause of this experimental error might be systematic error or random error or both. As systematic errors: there might  be malfunction in the Vernier's microphone device which is the equipment that I got my all data from, there might be malfunction in Vernier's Lab Quest 2 device which gave me wrong data occasionally or always, steel strings with copper wiring around might be cut a lot different in diameter which will cause a change in my data and equation as that equation is correct according to these variables and a change in a single variable will change the equation as well. As random errors: the carpenter who made the main L shaped wooden figure for the experiment might not drilled the hole in the right place so that when I put my dynamometer and string with copper wiring around and hang it from the pulley at the other end of the wooden figure, the string is not parallel to the surface of the wooden figure and got a little angle between them so my data might change, I might not pulled the string all the way to the surface in some trials so the force applied on the steel string with copper wiring around change with its frequency output, I might read wrong while looking to the Vernier's Lab Quest 2 device which ended up with the wrong data noted down to the paper.

To decrease my systematic error I could use more high quality materials. As better microphone, L shaped system and more steel strings with copper wiring around. However, that was all I got in my hands so this is the result for this experiment. For decreasing random error, I could have paid more attention to pull the steel strings with copper wiring around with the pick, drilling the hole in a better stop so the steel string with copper wiring could be parallel to the surface of the L shaped wooden system and read and checked the data a few times before going to the next steel string with copper wiring around.

Limitations of my experiment was that I only used 12 strings which are only different in width, but I could use more strings or searched for how different materials affects the frequency output of the string as there are not only steel strings with copper wiring around for guitars.

Bibliography:


1. https://www.britannica.com/science/standing-wave-physics

2. https://science.howstuffworks.com/resonance-info.htm

3. https://encyclopedia2.thefreedictionary.com/Acoustic+Resonator

4. https://www.vernier.com/products/interfaces/labq2/

5. https://www.vernier.com/products/sensors/mca-bta/