The Spring Spring Project:

Designs and Analyses of Springs for the Parker Fly Guitar

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Dedication

I’d like to thank to Professor Levey and Professor Manzo for their guidance and advice in this project. I’d also like to thank Laura Bünger, who created amazing instructions for using ANSYS, and who continued to show up to meetings even while she was busy. Finally, I’d like to thank Dr. Hera, who helped get me started in ANSYS.

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Summary

This project is centered around creating a spring for a very specialized type of guitar. There is currently limited manufacturing of this spring, and the objective of the project overall is to develop a method for manufacturing it. This term of the project focused on improving the spring design and/or making sure that the design we have now is the best. This is the step before going to manufacturing, as the manufacturing process will be difficult to change once complete.

In this term of the project, I designed additional springs that fit the parameters needed to work in the guitar. The designs were then run through ANSYS simulations using multiple materials and compared against each other by both material and design. The best values in each category/design were highlighted and used to determine which was the quantitatively best design. One of the main focuses was stress/strain, as stress values feed into fatigue, which determines how long the spring lasts. Therefore, it’s important to us that stress values are as low as possible.

Finally, we did a lab test using strain gages to confirm our results from ANSYS. We simulated the spring as close to the real-life version as possible, and then took lab results from the same point to see how close the strain values were to each other.

Introduction

This project centers around the spring used in a Parker Fly guitar. While these guitars function exceptionally well, the company that previously distributed the springs that are used in the guitar (part of the reason for their success), went out of business and stopped selling them. This left an obscure but dedicated market open. Eventually, the springs started getting distributed again, but not by the company. Instead, owners of the guitars would buy springs from manufacturers wholesale and sell them to others. Unfortunately, with no central company, these springs can be of questionable quality and origin.

The spring functions in the guitar by holding up the "bridge" of the guitar (the opposite end from the strings) as seen in **Figure 7**: Image of the spring in the guitar, taken by Professor Manzo. The most important function of the spring is to provide resistance for the player as she pushes the bridge forward and backward using a specialized handle, known as a whammy bar. There are two sizes of spring corresponding to the gage of the strings being played. When using 10-gage strings, a 10-gage spring is used. When using 9-gage strings, a 9-gage spring is used. The difference between the 9 and the 10 springs is the force they are designed to hold. The 9 spring is designed for 84.4 pounds of force (lbf), while the 10 spring is designed for 102.5 pounds of force (lbf). The original spring sold by the guitar company was made out of flat stock 1095 annealed and tempered steel coated with zinc nickel and trivalent chromate, as described by the company who originally manufactured them.

Problem Description

At the beginning of this project, there were two main problems to solve. One problem was that owners of the Parker fly guitar had no reliable or central source for springs. This means that you could order springs from two different sellers and get two wildly different products in quality and “feel”. Another problem is that the original spring design eventually wore out, as most springs tend to do. There were even some reports of the spring violently failing in a way that damaged the guitar.

While the overarching goal of this project is to create a reliable source of these springs for guitarists around the world, improving the spring design was the main focus of this term of the project. I needed a spring design that was less likely to break (or took longer to fatigue) and was easier to manufacture than the original. I also set out to compare the new designs of the spring to the original to ensure that I was improving the spring quantitatively. To do this, I focused on stress/strain, which lead to fatigue and eventually failure. As quality assurance, I also needed to get lab results that confirmed the simulation software was working correctly.

Methods

Designs

I designed 12 springs in total, which were grouped into five different series. Series 1 only includes the original spring design, Spring 1A **(Figure 9:** Spring 1A - Original spring design**.** The first design in a series is A and continues down the alphabet for different variations of the original idea. For example, Spring 4C is modeled after Spring 4A with different radii of curves. Both are similar in their overall design. The springs were designed in Solidworks. Each spring was swept along a line using the “Sweep Boss/Base” feature. The profile line was created on a front plane sketch, and the swept feature used the same “stock” dimensions from the originally manufactured spring. Any angles on the line were filleted. All lines on the profile were tangent to each other, meaning everything flowed into the same line without any sharp angles to concentrate stress.

Series 2 was based around a curved design, similar to the leaf springs of some trucks. The intention of the design was to create the most simplistic spring possible to get a “baseline” for other springs. Spring 2A (**Figure 10**: Spring 2A) had both clamped ends of the spring coplanar to each other. Spring 2B (**Figure 11**: Spring 2B) improved on this design by angling the ends, which made the spring more “pre-loaded” to deformation when clamped into the guitar.

Series 3 was based on creating angular springs that are similar to the original design. The intention was to improve the manufacturability of the original. Spring 3A (**Figure 12**: Spring 3A) is similar in shape to Spring 1A but does not overlap at all. This improves on the original, where the tight corners and overlaps make it difficult to press into shape in one step. Spring 3B (**Figure 13**: Spring 3B) takes a different direction and has an alternating pattern. It stands out for not being mirrored between top and bottom: both curves end on the top of the spring. Spring 3C (**Figure 14**) is similar to Spring 3A but increases the radius of the central curve. This is to decrease the possible stress concentration on that central feature. Spring 3D is the same as Spring 3C but increases the radius of the central point (**Figure 15**).

Series 4 was based off Spring 3B, but with a variation in design. In Series 4, the final amplitudes on each end of the spring are opposite each other. The purpose of this change was to decrease the spring's bias of deforming towards one side. Spring 4A (**Figure 16**) starts with radii of curves of 0.025 inches. Spring 4B (**Figure 17**) is the same, but with radii of curves of 0.05 inches. Finally, Spring 4C (**Figure 18**) has radii of curves of 0.075 inches.

Series 5 was based off of Spring 3A, but with a variation in design. In Series 5, the part of the spring which leads up to the central point is curved outwards instead of flat. The purpose of this change was to attempt to encourage the spring to deform over the larger region of the spring, rather than concentrating deformation and stress into corners. Each spring in the series bears the same design, with the only variation being in the radius of the central curve. Spring 5A (**Figure 19**) has a central radius of 0.10 inches, Spring 5B (**Figure 20**) has a central radius of 0.15 inches, and Spring 5C (**Figure 21**) has a central radius of 0.20 inches. These springs are still more manufacturable than Spring 1A.

ANSYS Analyses

The analyses of the springs were done in ANSYS, all using the same method. The methods were taken from the previous group, who created a useful guide to ANSYS. For brevity, the methods described here will assume someone is already somewhat familiar with ANSYS. If you would like more detail, please see the guide.

To start, a static structural analysis was chosen, and a model of the spring was brought into ANSYS through DesignModeler. The units for the model were set to imperial (inches, lbf, etc.). The mesh for the part was created using the default settings. Once the mesh was generated, a force was added to the flat end of the part closest to the origin. The force was set at -84.4 lbf for the original analyses (9-gage spring), though one analysis was increased to -102.5 lbf (10-gage spring). The force direction should be transverse to the spring body, pointing towards the main body. A frictionless support was added to the flat piece of the spring where it is normally clamped in the guitar. The frictionless support was transverse to the spring but was only applied to that face of the part. Finally, a fixed support was added to the other end of the guitar, mirroring the force component. Those were all the constraints applied to the spring. A deformation analysis, a von Mises stress analysis, and a von Mises strain analysis were all added to the experiment. The experiment was loaded, and the maximum, minimum and average values (from deformation, stress and strain) were noted for each analysis.

In ANSYS, the default material is structural steel. To add materials, I assigned a material to the model using a material assignment and then reran the experiment. The two materials I used besides structural steel were 1095 (annealed), and 5160 (hardened and tempered).

One exception to the above methods was the lab simulation test. These “actual” values were done using a 1095 (annealed) assignment with a surface coating of pure zinc. The purpose of this simulation was to get closer to the real strain values of Spring 1A for comparing against lab tests. The pure zinc coating approximated the zinc-nickel coating used on the original, as the proper Zn-Ni alloy properties could not be found.

Another test was done to see how Spring 1A behaved when used on different notches of the guitar clamp. To simulate this in ANSYS, calculations were done to find the components of force on the spring when it was changed from the middle notch (**Figure 8**). The distance from the middle notch to one of the outer notches was measured. From there, the angle was found, and was used to convert the force value into components in ANSYS. Finally, the ANSYS simulation was done using annealed 1095 steel.

Lab Strain Gage Test

List of Materials:

- Two Micro-measurements strain gages (**Figure 22**)
- Superglue (Loctite 4471 was used)
- Scotch tape
- Sharpie
- Wire (26-gage stranded, red)
- Wire (26-gage stranded, black)
- Wire (26-gage stranded, white)
- Solder
- Alcohol prep pad
- Nail polish remover

List of Tools:

- Strain gage testing setup
- Wire strippers
- Ruler
- Soldering iron

The strain gage test in the lab was used to validate the ANSYS simulations. It used two strain gages attached to the guitar by superglue, with individual wires for each strain gage. The strain gages were placed at 2.5 cm and 5.5 cm from the flat edge of the spring, on the centerline of the spring. I took a ruler and marked off the two points, first marking the length for both positions on the spring, then marking the center (width) with a sharpie.

To attach the gages, I first laid a strain gage out on the table, copper sides up (**Figure 23**). Then I took some Scotch tape, folded one end into a handle (**Figure 24**), and pressed it against the strain gage, making sure there were no air bubbles. Next, I took the piece of tape and stuck it onto the spring, lining the strain gage up with the point that I marked earlier. The strain gage should be perpendicular to the spring itself (**Figure 25**). I pushed air bubbles out of the tape, then lifted the folded end of the tape until the entire strain gage was off the surface of the spring. I took some Loctite 4471 (superglue) and put a few drops under the tape near the strain gage (**Figure 26**). I slowly pressed the tape back into place, making sure no air gets trapped inside the tape. Wait for the glue to dry fully before continuing. When the glue is dry, peel the tape back at a sharp angle, almost parallel to the surface of the spring. The strain gage should remain on the spring while the tape is all removed (**Figure 27**). If you accidentally pull off the strain gage, or the tape covers the soldering pads of the strain gage, remove all bits from that attempt and try again (use nail polish remover to dissolve adhesive). Repeat the above steps for the other point in the spring. Before you start into the next section, plug in a soldering iron.

Next, get three different colors of 26-gauge stranded wire and cut 12 inches of each. I recommend using red, black, and white for the colors. Use a wire stripper to strip off one end of each wire. Do not expose more than two millimeters, as you do not want them to short circuit. Twist the black and white wires together. Using an alcohol prep pad to clean the strain gage’s solder pads. Be careful not to use acetone, as that can dissolve the glue’s bond to the spring. Take the wires, now two distinct ends, and carefully lay them over the soldering pads. Make sure you leave enough space between the two. With one finger, hold the wires against the pad and tape the wires into that position. When you remove your finger, they should remain in place. When you’re satisfied with the positioning, take your soldering iron, and solder the wires to the strain gage. Be very careful to not use too much solder, and make sure the two wires do not bridge across and short circuit. If the solder bridges together, use a solder sucker or wick to remove it, and try again. Also make sure you are not holding the soldering iron against the strain gage for too long, as this can damage the sensor. Repeat the above steps with the other strain gage. When you are satisfied with your results, test that the strain gages have a reasonable resistance using a handheld multimeter, as stated on the packaging they came in (usually 120 Ohms). If you are reading infinite resistance, you have a break in your solder and must repeat the soldering. If you are reading zero resistance, you have a short circuit and must repeat the soldering.

The following are the methods I used to measure the strain when the spring was balanced. These methods used LabView software and instruments normally only available in HL 031. It is recommended for future project groups that you use other methods, which are explained in the Discussion section below.

Once I finished attaching the strain gages, I opened the LabView program from ME 3901 for measuring strain gages. I took the other ends of the three wires (from the first strain gage) and attached them to the data acquisition box (DAQ box) using a Wheatstone bridge setup, which amplifies smaller resistance values. I started the software, which measures microstrains and calibrates them. At this time, the spring was still not in the guitar. The bridge of the guitar was being held up by a folded piece of cardboard. From this point, I zeroed the software to what the spring is like at a resting state. Then I inserted the spring into the guitar (removing the cardboard insert first) and adjusted the screw until I could see three threads (about one centimeter). The spring was in the center shelf of the clamp. From there, I tuned the guitar using an electronic tuner. From this point, I was able to read the strain. I recorded the readings from the gage to an Excel file, around 15 seconds. I stopped the recording and saved the results. From there, I removed the spring and repeated the above steps for the other strain gage. This concluded the experiment.

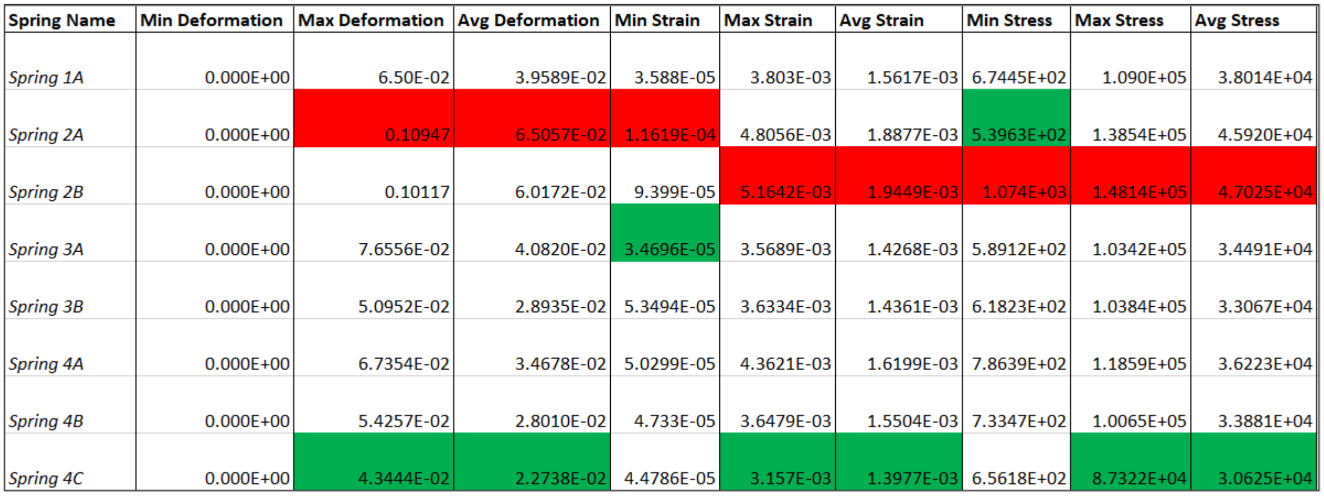
Results and Analysis

ANSYS Simulations

The ANSYS simulations are split into three main sections based on the material used: structural steel, 1095 steel (annealed), or 5160 steel (hardened and tempered). In the tables below, values that are highlighted in red are the highest values in the column, while those highlighted green are the lowest values in their respective columns.

The first set of analyses were done using structural steel. Springs from Series 2 consistently performed the worst (had the highest values), while Spring 4C performed the best in most categories. Interestingly, Spring 2A performed the best when it came to minimum stress despite doing poorly in other columns.

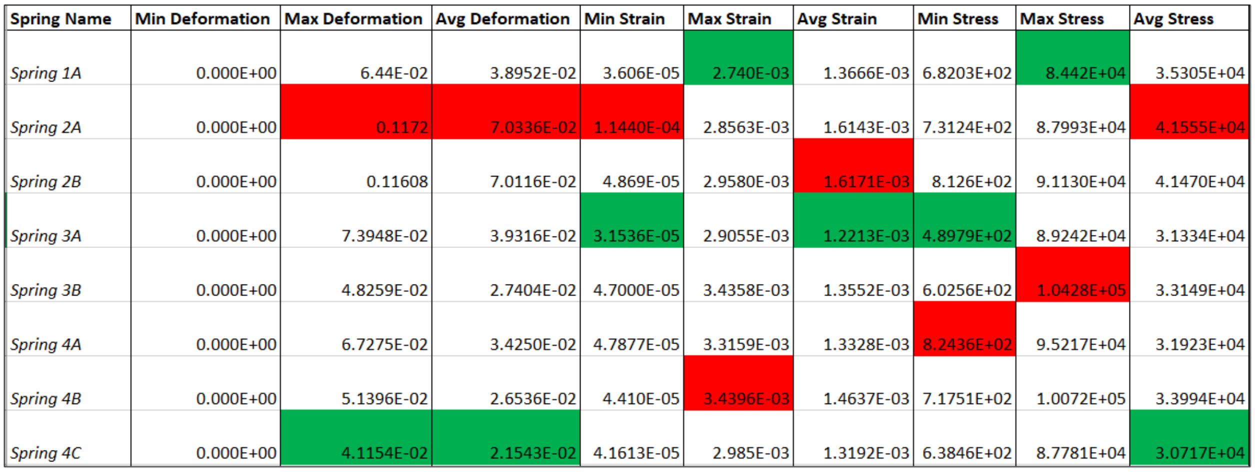
Table 1: Structural Steel Analysis Values for Spring Designs



Spring Name	Min Deformation	Max Deformation	Avg Deformation	Min Strain	Max Strain	Avg Strain	Min Stress	Max Stress	Avg Stress
Spring 1A	0.000E+00	6.50E-02	3.9589E-02	3.588E-05	3.803E-03	1.5617E-03	6.7445E+02	1.090E+05	3.8014E+04
Spring 2A	0.000E+00	0.10947	6.5057E-02	1.1619E-04	4.8056E-03	1.8877E-03	5.3963E+02	1.3854E+05	4.5920E+04
Spring 2B	0.000E+00	0.10117	6.0172E-02	9.399E-05	5.1642E-03	1.9449E-03	1.074E+03	1.4814E+05	4.7025E+04
Spring 3A	0.000E+00	7.6556E-02	4.0820E-02	3.4696E-05	3.5689E-03	1.4268E-03	5.8912E+02	1.0342E+05	3.4491E+04
Spring 3B	0.000E+00	5.0952E-02	2.8935E-02	5.3494E-05	3.6334E-03	1.4361E-03	6.1823E+02	1.0384E+05	3.3067E+04
Spring 4A	0.000E+00	6.7354E-02	3.4678E-02	5.0299E-05	4.3621E-03	1.6199E-03	7.8639E+02	1.1859E+05	3.6223E+04
Spring 4B	0.000E+00	5.4257E-02	2.8010E-02	4.733E-05	3.6479E-03	1.5504E-03	7.3347E+02	1.0065E+05	3.3881E+04
Spring 4C	0.000E+00	4.3444E-02	2.2738E-02	4.4786E-05	3.157E-03	1.3977E-03	6.5618E+02	8.7322E+04	3.0625E+04

The next set of analyses were done using 1095 steel (annealed). These are more closely related to the original spring because they are based in a real material that is used to manufacture the springs. Interestingly, these trends did not match those in structural steel or 5160 steel. Spring 2A continued to perform poorly. Both Spring 1A and Spring 3A performed well in 1095 steel. While Spring 4C also performed well, Springs 4A and 4B didn't do well when it came to stress, suggesting that the larger radii of Spring 4C reduced the stress. This was confirmed by graphing the average values for stress, deformation, and strain throughout Series 4. As we can see in **Figure 1**, the values for each spring decreased as the radii increased (from Spring 4A to Spring 4C).

Table 2: Annealed 1095 Steel Analysis Values for Spring Designs



Spring Name	Min Deformation	Max Deformation	Avg Deformation	Min Strain	Max Strain	Avg Strain	Min Stress	Max Stress	Avg Stress
Spring 1A	0.000E+00	6.44E-02	3.8952E-02	3.606E-05	2.740E-03	1.3666E-03	6.8203E+02	8.442E+04	3.5305E+04
Spring 2A	0.000E+00	0.1172	7.0336E-02	1.1440E-04	2.8563E-03	1.6143E-03	7.3124E+02	8.7993E+04	4.1555E+04
Spring 2B	0.000E+00	0.11608	7.0116E-02	4.869E-05	2.9580E-03	1.6171E-03	8.126E+02	9.1130E+04	4.1470E+04
Spring 3A	0.000E+00	7.3948E-02	3.9316E-02	3.1536E-05	2.9055E-03	1.2213E-03	4.8979E+02	8.9242E+04	3.1334E+04
Spring 3B	0.000E+00	4.8259E-02	2.7404E-02	4.7000E-05	3.4358E-03	1.3552E-03	6.0256E+02	1.0428E+05	3.3149E+04
Spring 4A	0.000E+00	6.7275E-02	3.4250E-02	4.7877E-05	3.3159E-03	1.3328E-03	8.2436E+02	9.5217E+04	3.1923E+04
Spring 4B	0.000E+00	5.1396E-02	2.6536E-02	4.410E-05	3.4396E-03	1.4637E-03	7.1751E+02	1.0072E+05	3.3994E+04
Spring 4C	0.000E+00	4.1154E-02	2.1543E-02	4.1613E-05	2.985E-03	1.3192E-03	6.3846E+02	8.7781E+04	3.0717E+04

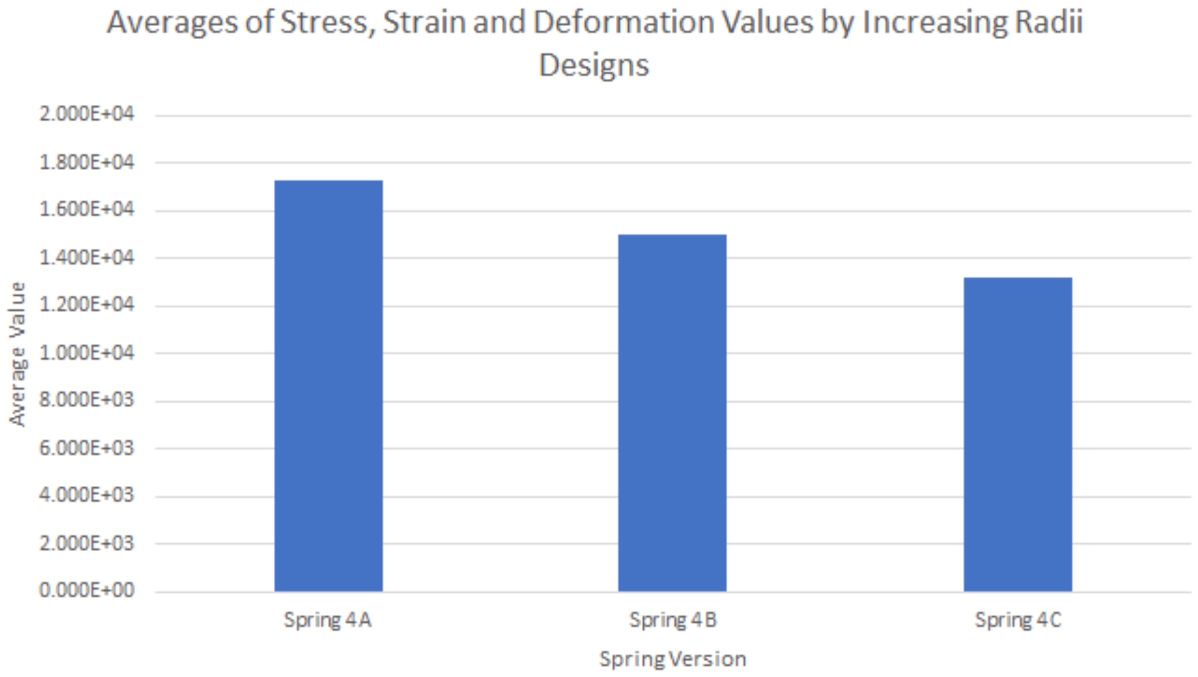
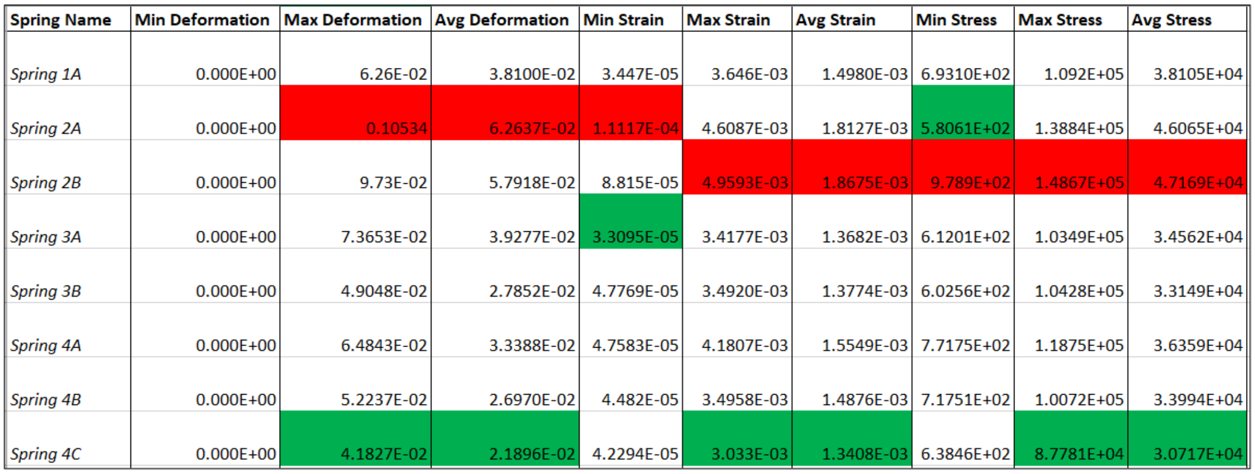


Figure 1: Graph of Averages of Stress, Strain and Deformation Values for Series 4 (increasing radii)

The final set of analyses were done using 5160 steel. The trends from this table completely matched structural steel, though the values were different. The springs from Series 2 continued to perform poorly, and Spring 4C continued to perform well.

Table 3: Hardened and Tempered 5160 Steel Analysis Values for Spring Designs



Spring Name	Min Deformation	Max Deformation	Avg Deformation	Min Strain	Max Strain	Avg Strain	Min Stress	Max Stress	Avg Stress
Spring 1A	0.000E+00	6.26E-02	3.8100E-02	3.447E-05	3.646E-03	1.4980E-03	6.9310E+02	1.092E+05	3.8105E+04
Spring 2A	0.000E+00	0.10534	6.2637E-02	1.1117E-04	4.6087E-03	1.8127E-03	5.8061E+02	1.3884E+05	4.6065E+04
Spring 2B	0.000E+00	9.73E-02	5.7918E-02	8.815E-05	4.9593E-03	1.8675E-03	9.789E+02	1.4867E+05	4.7169E+04
Spring 3A	0.000E+00	7.3653E-02	3.9277E-02	3.3095E-05	3.4177E-03	1.3682E-03	6.1201E+02	1.0349E+05	3.4562E+04
Spring 3B	0.000E+00	4.9048E-02	2.7852E-02	4.7769E-05	3.4920E-03	1.3774E-03	6.0256E+02	1.0428E+05	3.3149E+04
Spring 4A	0.000E+00	6.4843E-02	3.3388E-02	4.7583E-05	4.1807E-03	1.5549E-03	7.7175E+02	1.1875E+05	3.6359E+04
Spring 4B	0.000E+00	5.2237E-02	2.6970E-02	4.482E-05	3.4958E-03	1.4876E-03	7.1751E+02	1.0072E+05	3.3994E+04
Spring 4C	0.000E+00	4.1827E-02	2.1896E-02	4.2294E-05	3.033E-03	1.3408E-03	6.3846E+02	8.7781E+04	3.0717E+04

I noticed some interesting results when I compared the average values from 1095 steel to 5160 steel. The purpose of this comparison was to see the strengths and weaknesses of the different materials. The results were very clear. You can see in **Figure 2** that the average deformation for 1095 steel is much higher than 5160 steel. This makes sense, as the 5160 steel used was hardened. For strain, the opposite occurred as seen in **Figure 3**; 1095 steel had much lower average strain than 5160 steel. A full set of comparisons can be seen in the appendix (**Figure 30**). The results of these comparisons show that 1095 steel has lower strain and stress values, while using 5160 steel can help improve the spring's deformation value.

By comparing the maximum and minimum values from the 1095 and 5160 tables by indicating which values are the lowest (**Table 4**: Comparison of extremes of 1095 steel and 5160 steel), there is again a trend of high deformation values from 1095 while 5160 performs poorly in stress and strain. Minimum deformation values were removed from this comparison, as all were zeroes.

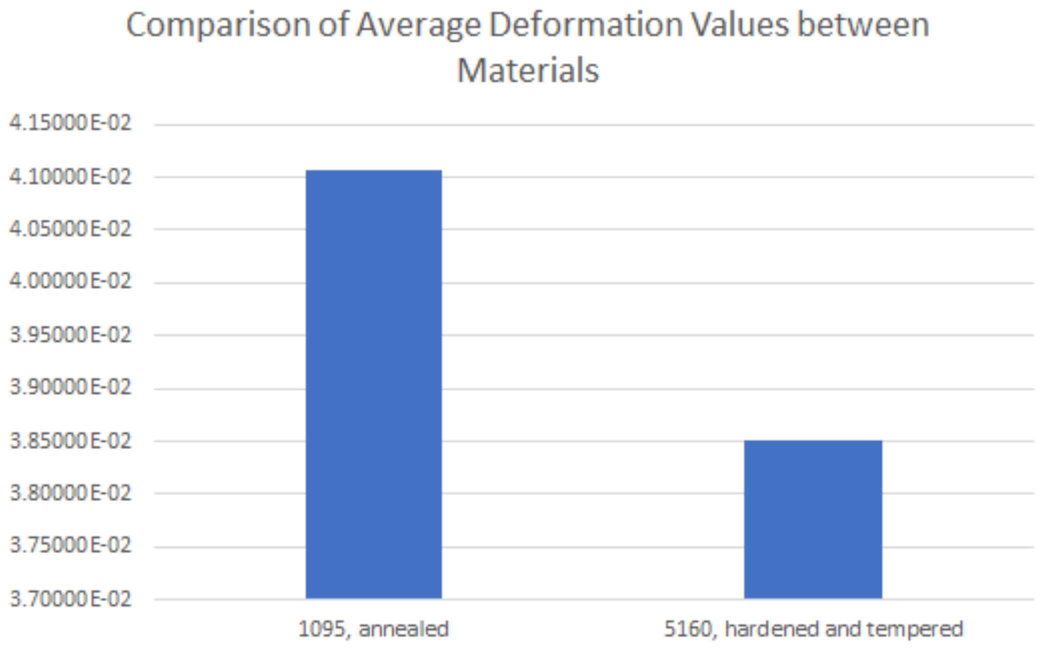


Figure 2: Graph comparing average deformation values between 1095 steel and 5160 steel

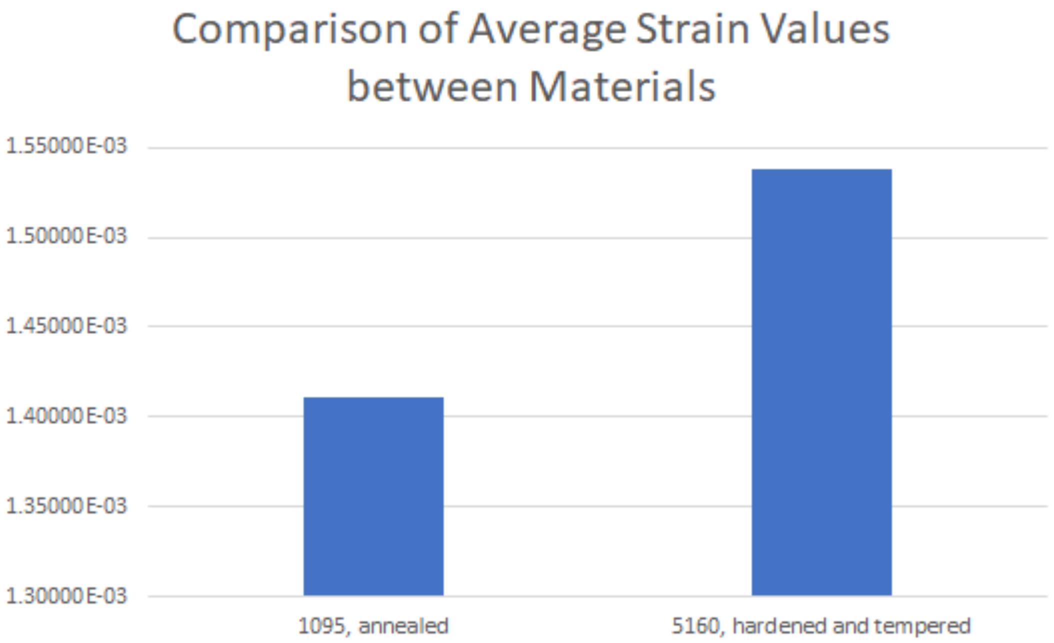
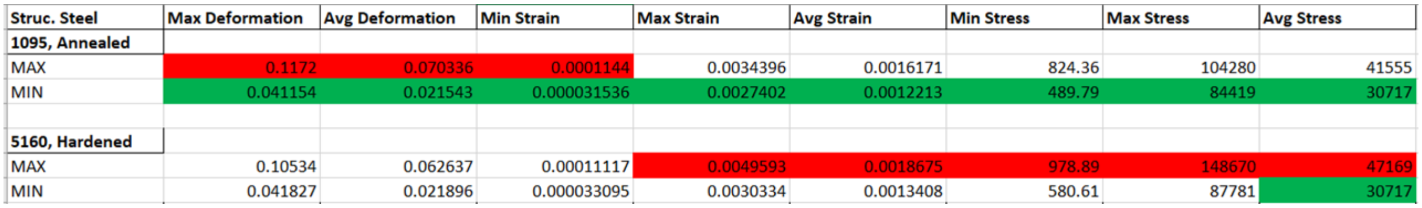


Figure 3: Graph comparing average strain values between 1095 steel and 5160 steel

Table 4: Comparison of extremes of 1095 steel and 5160 steel

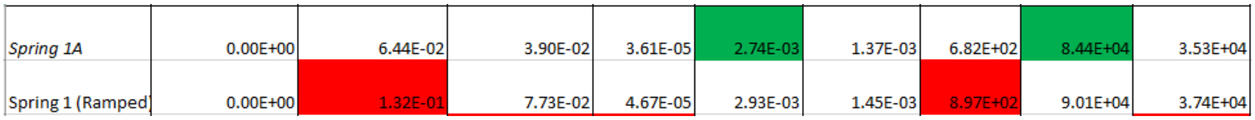


Struc. Steel	**Max Deformation**	**Avg Deformation**	**Min Strain**	**Max Strain**	**Avg Strain**	**Min Stress**	**Max Stress**	**Avg Stress**
1095, Annealed								
MAX	0.1172	0.070336	0.0001144	0.0034396	0.0016171	824.36	104280	41555
MIN	0.041154	0.021543	0.000031536	0.0027402	0.0012213	489.79	84419	30717
5160, Hardened								
MAX	0.10534	0.062637	0.00011117	0.0049593	0.0018675	978.89	148670	47169
MIN	0.041827	0.021896	0.000033095	0.0030334	0.0013408	580.61	87781	30717

Based on the results outlined above, the spring design that is eventually chosen should be based on values from the material that is used. While the 1095 steel deforms more, it has lower stress values, which is what we're interested in reducing. Therefore, it is recommended to use annealed 1095 steel unless a better material is presented in the future. If 1095 annealed steel is used, Spring 3A would be a good option. But if 5160 hardened steel is used, it would be best to use Spring 4C. Some sources of error in these analyses are the lack of surface coatings (versus the actual spring design), and possible variations due to the simplified mesh (model).

In addition to analyzing the new designs, I also analyzed the spring when it is placed in other positions within the guitar (i.e. other notches on the clamp). Seen below, the values for the angled spring were higher in all categories compared to the spring when it's in the center notch.

Table 5: Comparing results from the component force study to results from the original spring

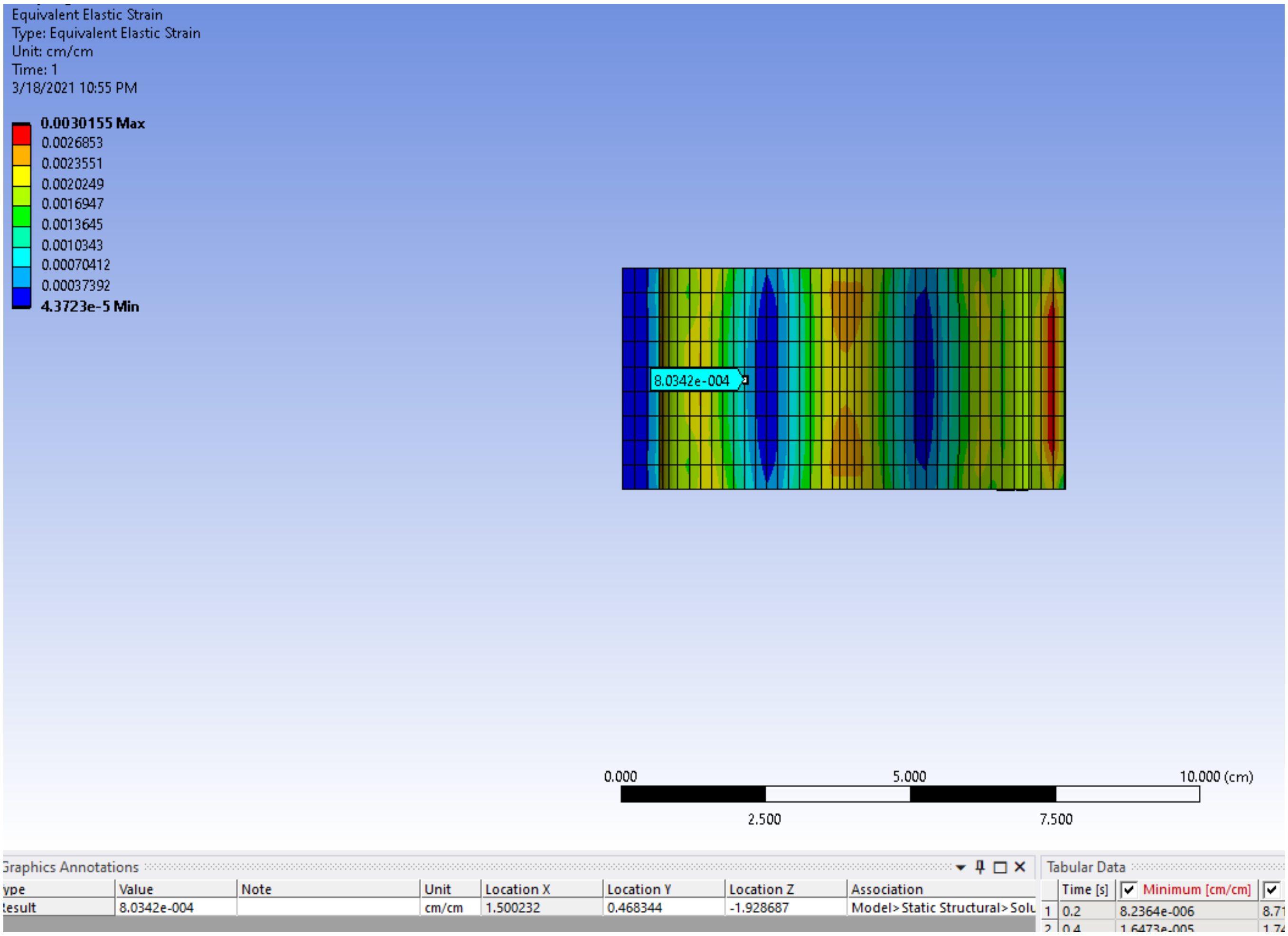


Spring 1A	0.00E+00	6.44E-02	3.90E-02	3.61E-05	2.74E-03	1.37E-03	6.82E+02	8.44E+04	3.53E+04
Spring 1 (Ramped)	0.00E+00	1.32E-01	7.73E-02	4.67E-05	2.93E-03	1.45E-03	8.97E+02	9.01E+04	3.74E+04

Lab Test Results

To confirm the ANSYS results, I had to have two analyses: simulating the part in ANSYS and measuring the strain in the lab. In **Figure 4**, we can see that at 2.5 centimeters from the edge of the spring, the strain is 8.0342E-4. To convert this to microstrains, we need to multiply it by 10^6. Therefore, the microstrains that we expect in the lab test are 803.42 (unitless).

In the lab test (**Figure 5**), we ended up getting two plateaus of data, one around 500 and one around 800 microstrains. The one around 500 is most likely due to the guitar bridge not being balanced and fully tightened, so we are going to focus on the 800 range of values (**Figure 6**). We can clearly see that the values oscillate about 800 microstrains and using Excel we can see that the average of that range of values is 799.2565 microstrains (**Table 6**: Calibrated microstrain of the spring while clamped in the guitar). This is very close to our theoretical results, with a percent error of 0.52%. Possible sources of error are the simulation being off due to the difference in surface coatings (the simulation uses pure zinc while the actual spring uses zinc-nickel alloy), and the strain gage not being exactly at 2.5 cm from the edge. However, because of how close these values are to each other, we can conclude that our ANSYS results roughly match those found in the lab.



Equivalent Elastic Strain
Type: Equivalent Elastic Strain
Unit: cm/cm
Time: 1
3/18/2021 10:55 PM

ype	Value	Note	Unit	Location X	Location Y	Location Z	Association
esult	8.0342e-004		cm/cm	1.500232	0.468344	-1.928687	Model>Static Structural>Solu

	Time [s]	☑ Minimum [cm/cm]	☑
1	0.2	8.2364e-006	8.71
2	0.4	1.6473e-005	1.74

Figure 4: Results from the ANSYS study to imitate actual spring values

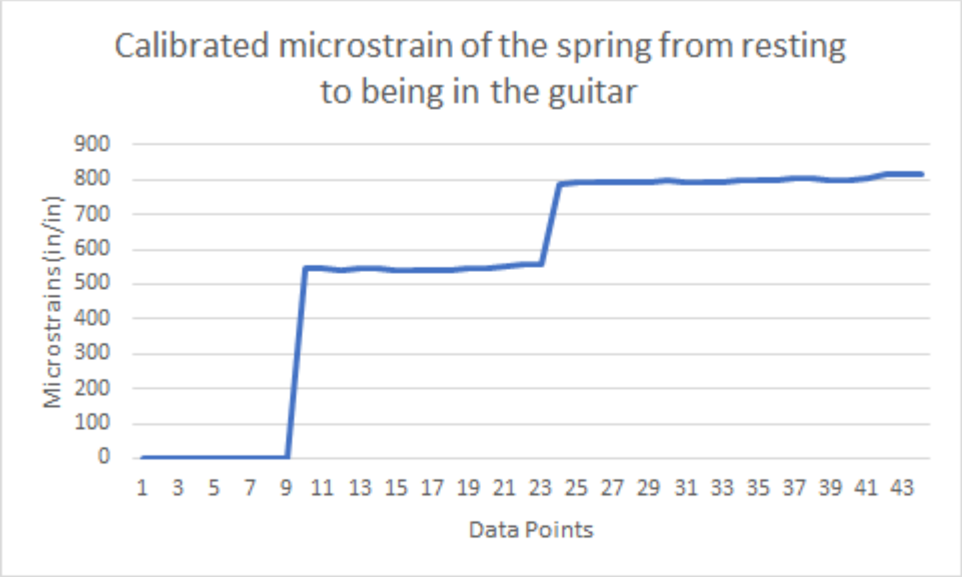


Figure 5: Graph of the calibrated microstrain of the spring from resting state to being clamped in the guitar

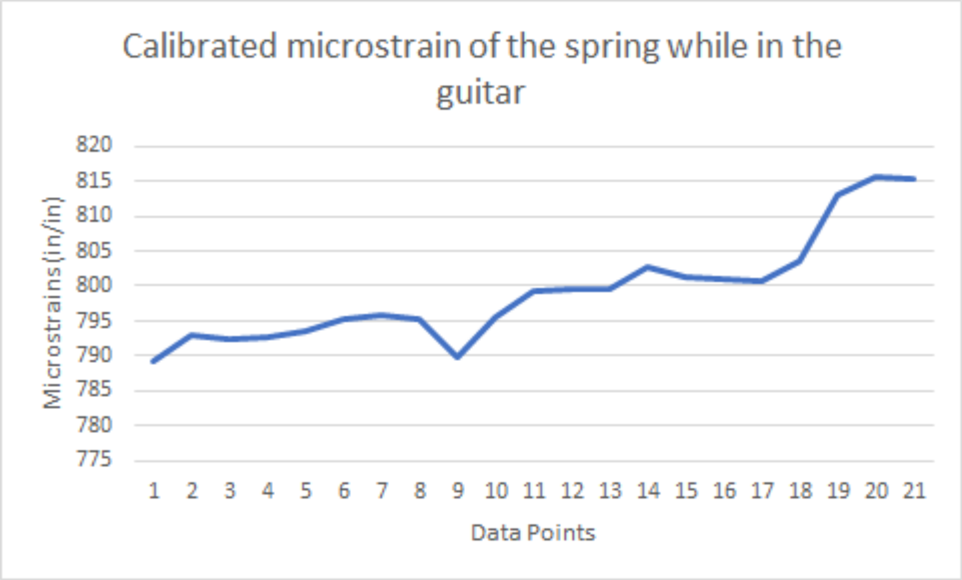


Figure 6: Graph of calibrated microstrain experienced by the spring while clamped in the guitar

Conclusions

Like most projects, this one was full of problems and things that could have gone better. For those going forward, I recommend you do not use a remote desktop to run ANSYS, as there can be errors that are based solely on the computer. Instead, use the computer lab in Higgins Laboratory. I also recommend that you do not use LabView for future studies with strain gages. Instead, use an Arduino program. An Arduino strain gage module found online would make connecting to the strain gage much easier. These values could be recorded onto an SD card, which there are also Arduino modules for.

There are also plenty of items that still need to be worked on. These are merely suggestions to teams that use this project in the future:

Do a scanning electron microscope analysis of the broken spring. There are possible patterns where the springs break in the same spot. While I didn't get to use the SEM this term, it could be useful to see how the original spring design has failed, and whether there's a pattern.

There is still room to grow for new spring designs. New teams should continue to create and test new spring designs. A concern was raised in this project about whether new spring designs would deform enough to hit the boundaries of the cavity, so future teams should also test whether those springs hit the boundary of the guitar. This could be done by increasing the force to see how much input force it takes to hit the boundaries. The probe tool in ANSYS is a great way to see how the spring's positions have changed.

When a spring design is selected to go forward with, teams should use fatigue analysis with S-N curves to quantify how many cycles the spring will take until failure. Maximum stress can easily be found in ANSYS. Future teams should also use modal and dynamic structural analysis in the final analyses of the spring. For their fatigue analysis, teams should determine how much force a guitarist applies to the spring and use this value to get a realistic stress value. This will make their data more accurate.

Quantifying the resistance of the eventual spring design could be important from a marketing perspective. Professor Manzo suggested using low, medium, and hard to describe how much the spring resists being deformed by the guitarist. This could be done by testing the deformation value in ANSYS, then testing the real-life value using a force gage and a spring.

Finally, when teams have completed all necessary steps, they should design a manufacturing process for the spring. From my research, I recommend that teams anneal the steel prior to manufacturing using a heat treatment oven. In lieu of this, teams can heat up the steel, then allow it to cool slowly in a folded piece of ceramic fiber blanket. I would recommend that teams attempt to continue to use a Zinc-Nickel alloy for coating, and top that off with trivalent chromate coating for protection against corrosion.

Appendix

Appendix A: Diagrams and Information

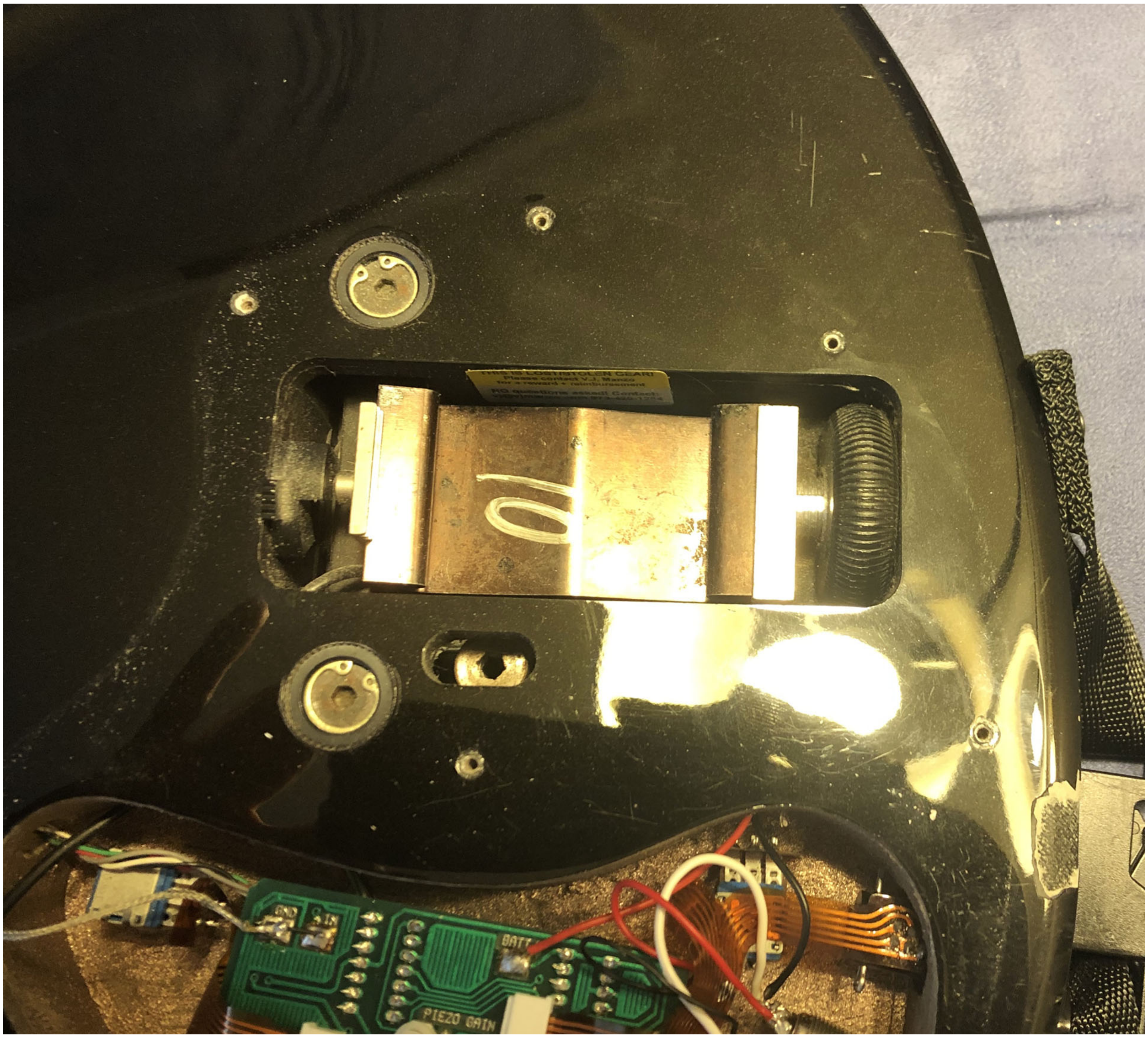
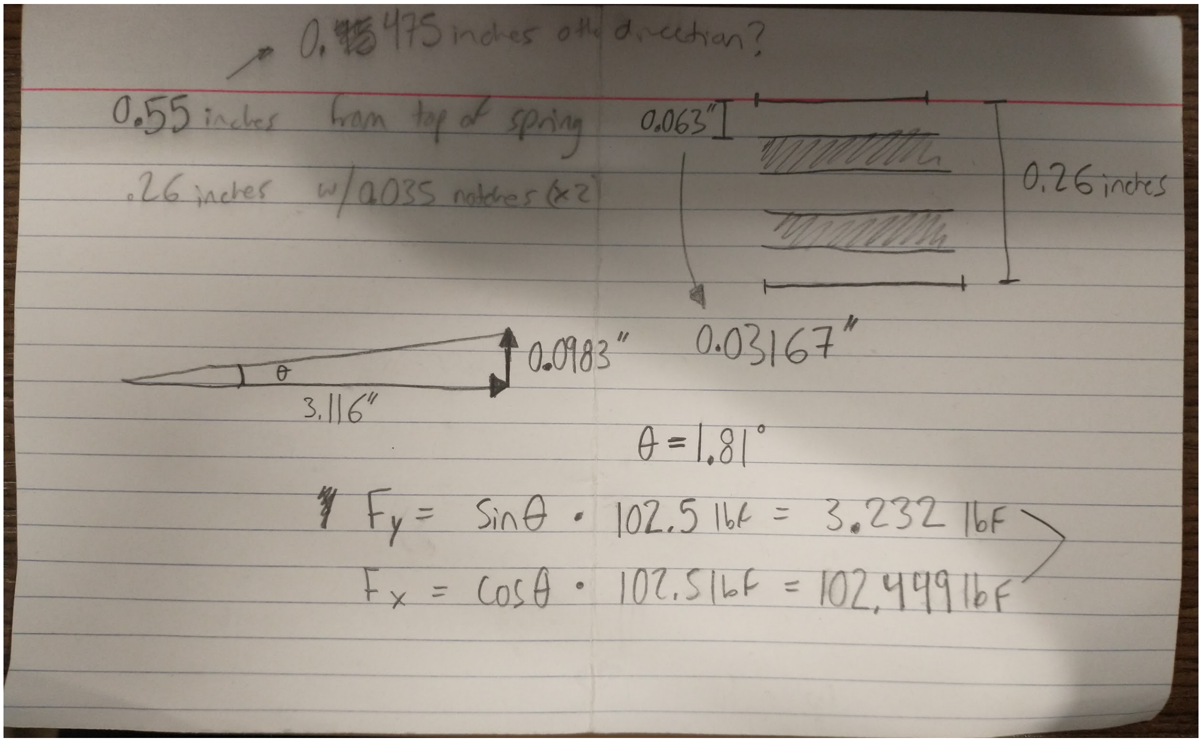


Figure 7: Image of the spring in the guitar, taken by Professor Manzo



0.475 inches oth direction?

0.55 inches from top of spring

.26 inches w/ 0.035 notches (x2)

$\theta = 1.81°$

$F_y = \sin\theta \cdot 102.5\ \text{lbf} = 3.232\ \text{lbF}$

$F_x = \cos\theta \cdot 102.5\ \text{lbF} = 102.499\ \text{lbF}$

Figure 8: Calculations for the components of force while the spring is clamped at an angle

Appendix B: Spring Designs

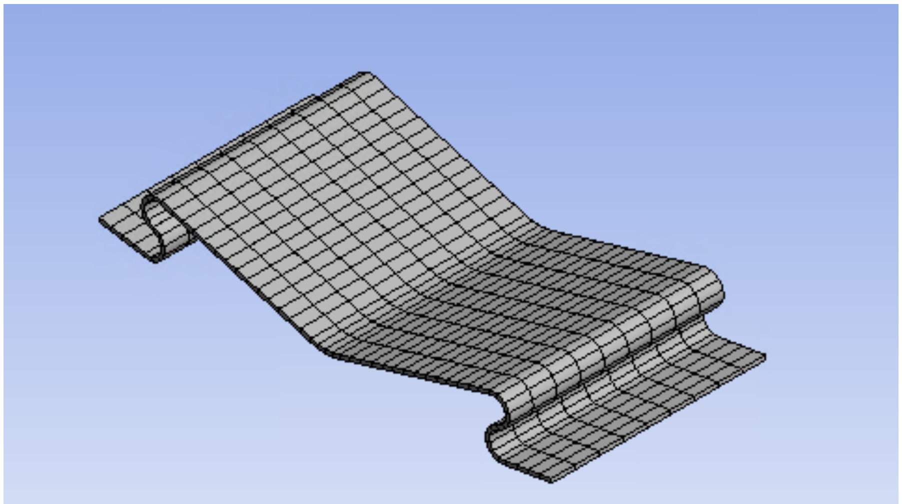


Figure 9: Spring 1A - Original spring design

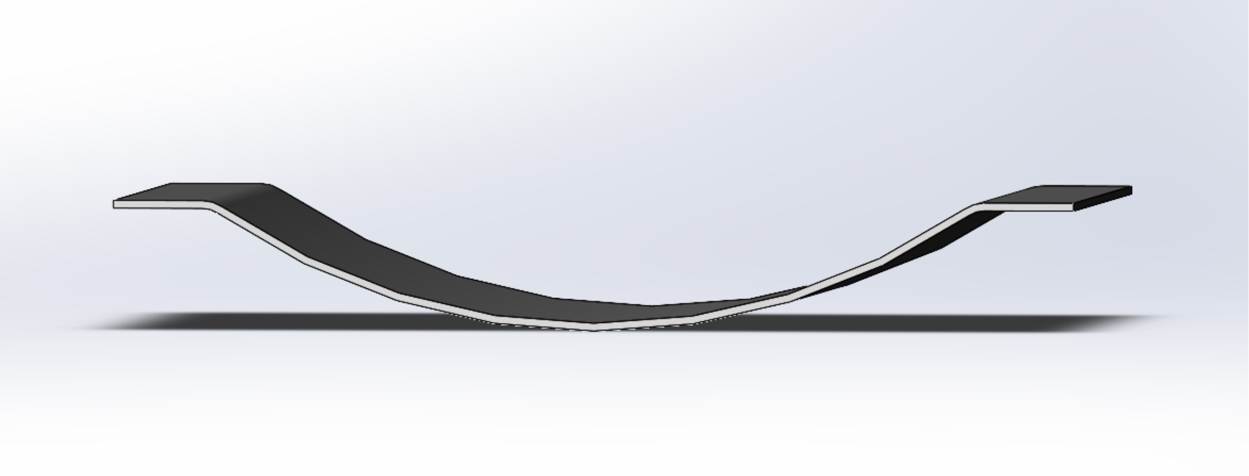


Figure 10: Spring 2A

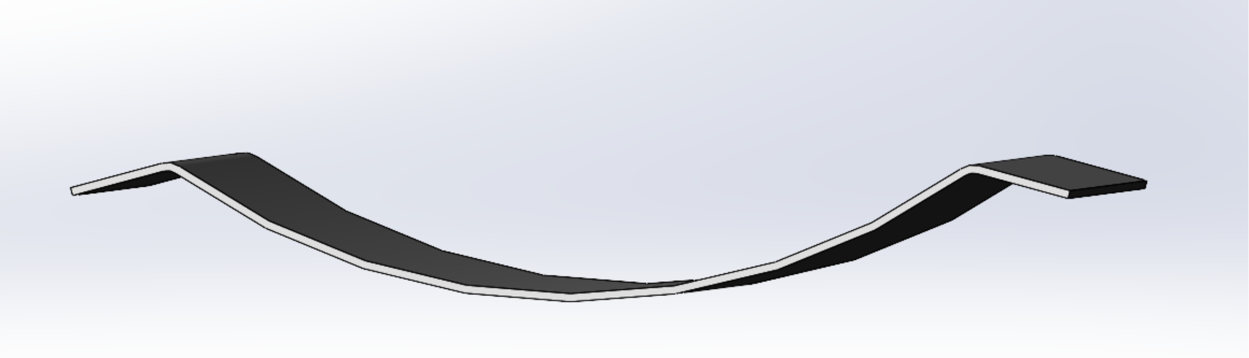


Figure 11: Spring 2B

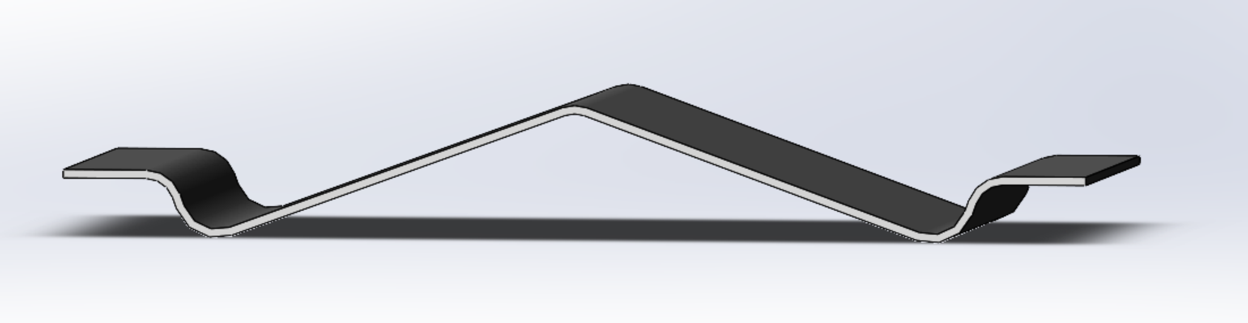


Figure 12: Spring 3A

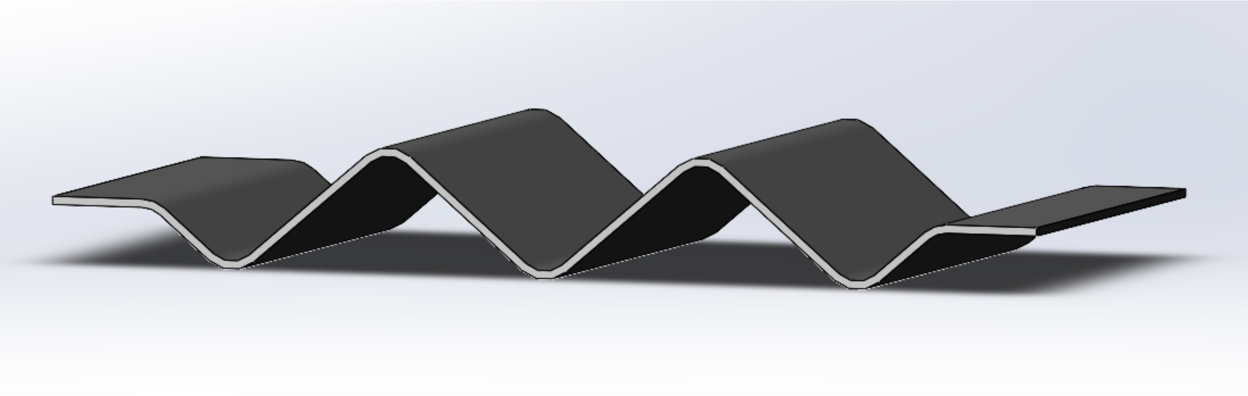


Figure 13: Spring 3B

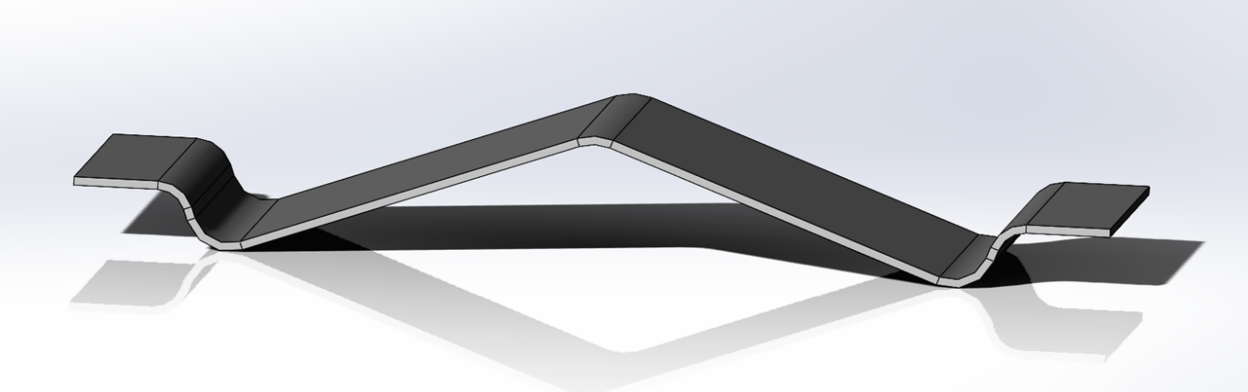


Figure 14: Spring 3C

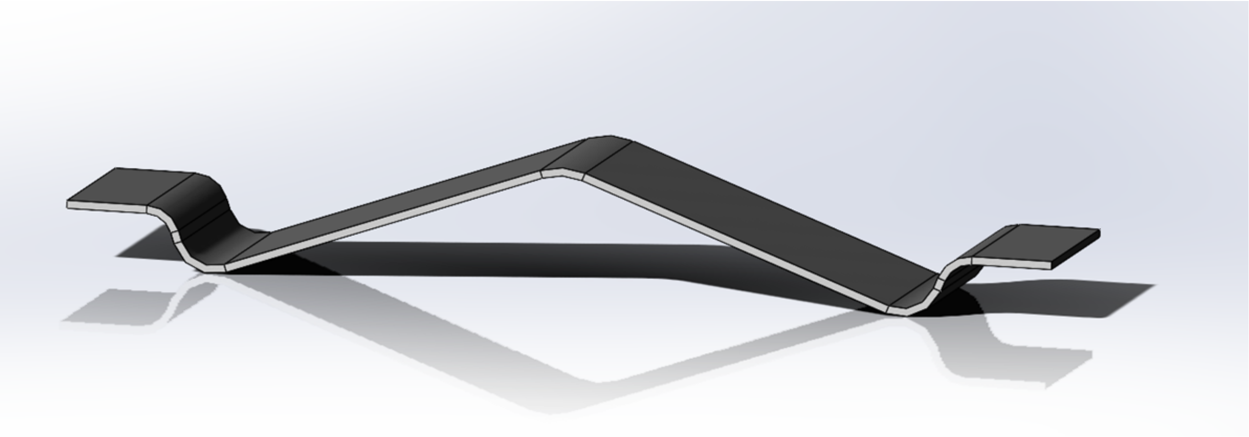


Figure 15: Spring 3D

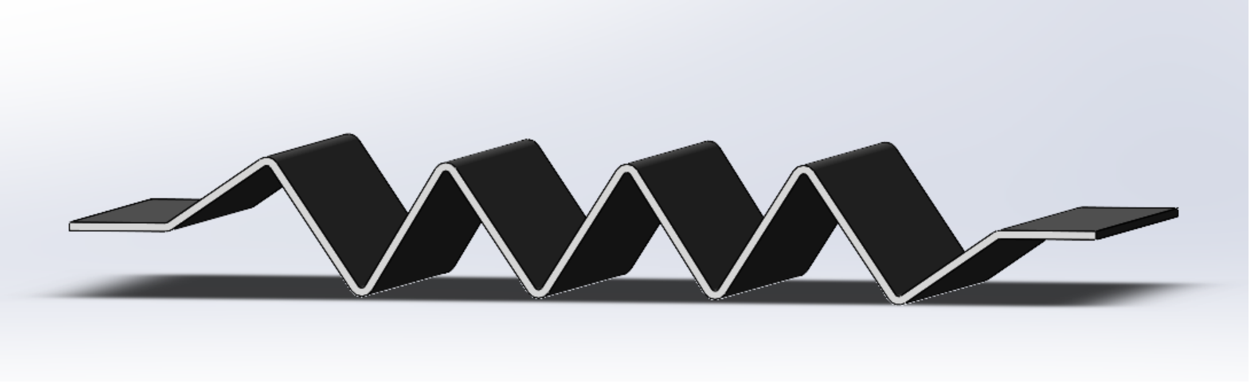


Figure 16: Spring 4A

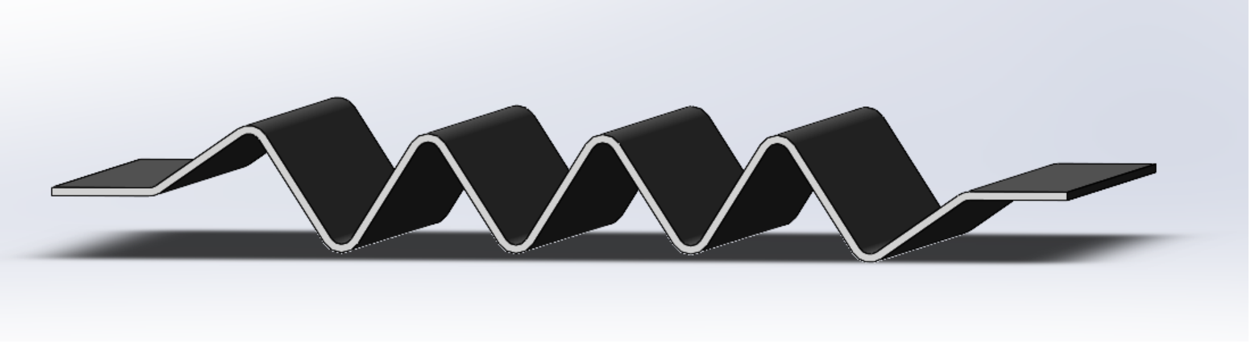


Figure 17: Spring 4B

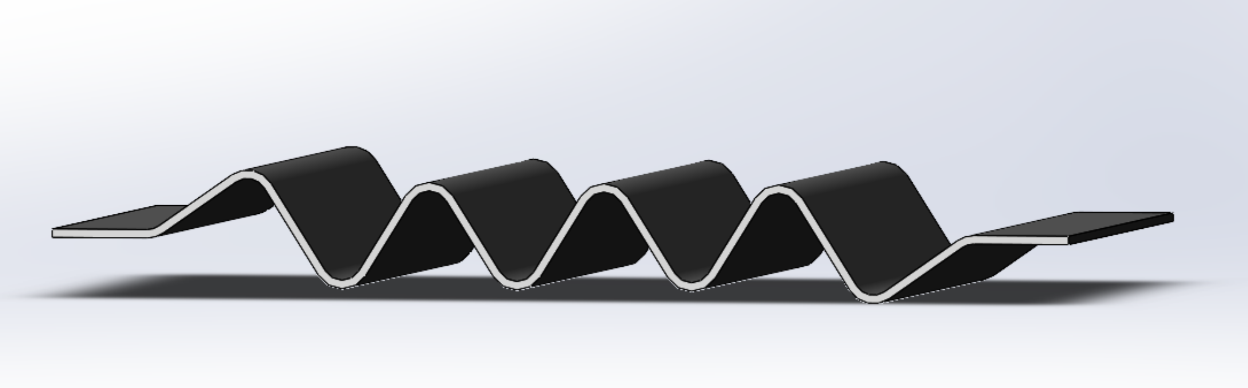


Figure 18: Spring 4C

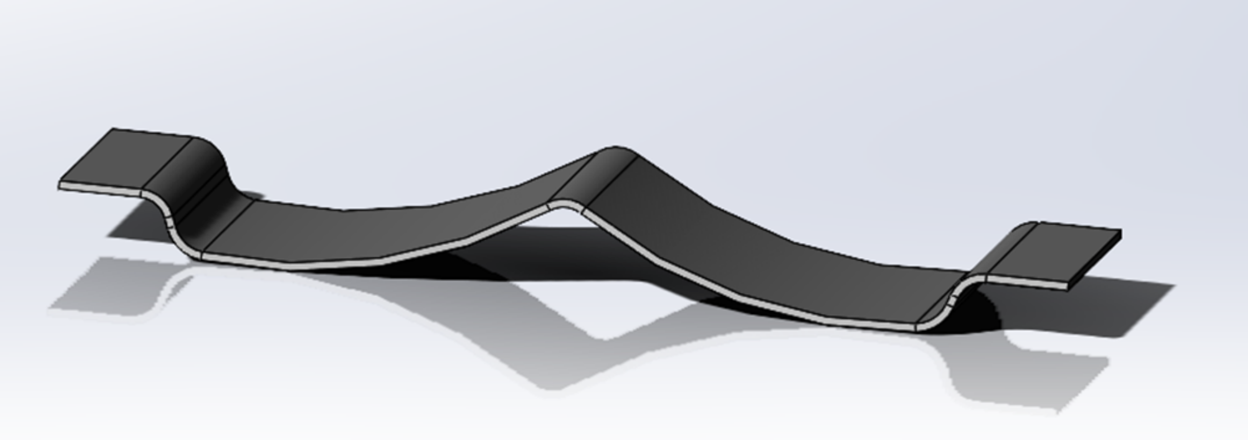


Figure 19: Spring 5A

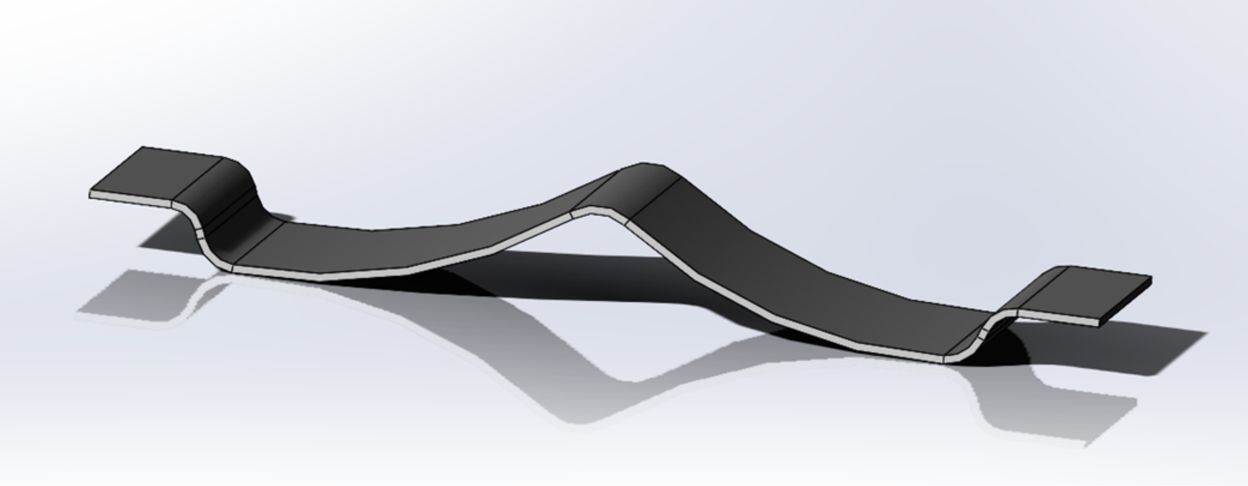


Figure 20: Spring 5B

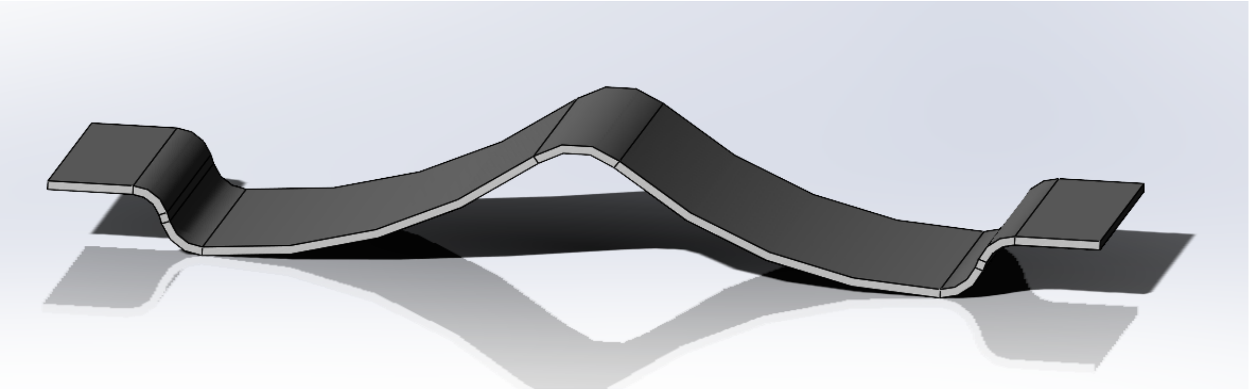
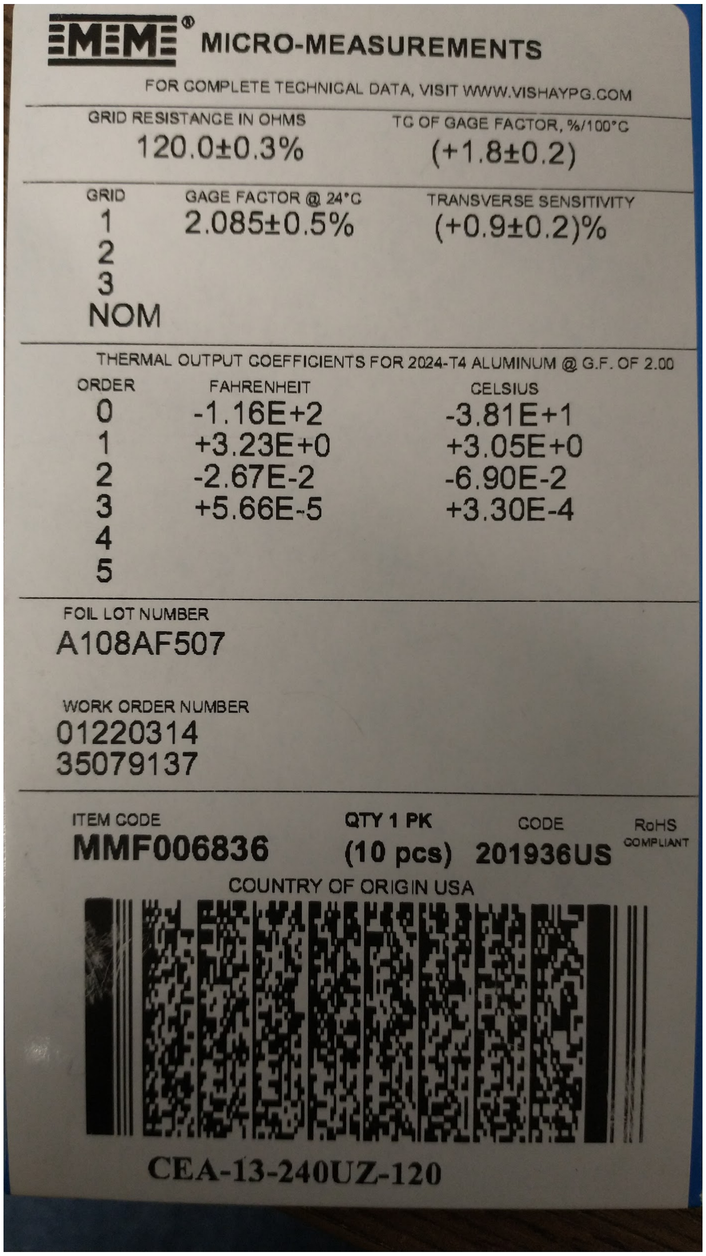


Figure 21: Spring 5C

Appendix C: Laboratory Setup



MICRO-MEASUREMENTS

FOR COMPLETE TECHNICAL DATA, VISIT WWW.VISHAYPG.COM

GRID RESISTANCE IN OHMS	TC OF GAGE FACTOR, %/100°C
120.0±0.3%	(+1.8±0.2)

GRID	GAGE FACTOR @ 24°C	TRANSVERSE SENSITIVITY
1	2.085±0.5%	(+0.9±0.2)%
2		
3		
NOM		

THERMAL OUTPUT COEFFICIENTS FOR 2024-T4 ALUMINUM @ G.F. OF 2.00

ORDER	FAHRENHEIT	CELSIUS
0	-1.16E+2	-3.81E+1
1	+3.23E+0	+3.05E+0
2	-2.67E-2	-6.90E-2
3	+5.66E-5	+3.30E-4
4		
5		

FOIL LOT NUMBER
A108AF507

WORK ORDER NUMBER
01220314
35079137

ITEM CODE	QTY 1 PK	CODE	RoHS COMPLIANT
MMF006836	(10 pcs)	201936US	

COUNTRY OF ORIGIN USA

CEA-13-240UZ-120

Figure 22: Specifications for the strain gage

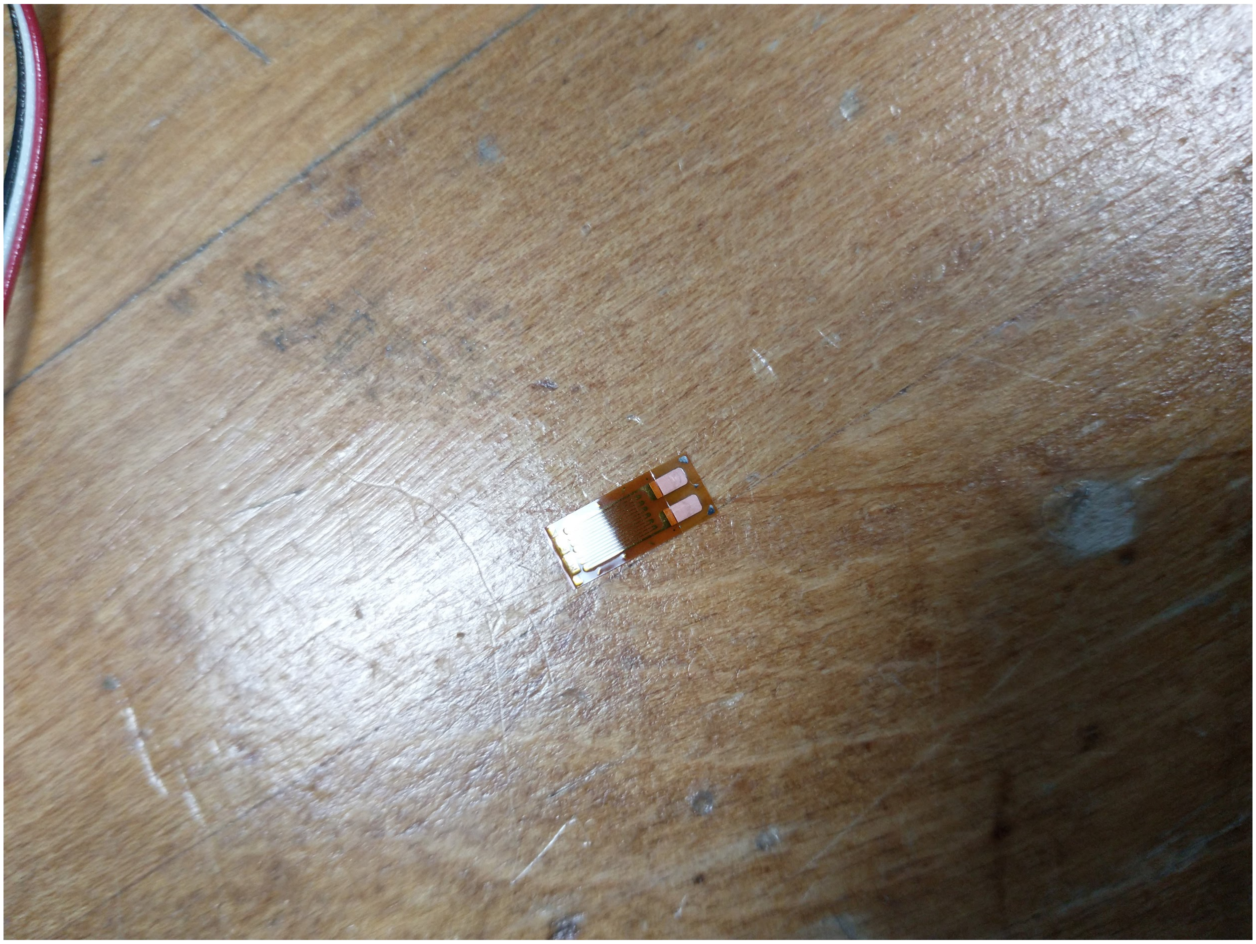


Figure 23: Lay the strain gage out on the table

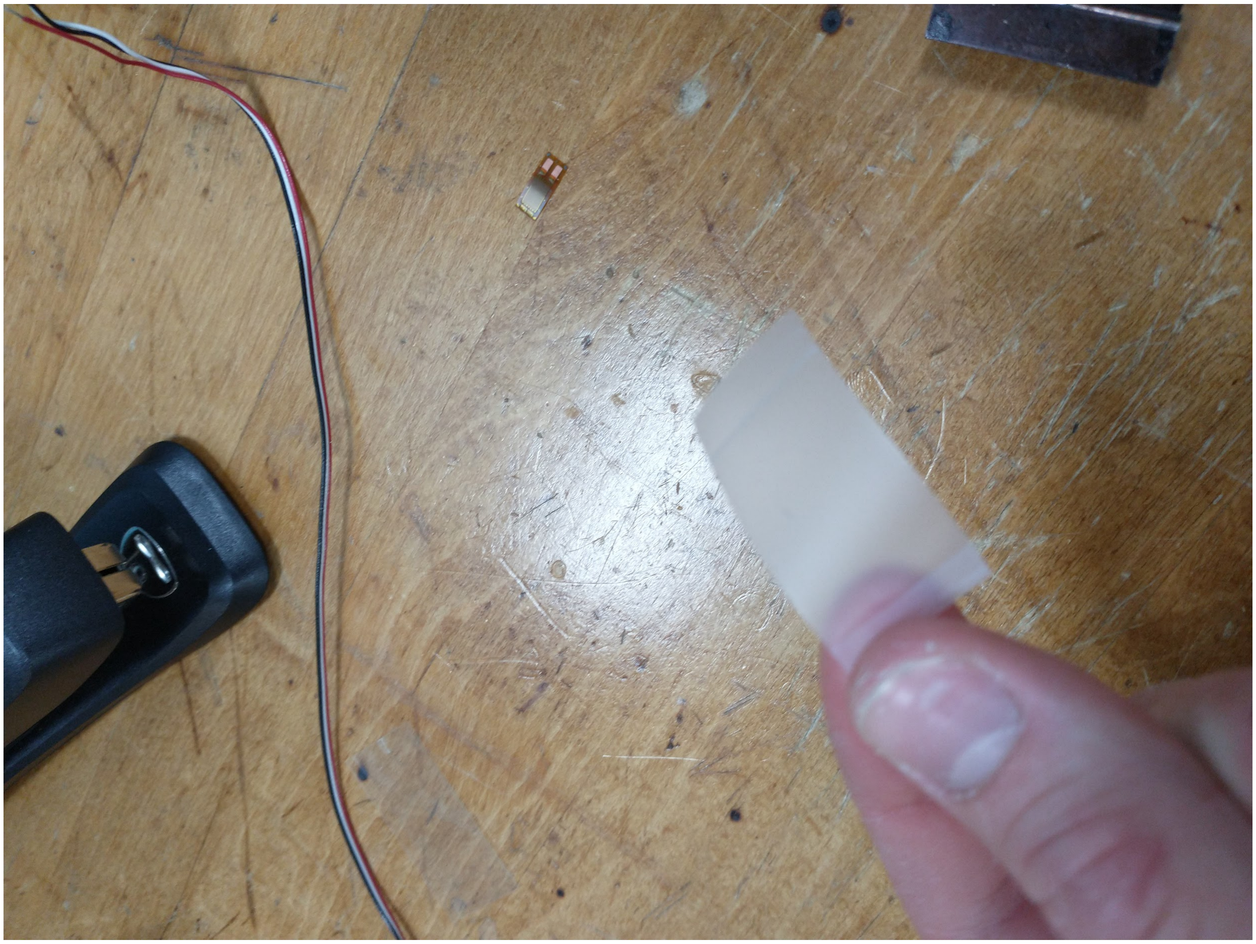


Figure 24: Fold one end of the scotch tape over

Figure 25: Strain gage attached with tape to the spring

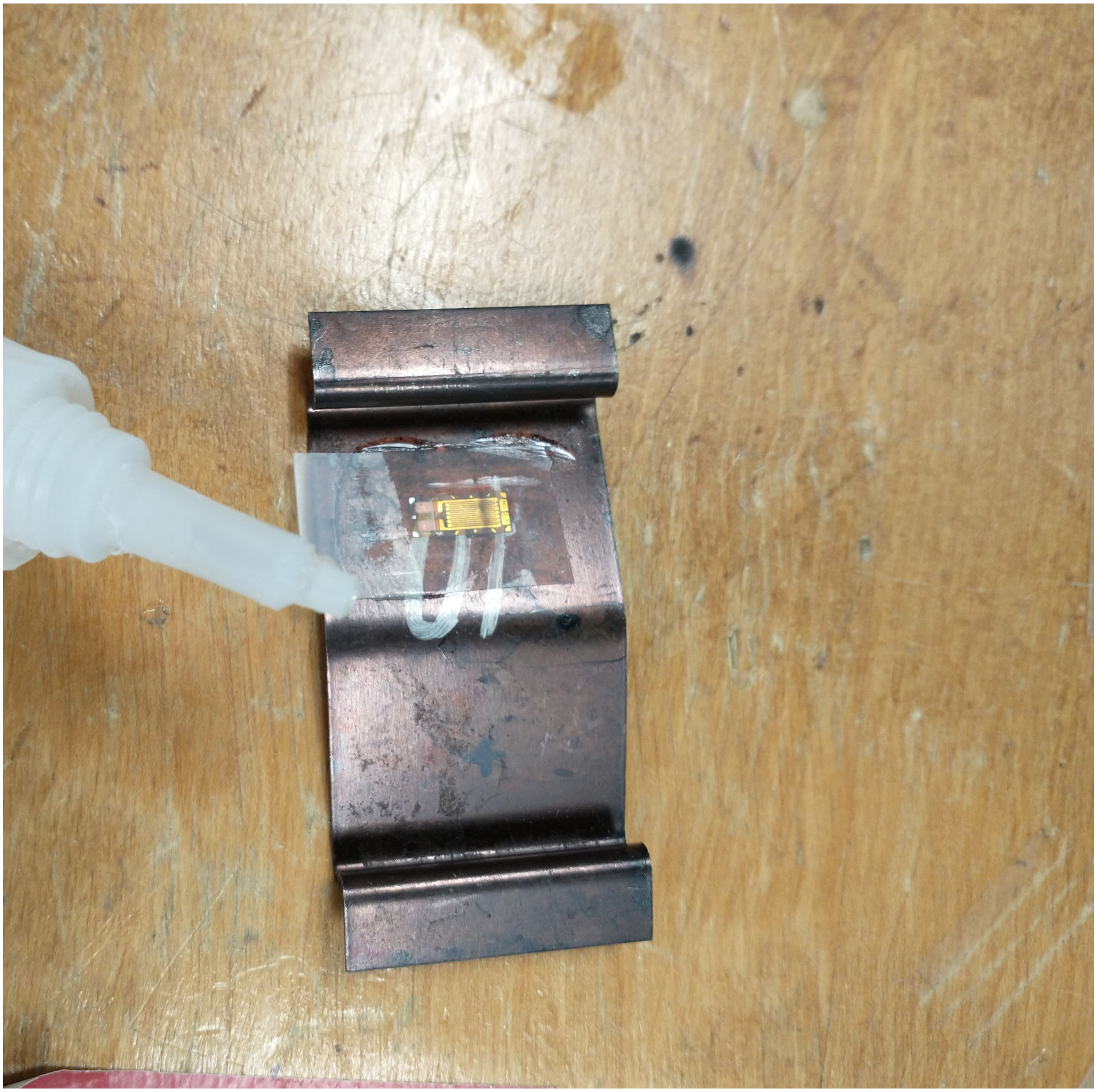


Figure 26: Gluing the strain gage onto the spring

Figure 27: Both strain gages glued to the spring

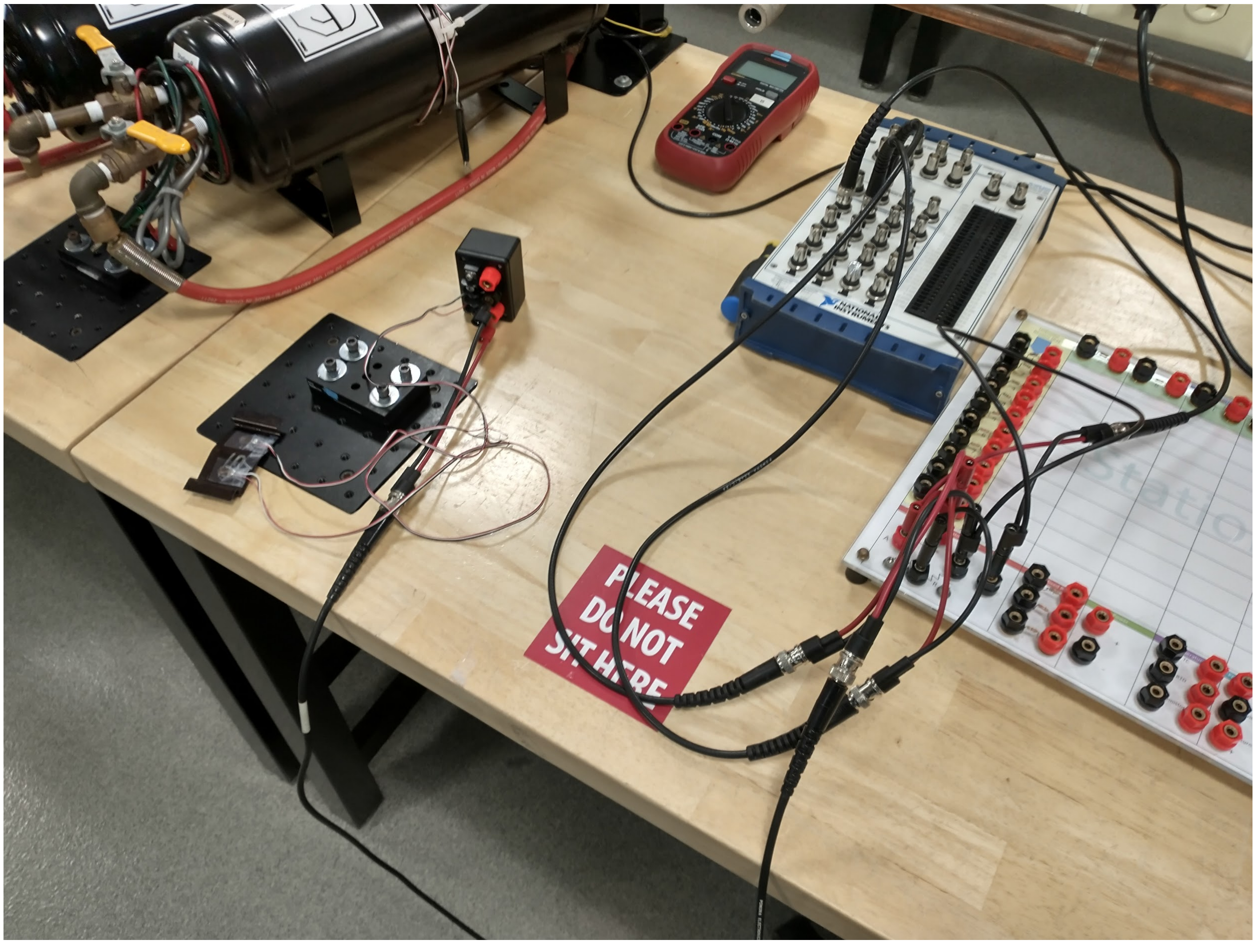


Figure 28: Set up for LabView software using a Wheatstone bridge

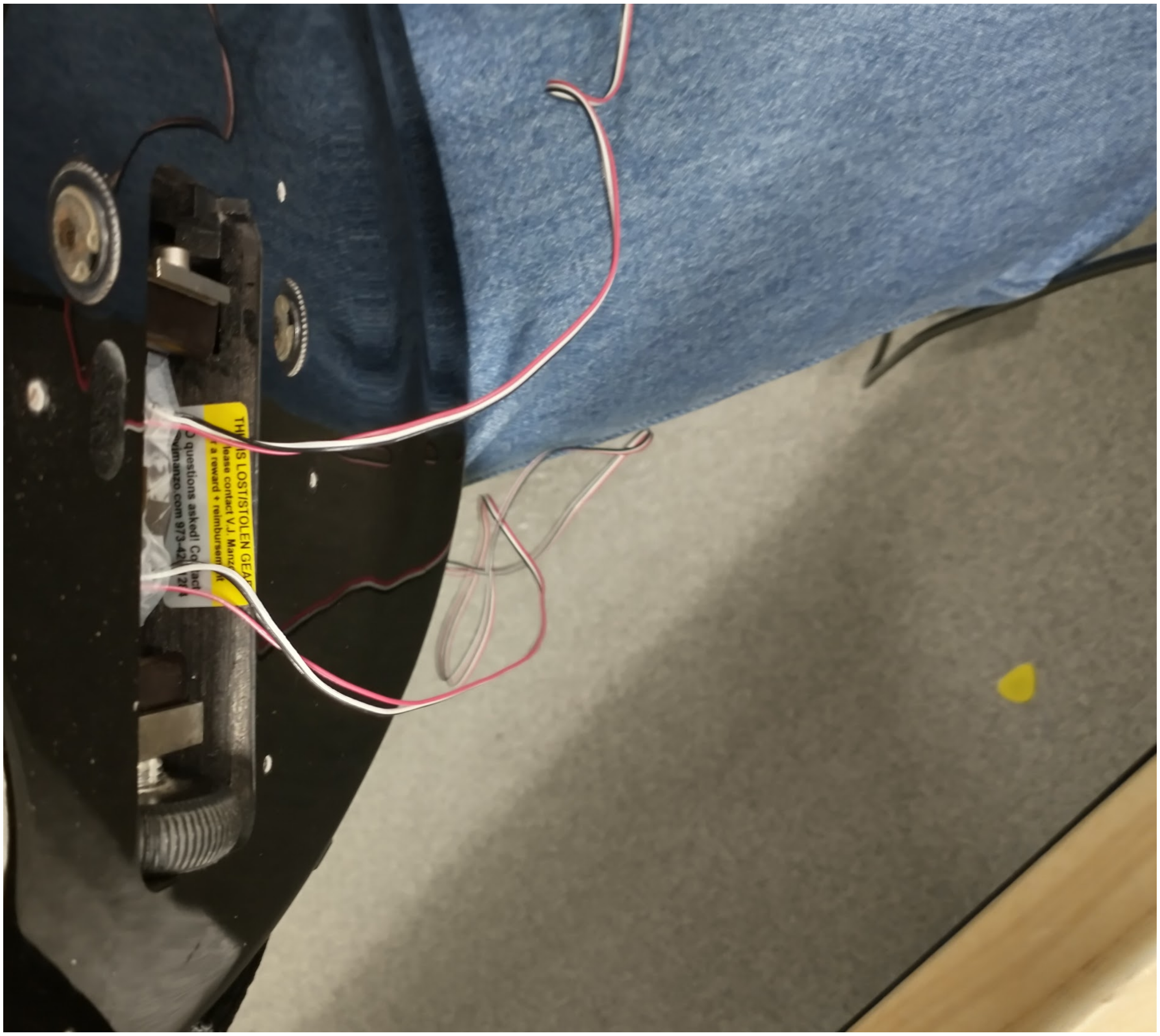


Figure 29: Guitar with the test spring inside

Appendix D: Tables and Charts

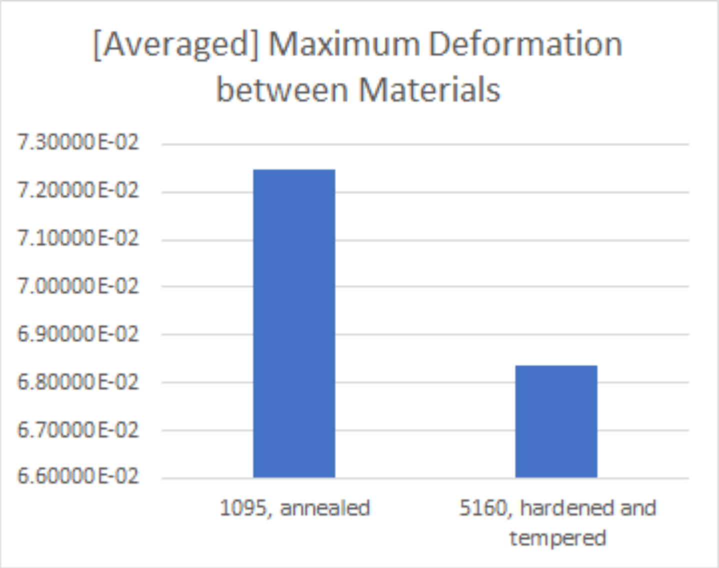


Figure 30: Graph comparing averaged maximum deformation values between 1095 steel and 5160 steel

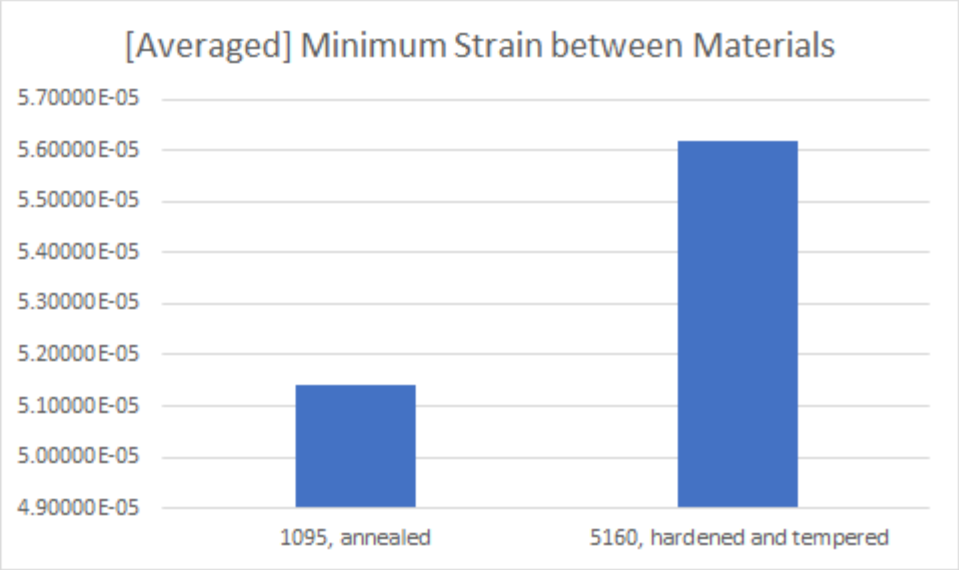


Figure 31: Graph comparing averaged minimum strain values between 1095 steel and 5160 steel

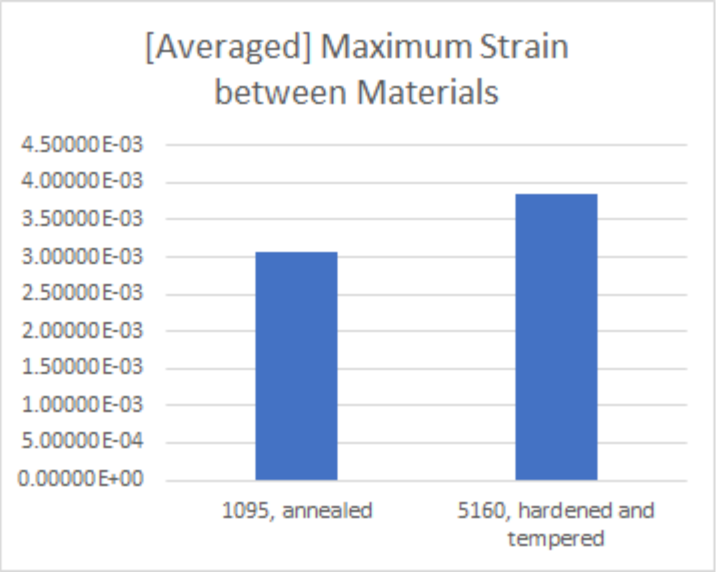


Figure 32: Graph comparing averaged maximum strain values between 1095 steel and 5160 steel

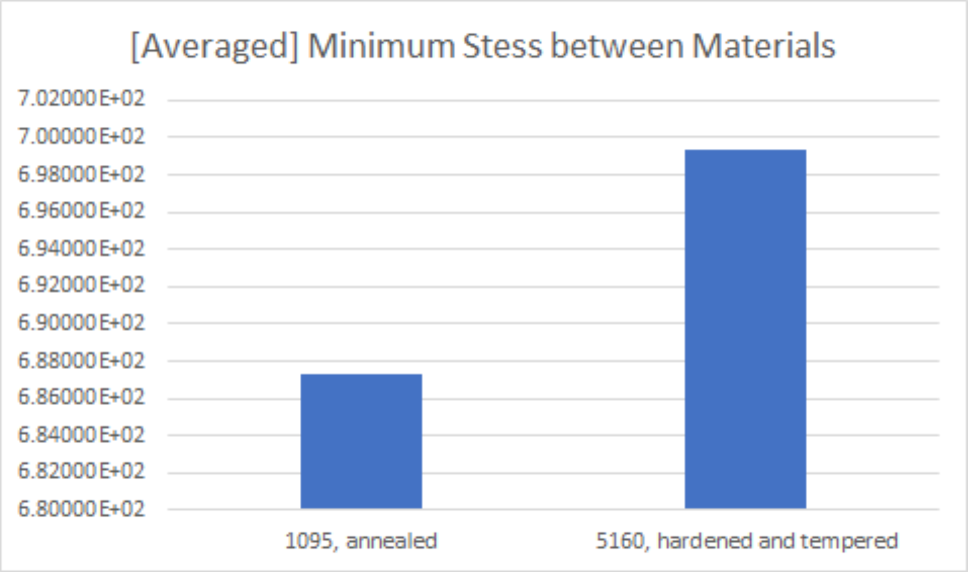


Figure 33: Graph comparing averaged minimum stress values between 1095 steel and 5160 steel

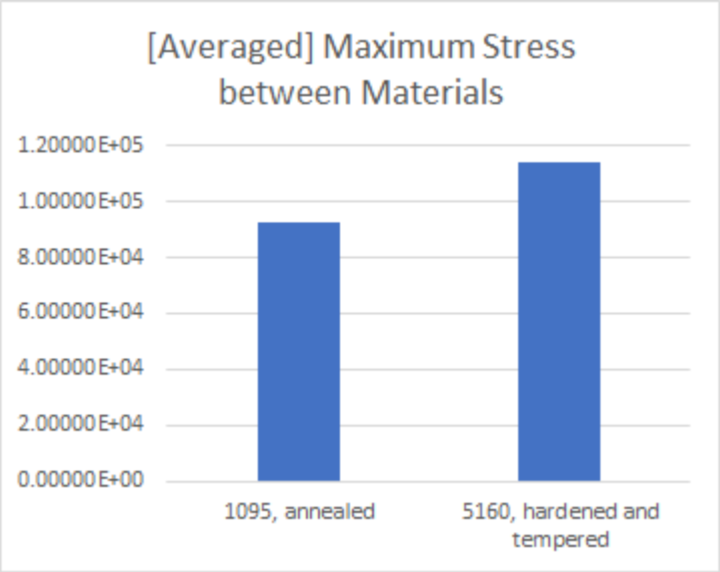


Figure 34: Graph comparing averaged maximum stress values between 1095 steel and 5160 steel

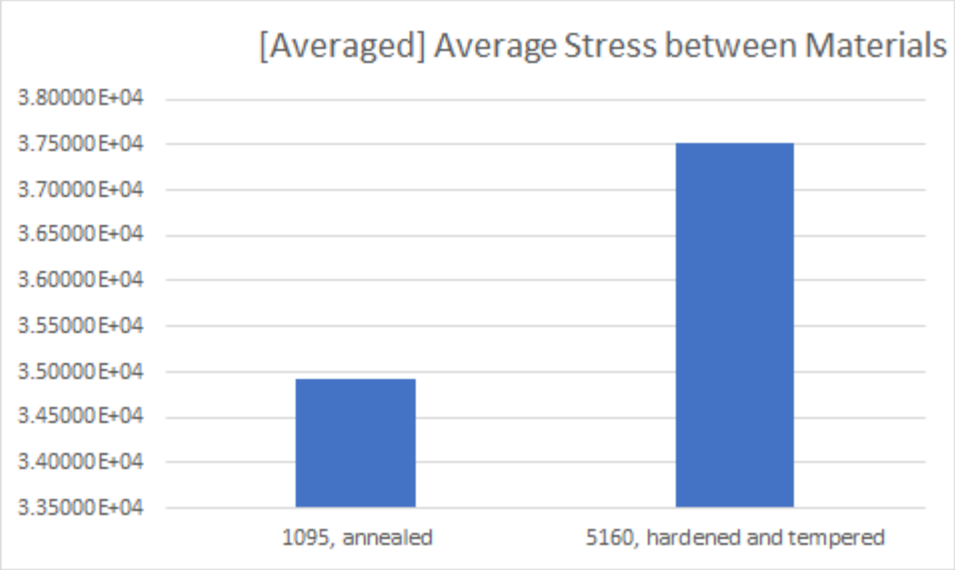
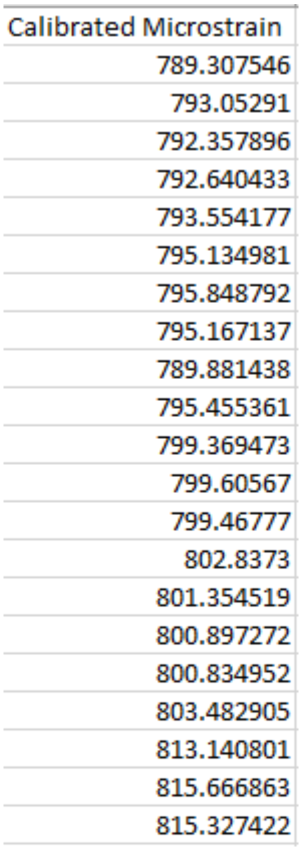


Figure 35: Graph comparing averaged average stress values between 1095 steel and 5160 steel

Table 6: Calibrated microstrain of the spring while clamped in the guitar



Calibrated Microstrain
789.307546
793.05291
792.357896
792.640433
793.554177
795.134981
795.848792
795.167137
789.881438
795.455361
799.369473
799.60567
799.46777
802.8373
801.354519
800.897272
800.834952
803.482905
813.140801
815.666863
815.327422