No Contact Gap Measurement – Final Report

Team 13

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ABSTRACT

This project arose from the necessity of measuring a micro gap between two cylinders that are used to hot roll raw material into thin films. The thickness of these films varies between 80 to 200 microns, and it is important to accurately gauge the thickness of the film samples as they are used in material property testing. The rollers used in this process are about 30 cm long, 6 inches in diameter, and are made of highly polished steel, making them expensive to manufacture and important to keep from scratching or denting. The current method used in measuring the gap employs the use of feeler gauges, which are thin metal wands with known thickness that are placed in the gap. Initial ideas for a non-contact method leaned heavily on the concept of laser triangulation systems or micrometers that would shine light through the gap to determine its thickness; however, laser products proved to be entirely too expensive for the project budget of $2,000. The final design involves rigidly mounting arms to the roller positioning blocks and measuring the gap with strain gauge based load cells. The displacement and bending of the designed load cell will result in voltage variances that can be used to determine the gap between rollers. A microcontroller is necessary to handle inputs of the capacitance sensors and the device will be calibrated to account for thermal expansion and irregularities in the rollers through experimentation and analysis.

ACKNOWLEDGEMENTS

1.   Introduction

General Capacitance is the company sponsoring this project, and the problem they presented to the design team stems from measuring a micro gap between two polished steel cylinders used to hot work raw material into thin films. These thin films are made of a variety of materials that are used in batteries, and they are fabricated with the intention of doing material property testing, specifically capacitance. The specifics of the materials being used and the details of their future application was spoken of in general terms to protect the intellectual property.

In order to gap the rollers, the lab technicians currently employ the use of feeler gauges which are thin strips of metal of known thickness. They slide the feeler gauges between the rollers, and if it goes through, then they know that the gap is at least as thick as the rollers. This method is effective and accurate enough to get the job done but has done serious damage in the past. The hot rollers are approximately 6 inches in diameter and approximately 20 inches in length, and they are about $10,000 each making them incredibly expensive to replace. The feeler gauges are made of metal, thus they have the potential to scratch or dent the rollers if used haphazardly or while the machine is on. This has caused critical damage in the past, as any flaws on the surface of the rollers will cause significant thickness variance in the material films.

Figure 1. The hot rolling machine.

The problem presented breaks down to solving the problem of measuring a microscale gap without making contact with the rollers. The early stages of designing a solution to this problem revolved around trying to determine a sensor to measure the gap. The sponsor initially suggested implementing the use of laser technologies in the form of laser triangulation or laser micrometers in order to measure the gap, but these instruments were outside of the budget restrictions. After researching the most appropriate sensors, strain gauges were determined to have the necessary resolution and fit inside the budget restrictions. The final design involves rigidly mounting arms to the roller positioning blocks and measuring the gap with strain gauge based load cells. The displacement and bending of the designed load cell will result in voltage variances that can be used to determine the gap between rollers. Once the design concept was finalized, it was deemed important to begin implementing the design with manufacturing, reliability, and economics in mind, and many decisions were made with the intent of optimizing these factors.

1.1   Need and Goal Statement

General Capacitance is currently determining the gap between the rollers of their hot rolling machine in AME with feeler gauges. The feeler gauges are of known thickness so that if they fit between the rollers, it can be determined that the gap is at least that wide. The problem with this method is that these feeler gauges can scratch and dent the rollers when they don't fit into the gap, and any resulting damage to the rollers has the potential to ruin them and they are incredibly expensive. The current use of feeler gauges to gap a pair of rollers is unreliable, time consuming, and potentially damaging. The goal statement adopted by the design team is to design a non-invasive, user friendly, accurate method of measuring the roller gap.

1.2   Constraints and Objectives

The constraints outlined from the sponsor were that the design must have a 2 μm resolution, stay within a $1,500 budget, and not come into contact with the rollers. The constraints provided a hard outline of the project, but the design team also established objectives including making the system easily attachable and removable, unaffected by the heat of the rollers, and easily operated without any formal training.

2.   Concept Generation

Determining what products were available and currently being used in non-contact gap measurement was a significant portion of the work involved in developing a design that was in the project scope, accomplished the defined objectives, and remained under the allotted budget. Dozens of products were considered and researched through product catalogue data sheets, email correspondence with engineering specialists of companies, and feedback from the project sponsor and advisors. The recurring themes that surfaced while researching available technology typically fell under the umbrella of either lasers, optics, capacitance, or load cell based sensors. Each option had its advantages and disadvantages, with load cells eventually prevailing because of their relatively low cost and its practicality to the project scope.

2.1   Background Research and Literature Review

Research started with determining what procedures are currently used. Because the market for measuring the gap between hot rollers is so miniscule, the market was stretched to encompass all of gap measurements. The different types of gaps that were being researched spanned from inch wide gaps between metal panels and micro gaps between machine pieces. These gaps were being determined through a multitude of methods. Some of the methods that were being utilized were laser-based triangulation, high resolution photography, long distance microscopes, capacitance and inductance sensors, and strain gauges. All of these devices had applications in proximity sensing and were all researched.

2.2   Laser Based Methods

The micro scale of the gap is one of the first hurdles involved in the problem solving process. Initial experimentation done in the lab with the machine revealed that it was difficult to observe white light passing through the gap with the naked eye, but light does pass through. The no contact constraint on the design placed working with laser or light sensors at the top of the brainstorming list. During the first meeting with project sponsor, Dr. Jim Zheng, the team was provided the product data for several of Micro-Epsilon's products that involved laser technology. Dr. Zheng had previously researched existing non-contact gap measurement systems and provided the team with some of his findings. Micro-Epsilon is a company that specializes in displacement and position sensors, and they have a device called gapCONTROL that is designed specifically to

be used to make non-contact gap measurements. It is uses the triangulation principle to measure the gap. This principle uses trigonometry to determine how far away the object being scanned is away from the sensor, as the distance between the camera and the laser emitter is known, as well as the angle that the emitter is positioned.
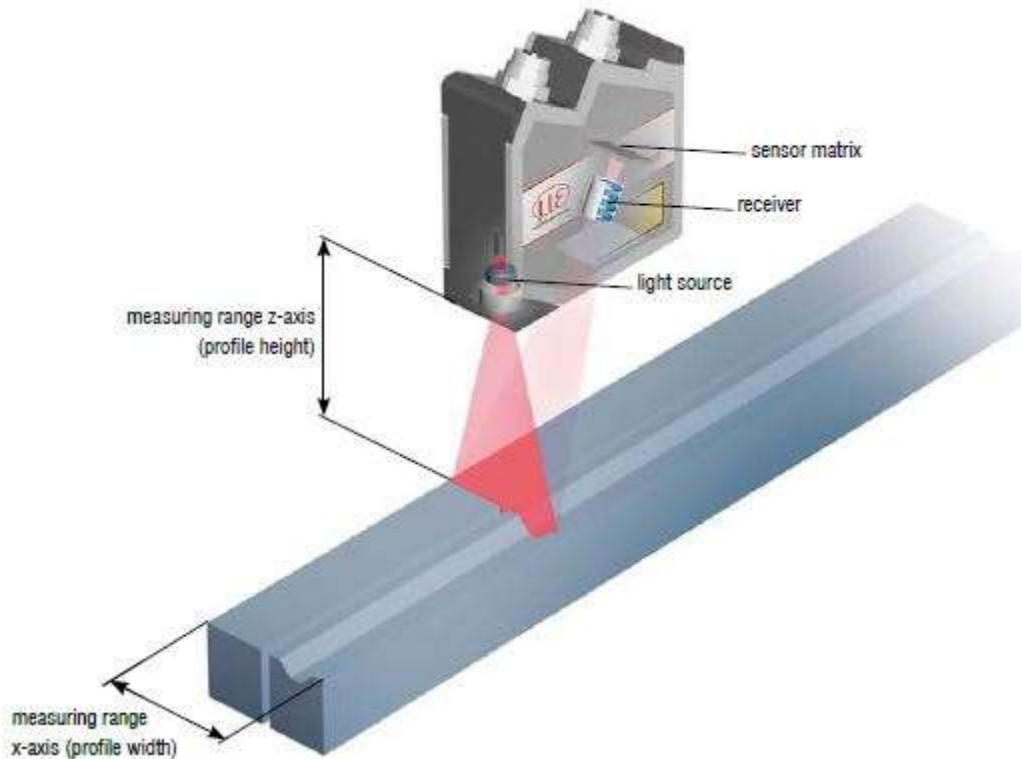
Figure 2. Laser triangulation gap measurement device from Micro-Epsilon.

The no-contact gap measurement device shown in Figure 2 is ideal because it has the necessary scanning range, working distance, and resolution needed for the project, but it retails for around $10,000. The triangulation method would be effective in imaging the rollers to determine the gap between them, but it is not practical for this project as it is out of the allotted budget.

Laser micrometers work effectively and are relatively simple. The idea behind laser micrometers is shining a laser at a gap and measuring the amount of light that makes its way through the gap. After knowing the amount of light that was initially sent through the gap and the amount of light that made it through, the gap could be determined using mathematical ratios. This is a quite effective way of measuring the distance between two objects, and the schematic of a Micro-Epsilon micrometer can be seen in Figure 3. The two main disadvantages of using laser micrometers is their price and spatial requirements. The first disadvantage is the price of the

system, as the price of one of these tools with the two micron resolution needed was about $4,000. There was no way of managing the money needed to pay for the tool. The second main disadvantage of the device was that the tool needed a receiver positioned below the rollers. The receiver portion would be exposed to heat as well as other materials that could fall through the gap. This would disrupt the work that was done in the lab and could possibly be broken through heat or something falling onto it. These two thoughts were taken into consideration when choosing the final design for the no contact gap measurement.

Figure 3. An example of a laser micrometer from Micro-Epsilon.

2.3   Capacitance and Inductance Sensors

Capacitance and inductive sensors were the next step that was taken with this project. The two sensors are able to detect ferrous metals at small distances away with extremely small precision. These types of sensors are generally inexpensive, power efficient, and very reliable.

2.3.1   Capacitance Sensors

There are more than a few advantages to using capacitance sensors for sensing something with this small of resolution. The capacitance sensor works by creating capacitance with a ferrous material. The ferrous material does not have to be part of the sensor. The capacitance between the sensor and the ferrous material changes with tiny movements between them. The change in capacitance is measured and sent as a voltage to some input. The input could be a microcontroller for instance. The capacitance sensor comes in different types and can detect a number of different materials. There are even some capacitance sensors that can detect plastics.

Capacitance sensors come very inexpensive compared to the other options that were proposed. Most of them are well under two hundred dollars; however, measuring the distance between two rollers would be very difficult because the sensor would have to be mounted on one

of the rotating rollers and would inevitably be crushed. Using this sensor would require some sort of arm or other protruding device be mounted on the rollers or something that the rollers are attached to.

2.3.2   Inductance Sensors

There are few differences in the applications between capacitance sensors and inductive sensors. They both are used for proximity sensing at miniscule distances. The way that an inductive sensor works is completely different from a capacitance sensor however. The inductive sensor works by creating a magnetic field in the proximity of the sensor. The magnetic field in return produces a certain electric current. The electric current changes by what material is inside of the electric field. The change in current is what the sensor reads and sends to the input of some other device. Both of these sensors could work properly and efficiently in the application of measuring something with the resolution of two microns.

Inductive sensors are also very cheap compared to the other options. The sensors cost about the same as a capacitance sensor at under two hundred dollars. The problem with these sensors again lies in the installation. The inductive sensors need to be rigidly attached to something that does not move for accurate readings. Research was conducted into the technical specifications needed and those available on the market, and the Keyence EX-422V inductive proximity sensor was selected, as it offered a working distance of 10 mm, and a resolution of 2 microns. A stock image of what a Keyence inductive sensor looks like when run into a microcontroller and display screen is seen in Figure 4.

Figure 4. Keyence EX-422V inductive proximity sensors that satisfy all requirements.

2.4 Strain Gauges

Strain gauges were suggested to measure microscale displacement by Dr. Nikhil Gupta. Strain gauges are sensors designed to measure the strain put on a mechanical structure that undergoes a force with a resulting displacement. They are made up of thin conductive metal that is wound so that as it is stretched it will increase in electrical resistance from end to end. Figure 5 shows four strain gauges strategically placed in a full Wheatstone bridge which gives an initial, non-displaced beam a voltage reading of zero as the strain gauges have identical resistance values. As the beam end is displaced and the beam begins to bend, the strain gauges are bent, resulting in a voltage change, as seen in Figure 5.
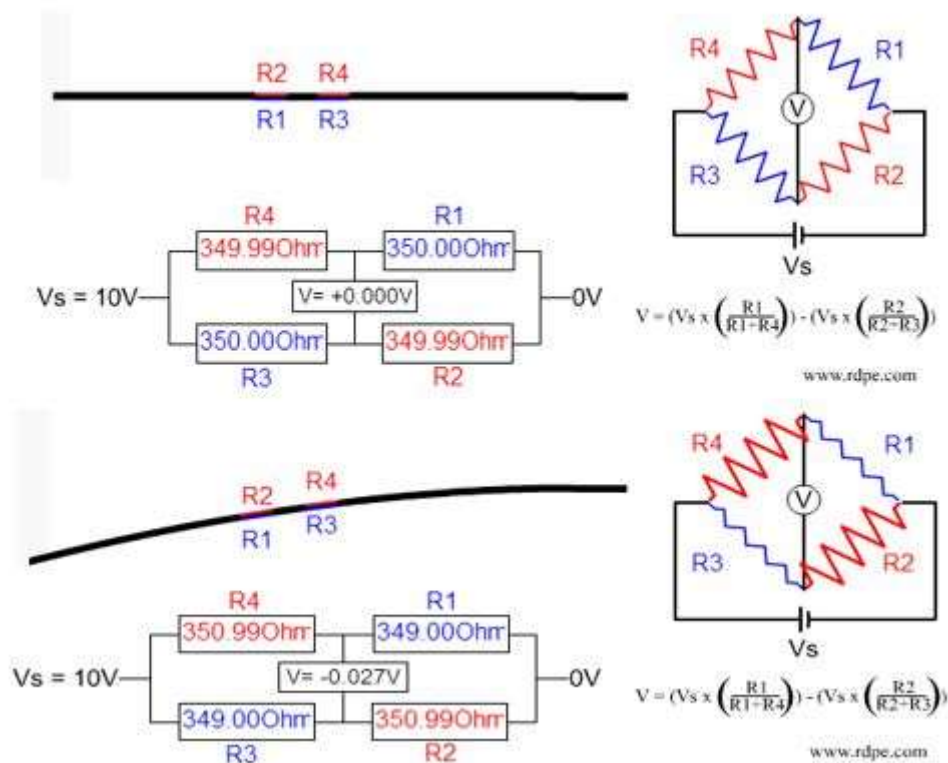

Figure 5. Four strain gauges placed in a full Wheatstone bridge.

This voltage variance can be used to calculate the displacement of the beam, which can be used to measure the gap between the rollers. A strain based load cell was the decided upon sensor that the rest of the final design was constructed around.

3.   Final Design

The final design involves the use of the strain gauge system. A Wheatstone bridge is utilized with four strain gauges acting as resistors. When the strain gauges are in tension or compression, the resulting resistance will change. This change will result in a voltage that can be used to measure the gap of the hot rollers. The hot rollers are rigidly attached to blocks and these blocks are responsible for moving the rollers to increase or decrease the gap. By rigidly attaching arms to the blocks, the arms will move proportionally to the rollers. With the installation of the strain gauge load cell to the arms, there is a way to displace the strain gauge proportionally as well. The amount of strain that the gauges will experience will be minor, therefore the resultant differential in voltage will be small. The load cell is wired to a Sparkfun load cell amplifier which will amplify the voltage and make it possible to make more accurate readings. The load cell amplifier is then connected to an Arduino Uno microcontroller. The microcontroller is able to interpret the voltage, and through programming and calibration the gap distance is calculated and displayed through an LCD screen connected to the Arduino.
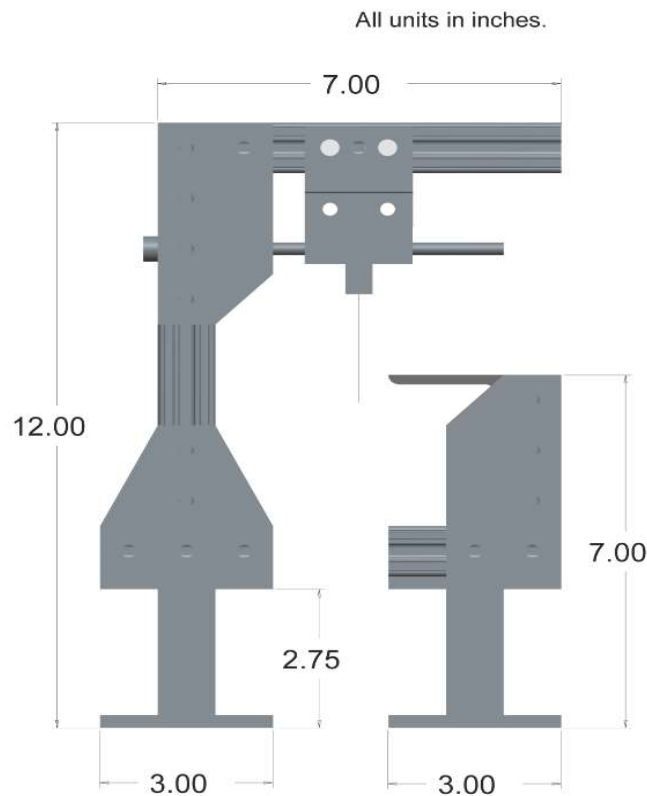

Figure 6. CAD drawing of final design.

Figure 6 shows the CAD drawings of the final design with the aluminum arms and strain gauge load cell. The aluminum that was used in the design is aluminum 80/20 with some solid aluminum 6061. The design is used to keep the strain gauge contained, the arms rigidly attached to the blocks, and raised up high enough to not be affected by the heat. The left arm is raised up to 12 inches and the right arm raising to 7 inches. The left arm contains the shim stock that contains the four strain gauges and is locked into a block of solid aluminum. The shim stock is securely attached to aluminum block which is connected to a linear translation rail which is controlled by a lead screw. The right arm has an attached bracket used to push into the shim stock in order to strain it. The I-beams connected to the bottom of arms are made of solid aluminum and were machined specifically for the device. These beams were utilized because the aluminum 80/20 was too wide and would have hung over the side of the block. Instead the I-beams lifted the arms 3 inches higher to an open space with more clearance. The final design set up on the rolling machine can be seen in Figure 7. A better look at the shim stock and locking block can be seen in Figure 8.

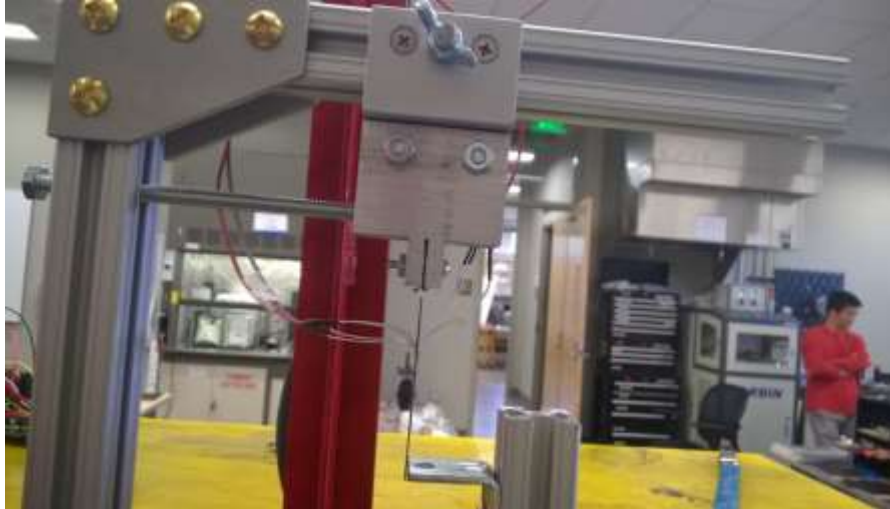Figure 7. The device mounted onto the machine.

Figure 8. Another view of the shim stock with the strain gauges attached.

3.1   Design for Manufacturing

The design was initially completed without concern for difficulty in manufacturing. The arms that attach to the roller positioning blocks were dimensioned and designed to originally be cut out of solid aluminum. When the drawings were procured and delivered to the machine shop, they suggested that the solid aluminum concept be thrown out and replaced with aluminum 80/20 components. Aluminum 80/20 is a t-slotted aluminum based "erector set" company that has what are essentially Lego pieces available to download, design, purchase, and fabricate for a fraction of the price of solid aluminum.

3.1.1   Assembly

Assembly time for the mechanical portion of the design with the necessary 80/20 parts, solid aluminum parts, and screwdriver is approximately 30 minutes. The incorporation of 80/20 parts and minimizing of custom parts paid dividends in manufacturing repeatability and assembly. A team starting from scratch with the provided bill of materials and assembly guidelines could complete the entire project as fast as the turnaround time for ordering materials would allow. A full parts listing is available in Appendix D.

3.1.2   Timeline

The timeline for the completion of this project was spaced out over a semester. Having the final design outline and plans would allow the fabrication and assembly to be done in an incredibly

timely manner by any team who wanted to repeat, replicate, or improve on the final design. The manufacturing and assembly involved was only a fraction of the total time spent on this design project, with most of the time and effort spent on initial design concepts and research into potential solutions.

Table 1. Major tasks and dates of project assembly.

Major Task	Date Completed
Strain Gauges Ordered	2/11/16
Strain Gauges Applied to Cantilever	2/25/16
80/20 Aluminum Ordered	3/10/16
Aluminum Drawings Submitted Shop	3/23/16
All Parts Arrived / Assembled	3/29/16
Prototype Testing and Calibration	3/31/16

3.1.3   Parts

The parts that were machined and/or required assembly included the strain gauge load cell, the 80/20 arms, and the aluminum block portions of the device. The process of applying the strain gauges to a cantilever arm to make a load cell required the use of a Strain Gauge Application Kit, which was lent to the team by Dr. Raphael Kampmann of the Civil Engineering Department. There is extensive material available online that outlines the process of applying strain gauges, so with the proper materials and instruction, this process took approximately 3 hours. Figure 9 shows some of the contents of the application kit used to apply the strain gauges to an aluminum cantilever arm, including sandpaper, conditioner, neutralizer, catalyst, and adhesive. Figure 10 shows the final product after the strain gauges had been attached.

The mechanical framing of the measuring device was constructed of Aluminum 80/20, which is assembled with ease using a screwdriver to rigidly attach the pieces. The CAD drawings of the parts were downloaded and assembled prior to ordering the 80/20 to ensure proper dimensioning and to assemble a bill of materials. The exploded view of the entire assembly is available in Appendix A.
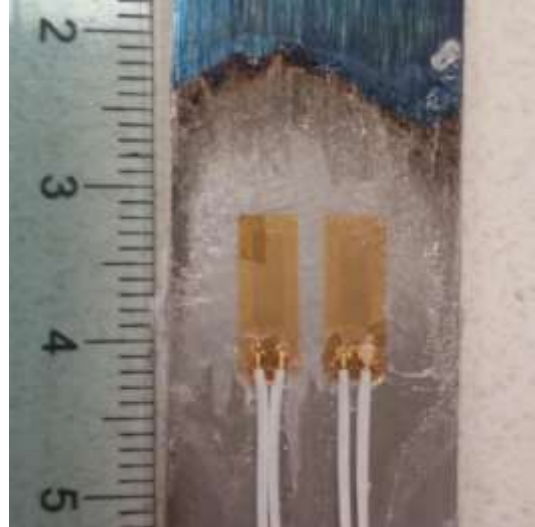
Figure 9. Strain Gauge Application Materials.

Figure 10. Load Cell Assembled.

3.1.4   Challenges

The main challenges came initially from budget restrictions, as all of the sensors that satisfied the technical specifications of the design were too expensive for the allotted budget. By the time the strain gauge design was researched and developed, time became the biggest challenge to overcome. Getting the solid aluminum pieces machined would make repeatability an issue, as it has typically a 2-3 week lead time. Further research into using off the shelf parts from 80/20 or other vendors for the entire assembly would reduce the complexity of the assembly.

3.2   Design for Reliability

The technical challenges in designing for reliability arose from the heat of the rollers and the vibration of the machine. The rollers heat up to a maximum of 300°C, and usually run at a working temperature of 100°C, so the design had to be spatially removed from these rollers or heat resistant. Finite element analysis was used to determine the ambient temperature of the air space above the rollers in order to determine how far the sensors should be removed. Figure 11 shows is a 2D cross-section of the airspace above the rollers, and this profile allowed for the conclusion to be made that any sensor placed above 2 roller radii would be essentially unaffected by the heat rising from the rollers.
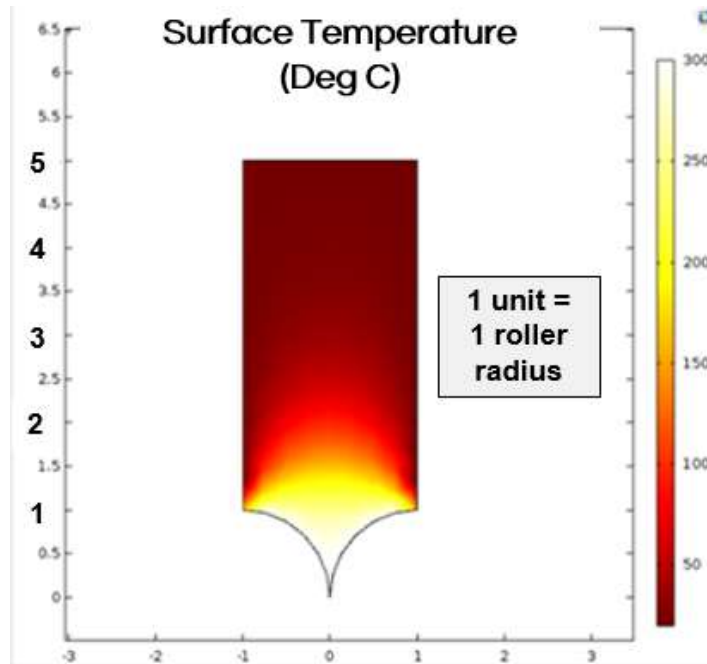
Figure 11. FEA done to analyze the temperature profile in the air above the hot rollers.

The final design incorporated removing the strain gauges as far away from the hot rollers as possible, which was about 12 inches, as the safety bars would be in the way at any higher position. The cantilever arm that the strain gauges were attached to had to be signed to get voltage variations in response to displacements of micrometers while keeping reliability in mind. The mathematics were worked out in cooperation with Dr. William Oates of the Continuum Mechanics Department, and it was determined that an ideal ratio of length to thickness of the cantilever should be greater than 10. The lifetime of the assembly is directly related to the lifetime of the strain gauge load cell, as it is essentially the only thing experiencing any physical cyclical loading. Stress equations were used to calculate the maximum deflection that the cantilever could stand before plastic deformation, as seen in Figure 12.

The cantilever can be deflected approximately half of an inch before experiencing plastic deformation, and the maximum deflection it will experience while in use is .005 inches, which allows for the conclusion to be drawn that the life cycle of this setup, with this minimal micro strain, is indefinite assuming proper use and maintenance.

The biggest frustration in reliability was the challenge of going from analog to digital signal. The quality of each electrical component in the circuit turned out to be incredibly important

because signal noise had to be minimized in order to accomplish the desired resolution
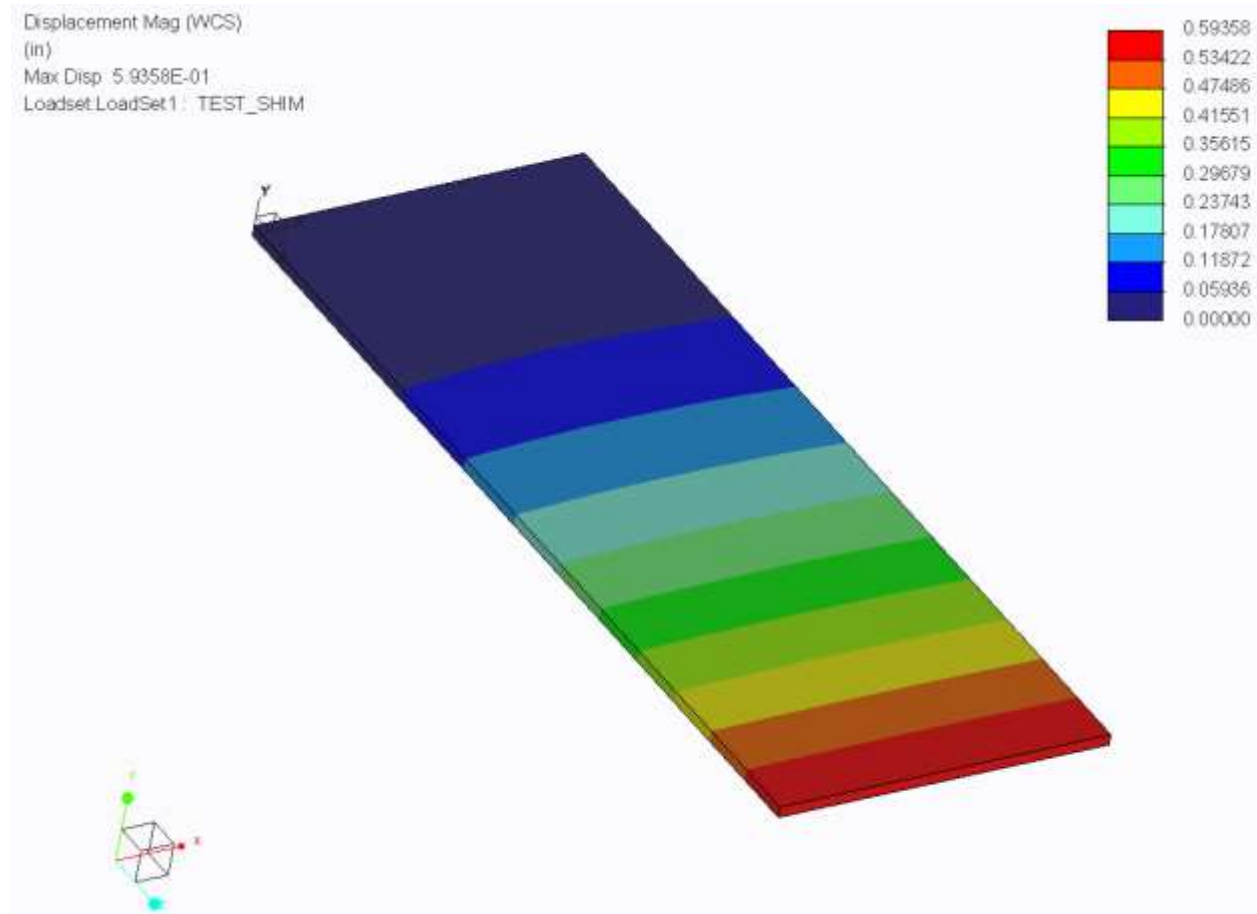
Figure 12. Maximum deflection in inches before plastic deformation analysis.

requirements. High quality wires, amplifier, and analog to digital converter are necessary to attain the 2 micron resolution.

3.3   Design for Economics

The aluminum portion of this design accounted for the majority of the expenditures, but economics was at the forefront of deciding to go with 80/20 aluminum rather than machining the whole frame from scratch. The original design for the rigidly attached arms that was drafted on CAD had an estimated cost of approximately $450 as it would have required a 24"x24" sheet of aluminum. The machine shop employees pointed out the waste and unnecessary expense of this design, and encouraged that a new design be considered using 80/20. This design still minimized machining required and dropped the price of aluminum down to $109.80, as seen in Table 2.

Table 2. Cost of Aluminum in Final Design.

Mechanical Arms Attached to Machine					
Component	Part #	Vendor	Cost	Qty.	Total
3" x 3" x .75" Aluminum Plate	6061-T651	Online Metals	$4.36	2	$8.72
2" x 2" x 1" Aluminum Plate	6061-T651	Online Metals	$3.57	1	$3.57
Four Open T-Slotted, 10 Series 8020	1010	Adams Air & Hydraulics	$18.51	72"	$18.51
10 Series 5 Hole – Tee Flat Plate	4140	Adams Air & Hydraulics	$6.80	2	$13.60
10 Series 4 Hole – 90 Degree Angled Flat Plate	4150	Adams Air & Hydraulics	$5.10	4	$20.40
10 Series Single Flange Short Linear Bearing with Brake Holes	6415	Adams Air & Hydraulics	$38.60	1	$38.60
¼ - 20 Slide-in Economy T-Nut	3382	Adams Air & Hydraulics	$0.21	40	$8.40
¼ - 20 x 0.5" Socket Cap Screws	3625	Home Depot	$0.28	24	$6.60
		Adams Air & Hydraulics	25% OFF	Student Discount	-$21.82
Total Cost (after taxes, charges, and shipping)					$109.85

The electronics portion of the design was also relatively cheap when compared to design alternatives. A basic microcontroller was needed to collect and analyze the analog data from the strain gauges. The simplicity, price, and availability of related open source code made the Arduino Uno optimal for design purposes. The strain gauges themselves were ordered in a ten pack from Omega Engineering for $165, and came pre-wired and ready to apply to the cantilever arm. The final design employs the use of four of these strain gauges and they are placed in a full Wheatstone

bridge. The full listing of electrical parts is available in Appendix D. The pie chart of the total project cost can be seen in Figure 13.
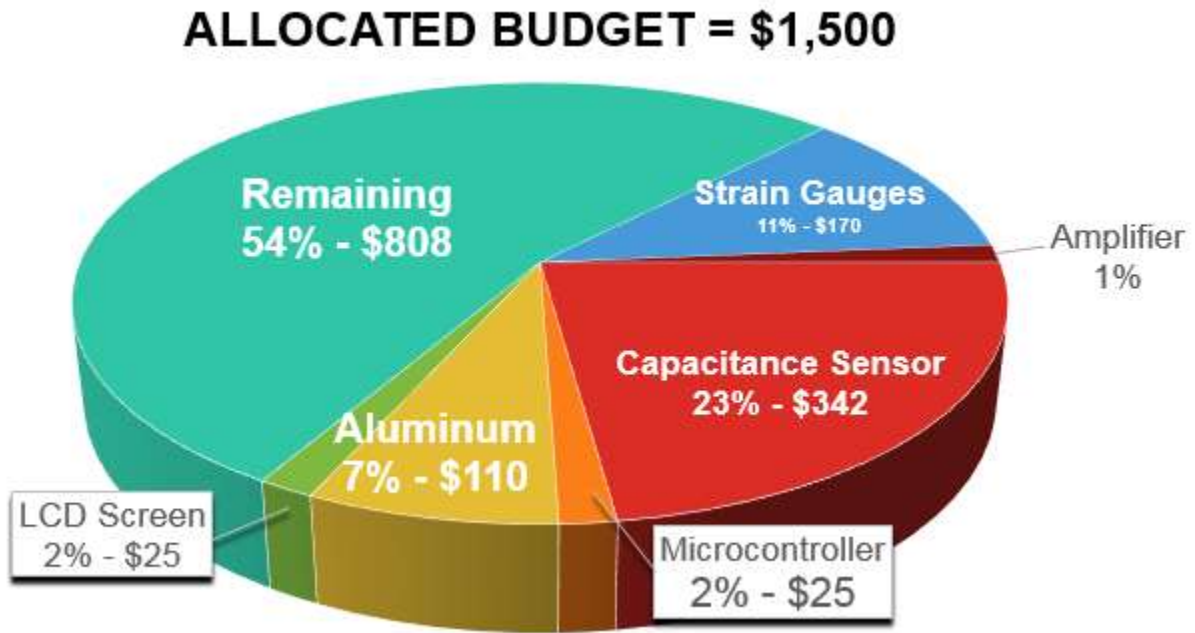

Figure 13. Total project cost, including Capacitance Sensor which was not used in final design.
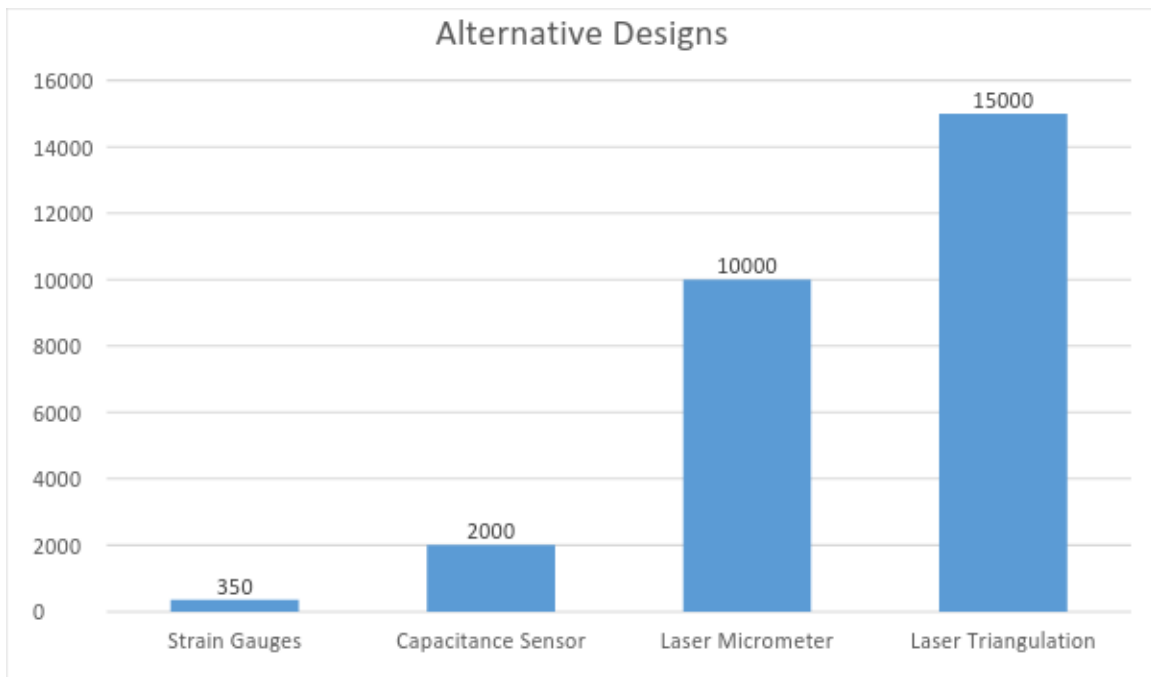

Figure 14. Alternative Design Cost Comparison.

Figure 14 shows how comparing design alternative costs to the final design cost was one of the major deciding factors in developing the design using strain gauges. The cost of a final design that made use of strain gauges as its primary displacement sensor was far and away the most cost effective, and the only design that stayed within the allotted budget of $1,500.

3.4   Design for Experiment

After the pieces for the final design were ordered and put together, the experimentation was conducted. This experimentation was completed to check the resolution of the strain gauges and to calibrate them to display the proper values and account for the thermal expansion of the rollers. The experiment was set up under the consent of the lab technician Steven and was done early in the day. The two arms, with the shim stock and gauges attached, were installed on the machine. The gauges were connected to the amplifier and the microcontroller. The readings were being printed onto a screen on a laptop because the LCD screen was not set up. The main idea was to gap the distance of the rollers to about five hundred microns, or half a millimeter, record the value that was read and make that value the zero mark. Then the rollers were decreased in increments of one hundred microns and those values at those points were recorded. Once there were five readings, one for every hundred mark, the reading when the gap was completely closed was taken. With all of these values, a linear relationship was created. The resolution of the system was also determined through this procedure. There had to be two hundred and fifty discernable units between the five hundred micron gap and the zero point for the resolution of two microns to be achieved. However, there were only around thirty-two discernable units between those two points meaning that there was a resolution of around fifteen microns. This was mainly caused by too much noise in the system. The noise that was being read could have come from a plethora of different variables including improper wires or solder points, the strain gauges not being glued properly, or even the code on the microcontroller. There was no way of acquiring a better resolution with the exact setup that was being applied.

3.5   Considerations for Environment, Safety, and Ethics

There should always be a concern for the environment, safety, and ethics when considering any engineering project, and this one is no different. The details of the project and objectives limit any potential harm to the environment. The rolling machine is located in a lab indoors and the

machine relies solely mechanical and electrical principles. There should be an effort to properly maintenance and dispose of electrical and mechanical pieces involved. Because the device is utilized in such a small scale, there are only concerns with safety in terms of the rolling machine itself. Always pay close attention when using the rolling machine and measuring device simultaneously. The device is used purely for measurement data, but because of the wide range of application with the strain gauge setup, it is important to use and record data for scientific purposes only. Using this device in other manners could come into a conflict of ethics.

4.   Project Management

4.1   Schedule

There was plenty to accomplish throughout the entire year. This may have been easy to manage with a one or two person group, but procedures had to be followed to help with organization of time for a three or more member group. The critical time path was followed using a Gantt chart. This chart was created by a member of the group and then sent out to the other group members to be studied and critiqued. This Gantt chart included the dates for major portions of the project and when they were to be completed, an outline of everything that needed to be completed, major and minor milestones along the way, and finally all the dates and times for presentations and reports. This Gantt chart helped keep the entire group on the correct time track throughout the entire project. If a milestone was missed, or if time the team was behind, then the Gantt chart was reevaluated with the new information taken into consideration. The Gantt chart was the main form of time control in the project and every member referred to it with any time constraint questions. The Gantt chart was evaluated often but followed very closely. After the completion of the design, the Gantt chart was accurate in the milestones.

4.2   Resources

The resources that were made available for our team throughout the course of the project were two machine shops, with their machinists; Home Depot; and certain electronics stores. The machine shops that were used were Mr. Larson's machine shop and the mechanical engineering shop. Most of the pieces that were machined were done in the mechanical engineering machine shop while only one part was completed in Mr. Larson's shop. The machinists were the ones to complete the work orders and machine jobs. The parts that needed to be machined were handed in

along with their metals or materials that they were made from, and a machine drawing for each piece. Because of the flexibility of the aluminum 80/20, there were few complicated designs that needed to be created. Most of the machine shop visits were for cutting one of the T-slotted bars into a smaller section or created a hole through them for other pieces. There were a couple of pieces that were created out of solid blocks of aluminum. These were the most complicated pieces in the design. These were taken to the shops with their drawings to be machined. Their drawings can be seen in Appendix E.

We were given plenty of help while shopping in Home Depot on our locking mechanism. The locking mechanism was necessary for the linear motion system but did not come with the piece from the aluminum 80/20 website. A design for this was then needed. During our visit to Home Depot, one of the workers there helped create the locking mechanism by cutting, grinding, and reshaping one of the bolts that was being offered. After the transformation, the locking mechanism worked and was usable.

4.3   Procurement

At the beginning of the project, the budget that was assigned was $1,500. This money was to be used for everything: parts and experimentation. The budget was not enough for any system that used laser triangulation or photography. Because of this, we were left with few options. The main option that remained was to create our own circuits with strain gauges. This option was the cheapest, however the resolution could not be estimated precisely. The strain gauge setup was extremely inexpensive. Ten of the strain gauges were only $170 instead of one inductance sensor being almost $350. Other expenses included the microcontroller, the LCD screen, the aluminum 80/20, the amplifier, and the aluminum blocks. The microcontroller only costed us around $30; the LCD screen costed around $30. The aluminum 80/20 was cheap at around $100 for all the pieces, including the linear motion system. This was a clear advantage over solid aluminum blocks for the metal because the aluminum blocks would have been in upwards of $600. The amplifier was under $10. Finally, the aluminum blocks that were purchased for the shim holder and the mounting feet were around $15. The budget that was assigned was appropriate for our expenses and we still have more than $500 left in our budget. The completed bill of materials can be seen in Appendix D.

4.4   Communications

The main form of communication between the group and the sponsors or advisors was email. The sponsor, Dr. Zheng, and the advisor, Dr. Shih, were emailed before every presentation and asked to attend. There were some problems with communication with Dr. Zheng during the beginning of the project, however, we would get ahold of him through his office hours. He did not attend any of our presentations even though he was contacted before every one of them. Communication with Dr. Gupta was accomplished through email and meetings. Through the entire year, we had regular meetings with Dr. Gupta to discuss our progress and our speed bumps. Many different ideas and progress were made through the regular meetings with Dr. Gupta.

5.   Conclusion

The final design concept was implemented with manufacturing, reliability, and economics in mind, and many decisions were made with the intent of optimizing these factors. The manufacturing went better than expected, as the 80/20 made the mechanical portion of design and assembly incredibly straightforward, and the machine shop was able to machine our parts with ease and get them back quicker than anticipated. The reliability of the final design turned out to be one of the pitfalls because there was a lot of noise when trying to go from analog to digital signal. The economic portion of design was successful, as the final design is much cheaper than anything else on the market for similar use, and the project was able to remain well under budget.

This project should be relatively simple for future teams to complete because the research on how to complete it within the budget has already been finished. This was the largest portion of the project and took the most time. Going back and doing this project again, strain gauges would be the first thing we would look at. If the strain gauges were made known last semester, then the entire second semester could be used to perfect the system and drastically reduce the noise which would increase the resolution.

References

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Appendix A – Exploded View Assemblies

All units in inches.
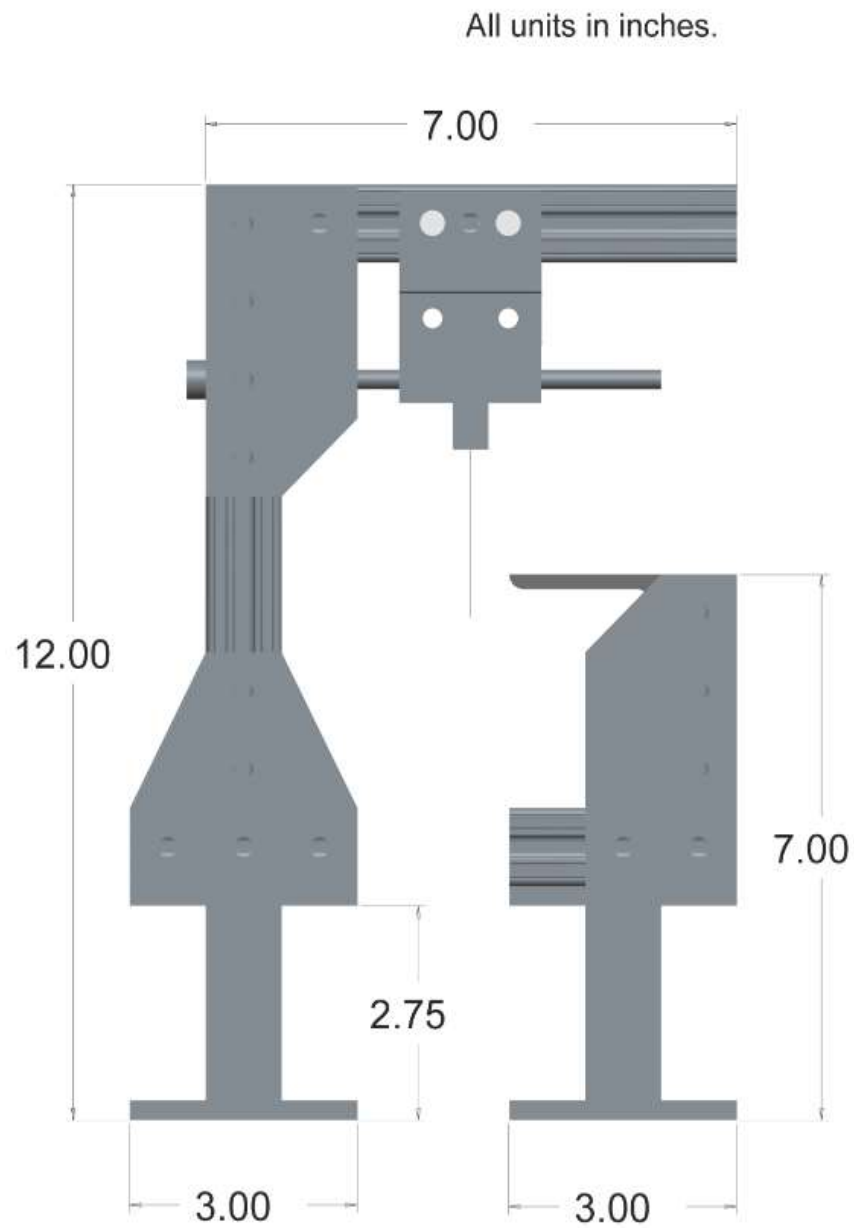
Appendix A - 1. Assembled view with dimensions.
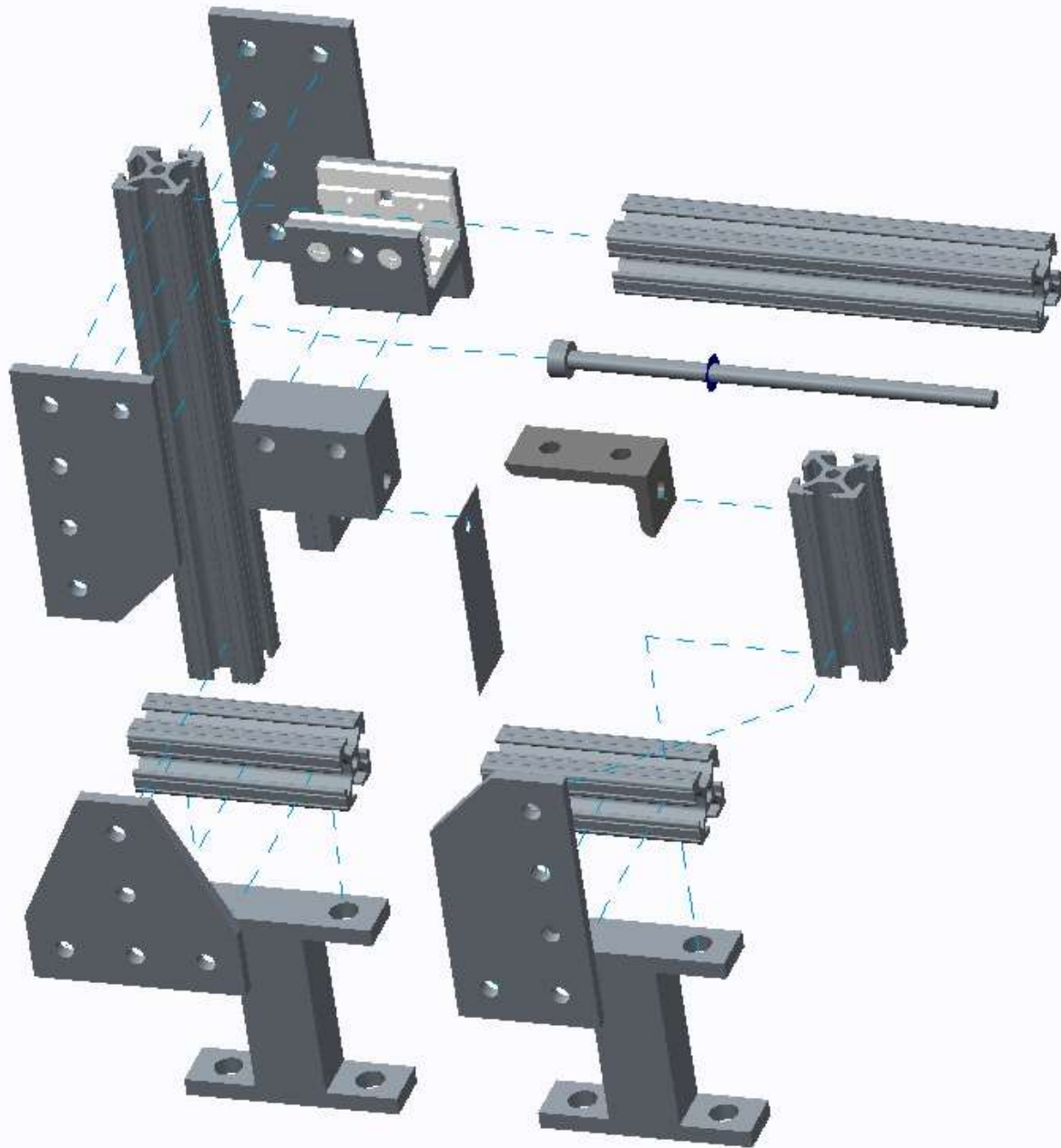
Appendix A - 2. Exploded view of assembly.

Appendix B – Cantilever MathCAD Analysis

Geometric Constraints

$h := 0.024\,in$ $C := 1$

$b := 0.75\,in$ $C_1 := 3$

$L := 2\,in$

Material Constraints (Aluminum 6061)

$sigma := 40\,ksi$

$E := 10 \cdot 10^6\,psi$

Onset of Plastic Deformation

$z := \dfrac{b \cdot h^2}{6} = 7.2 \times 10^{-5}\,\cdot in^3$

$\boxed{F_f := C \cdot z \cdot \dfrac{sigma}{L} = 1.44 \cdot lbf}$ Force required to cause plastic deformation.

Bending Force

$I := \dfrac{b \cdot h^3}{12} = 8.64 \times 10^{-7}\,\cdot in^4$

$delta := \begin{pmatrix} 0.05 \\ 0.10 \\ 0.15 \\ 0.20 \\ 0.25 \\ 0.30 \\ 0.35 \\ 0.40 \\ 0.45 \\ 0.50 \end{pmatrix} in$

$F := \dfrac{delta \cdot C_1 \cdot E \cdot I}{L^3} =$

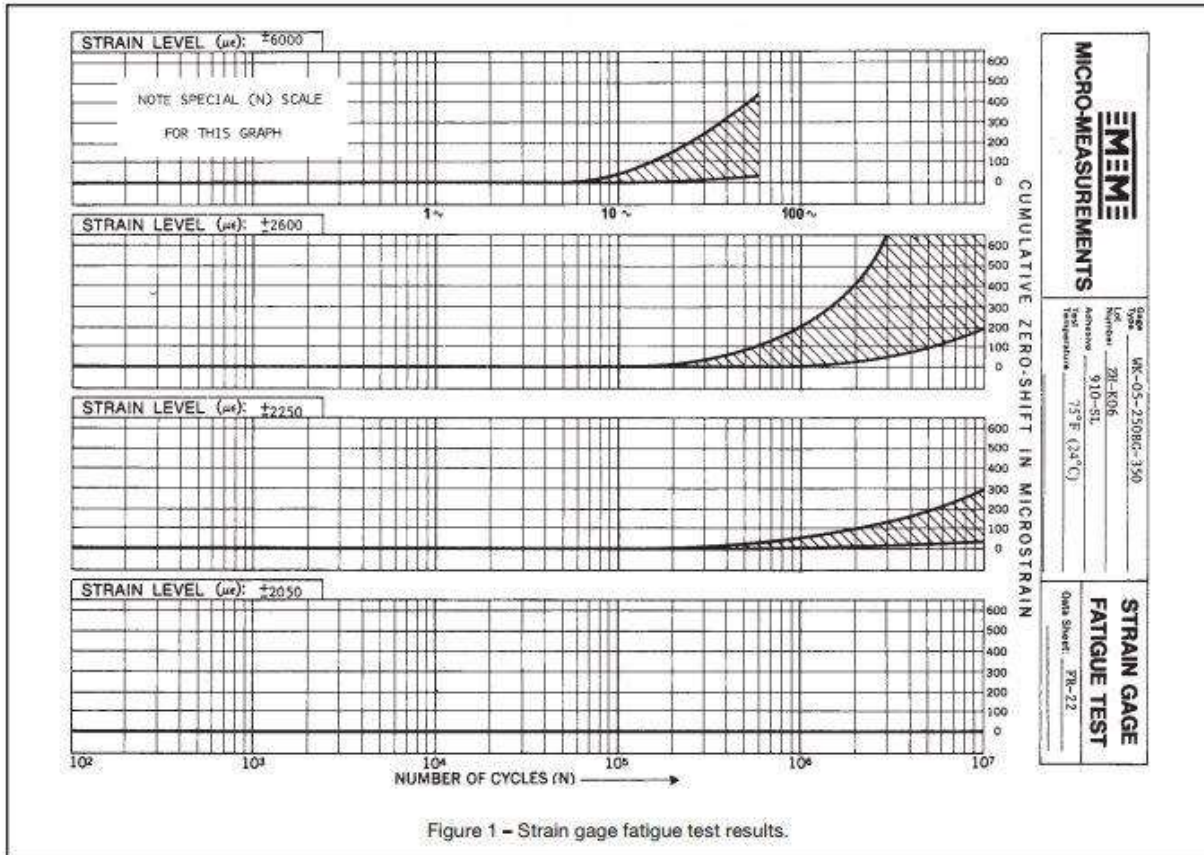|	0
0	0.162
1	0.324
2	0.486
3	0.648
4	0.81
5	0.972
6	1.134
7	1.296
8	1.458
9	1.62

$\cdot lbf$

Force applied at different bending distances.

Appendix B - 1. MathCAD data for solving for plastic deformation of the shim stock.

Appendix C – Strain Gauge Fatigue

Appendix C - 1. Strain gauge fatigue test data.

Appendix D – Complete Parts List

Mechanical Arms Attached to Machine					
Component	**Part #**	**Vendor**	**Cost**	**Qty.**	**Total**
3" x 3" x .75" Aluminum Plate	6061-T651	Online Metals	$4.36	2	$8.72
2" x 2" x 1" Aluminum Plate	6061-T651	Online Metals	$3.57	1	$3.57
Four Open T-Slotted, 10 Series 8020	1010	Adams Air & Hydraulics	$18.51	72"	$18.51
10 Series 5 Hole – Tee Flat Plate	4140	Adams Air & Hydraulics	$6.80	2	$13.60
10 Series 4 Hole – 90 Degree Angled Flat Plate	4150	Adams Air & Hydraulics	$5.10	4	$20.40
10 Series Single Flange Short Linear Bearing with Brake Holes	6415	Adams Air & Hydraulics	$38.60	1	$38.60
¼ - 20 Slide-in Economy T-Nut	3382	Adams Air & Hydraulics	$0.21	40	$8.40
¼ - 20 x 0.5" Socket Cap Screws	3625	Home Depot	$0.28	24	$6.60
		Adams Air & Hydraulics	25% OFF	Student Discount	-$21.82
Total Cost (after taxes, charges, and shipping)					**$109.85**

Appendix D - 1. Cost of Aluminum in final design.

Electrical Portion of Design					
Component	**Part #**	**Vendor**	**Cost**	**Qty.**	**Total**
Arduino Uno	A000066	Arduino	$24.95	1	$24.95
Cytron LCD Keypad Shield	RB-Cyt-73	Robot Shop	$29.14	1	$29.14
SparkFun Load Cell Amplifier	HX711	SparkFun	$9.95	1	$9.95
Total Cost (after taxes, charges, and shipping)					**$64.04**

Appendix D - 2. Cost of the electrical portion in the final design.

Appendix E – Shop Drawings
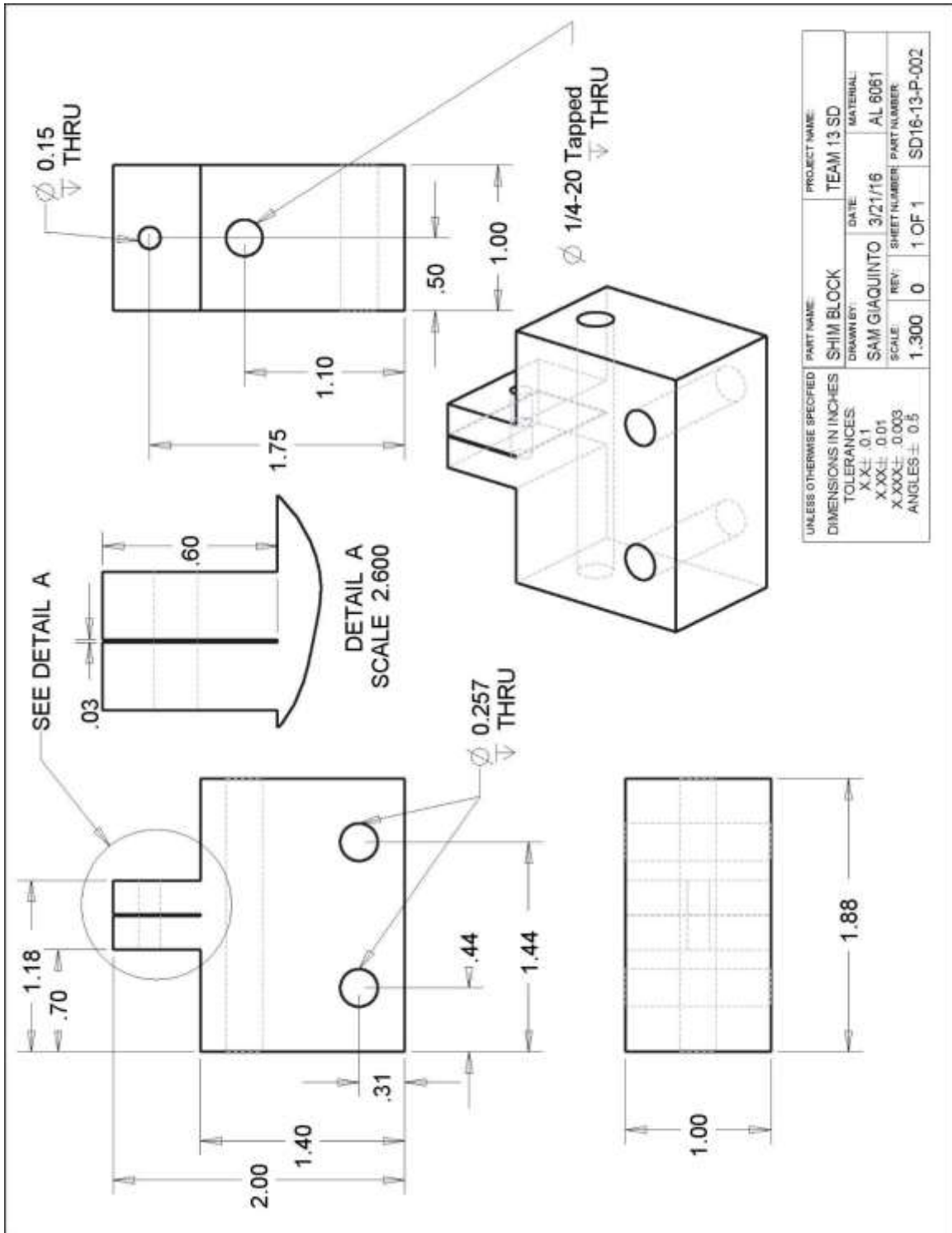
Appendix E - 1. The drawing for the shim holder that was given to the machine shop.
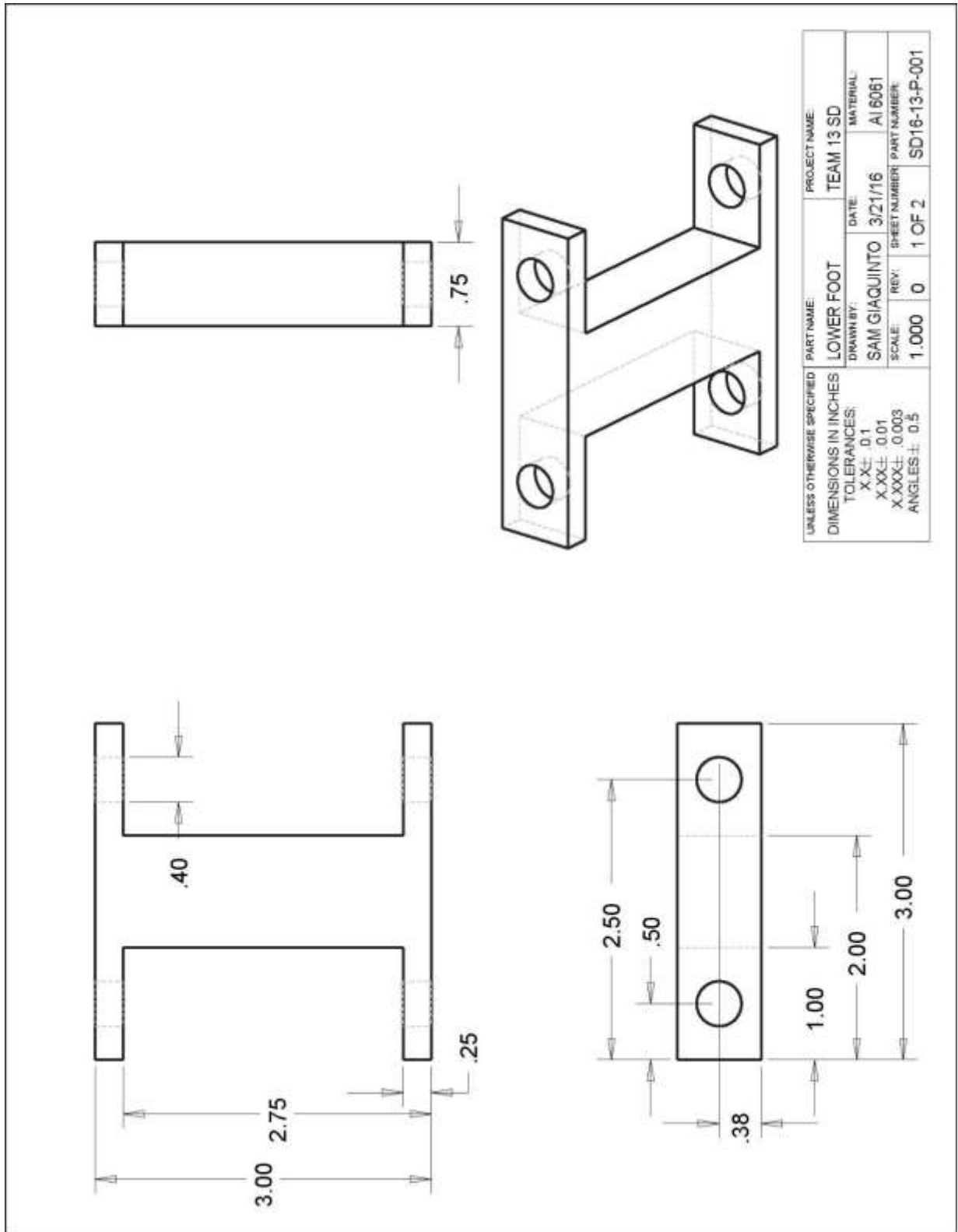
Appendix E - 2. The drawing for the lower foot that was handed into the machine shop.

Biography

Samuel Giaquinto is a mechanical engineering undergraduate at Florida State University's college of engineering. Currently pursuing the dynamics track, Samuel is interested in design work using CAD software. Expecting graduation in May of 2016, he is pursuing work in the automotive field.

Matt Nagy is a mechanical engineering undergraduate at Florida State University's college of engineering where he is currently pursuing the thermal fluids track. He is on pace to graduate in May of 2016, and hopes to work in sustainable energy.

Forrest Parker is a mechanical engineering undergraduate at Florida State University's college of engineering. Project management, website design, and computer programing are his strengths and interests. He plans on going into construction management as an assistant project manager after graduation.