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Four Point Flexure Beam Fixture

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by

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Abstract

Structural design is one of many important aspects in mechanical engineering. Newly discovered composites are making their way into the engineering world. These materials have certain properties which need to be tested in several ways before they can be put to application. One of such tests include the four-point bend test. The fixtures that can be purchased currently can be expensive, typically ranging from $700-$1,000. The University has been struggling to afford commercial jig at this cost and would be helpful if one were available. The device consists of a 6061-aluminum base making it light, cheap, and faster to manufacture than other alternatives. The base secures to the Instron with pins, making it a quick process. The 4 contact points are made from A-36 steel which can be easily assembled to the base with a socket head screw. The device was thoroughly analyzed beforehand to withstand a maximum load of 1000 lbf, which easily met that requirement. Upon project completion the device total cost totaled to $246, or much cheaper than what is available for purchase. Testing will consist of assembling the fixture and installing it onto the Instron. As well as performing a four-point bend test on a known material such as aluminum to see the difference in percent error between actual bending stress and experimental.

1. Introduction

1.1 Description

The four-point bend fixture is a fixture that is made to test material flexural strength. It is important in many engineering scenarios to understand behavior of materials under certain conditions so that they are built for certain applications. The 4-point bend test is made to bend the material and measure stress at the point of failure by measuring force vs deflection on an x-y graph.

1.2 Motivation

This project was motivated by providing a 4-point flexure beam to Central Washington University as the University needs one for their universal testing machine. The motivation also comes from learning about 4-point bend interest in observing what occurs to different materials when they are bent.

1.3 Function Statement

The device is needed to perform a 4-point bend test to test material bending strength and to determine the modulus of elasticity for a material.

1.4 Requirements

The requirements and design of the project will follow ASTM standard for a 4-point jig. Along with the following requirements

- Each component weight under 10 pounds
- Part assembly less than 20 pounds
- Cost under $600
- Size constraint within the Instron
- Withstand 1000 pounds of force

1.5 Success Criteria

Perform the bend test and compare measured and calculated bending modulus to known value of a specimen.

1.6 Scope of the Effort

Will include bottom 2-point fixture, upper 2-point fixture (4-point bend), and upper single point support (3-point bend).

1.7 Benchmark

The three- and four-point bend fixtures already exist the problem is that they are very expensive, So the benchmark would be to minimize the costs of the project. Most 3-4-point bend jigs can be as much or more than $700, the goal is to keep it under $600.

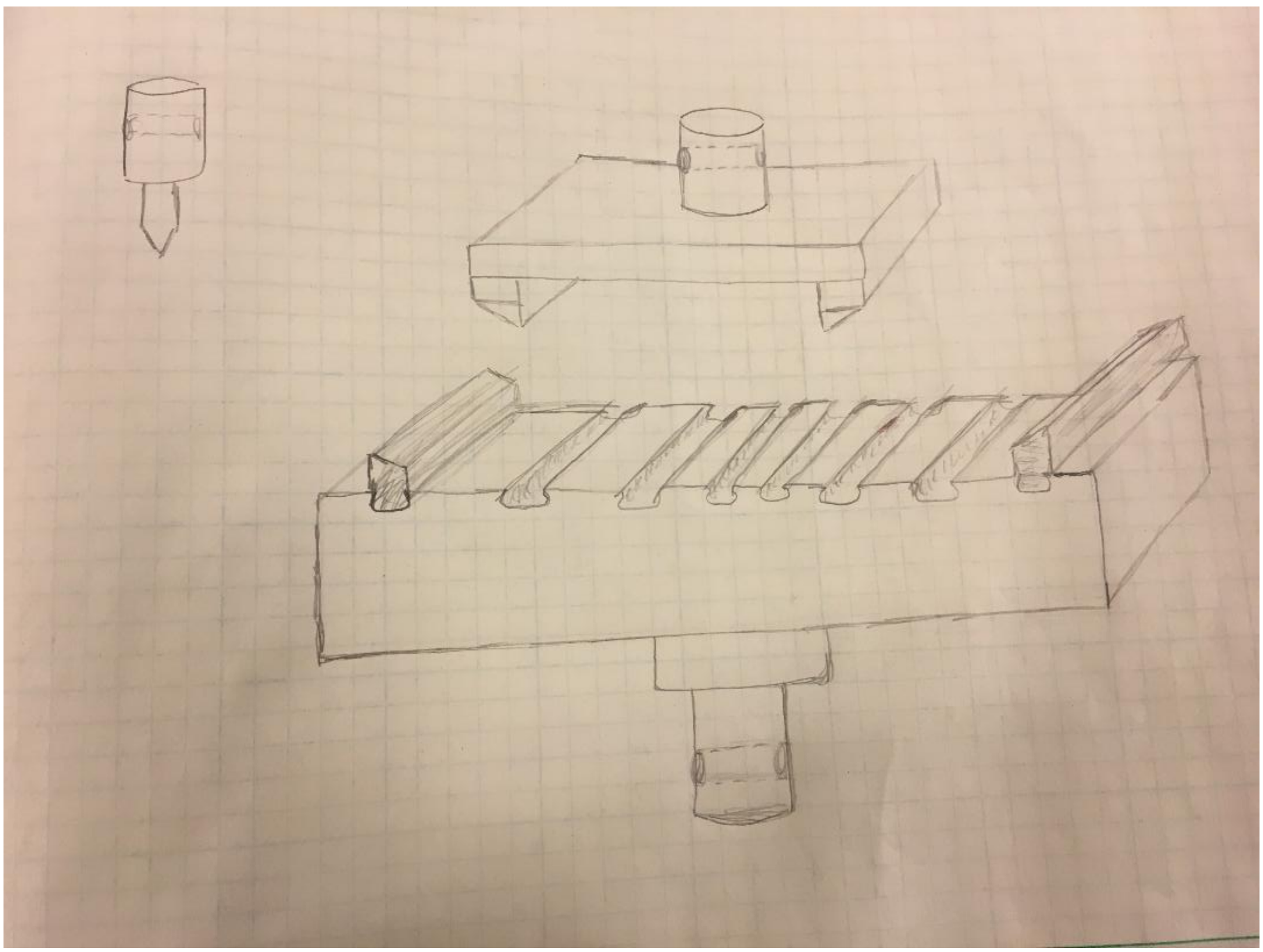
1.8 Success of the Project

Success depends on the capability of measuring the flexural stress on universal tensile machine and comparing the tested values.

2. Design and Analysis

2.1 Approach

The idea of the design was planned by examining ASTM standards of a 4-point jig in E855 (page). Initial idea of the design was also suggested by Dr. Johnson. To accommodate the requirements, the assembled part of the bottom section of the 4-point bend must weigh under 20 pounds. In this case the base of the jig was determined would be best to be made of a light material such as Aluminum. While the contact points of with the specimen will be made out of a stronger material such as Steel. The jig will be able to perform the test on specimens measuring 2 in x 12 in. The 4-point jig will look something like this:



2.2 Benchmark

The benchmark for this project is to compare existing 4-point jigs on the market and reduce the cost by around $100 dollars. The most important requirement is the jig must mount on to the Instron machine. Therefore, precision is very important when designing the mount of the jig.

2.3 Performance Predictions
The 4-point bend jig will secure onto the Instron. The bottom section of the jig will be the heaviest and will have to meet the requirement of weighing under 20 lb., so it shouldn't be a problem to install.

2.4 Description of Analysis

Appendix A1:
Drawing Free Body Diagram of all forces acting on a specimen and finding shear and moment diagrams of the specimen under the maximum load of 1000 pounds. This is repeated to find the maximum moment possible, which would occur when the length between the top two supports is at a minimum of 2 inches apart or 1 inch from the midpoint.

V_{max} = 250 lb
M_{max} = 1250 lb*in

Appendix A2:
Finding Permanent Deflection for four-point loading

Permanent Deflection = 0.276 in

Appendix A3:
Finding shear and moment diagram for the base

V_{max} = 250lb
M_{max} = 1500 lb

Appendix A4:
Finding normal stress, deflection, shear stress, and bending stress

Normal Stress = 83.33 psi
Deflection =0.000117 in
Bending Stress = 750 psi
Shear Stress = 125 psi

Appendix A5–A6:
Finding the volume of the base. Threads are simplified into cylinders to simplify finding the volume. The base is divided into two sections to simplify the calculations.

Volume =94.02 in^3

Appendix A7:
Finding the total mass of the part to determine if the part fits the requirement of weighing under 10 pounds. The base will be made of 6061 aluminum and 0.0975 lb/in^3 density is used. Also,

the total cost of the raw stock material for the base of the top and bottom assembly is found by looking at the prices on Midweststeelsuppy.com.

m_b = 9.167 lb
Base Cost Bottom = \$73.63
Base Cost Top = \$65.03

Appendix A8-A9: Finding the volume of the supports. There is four supports total, two on each assembled part. Finding the Mass and the cost of the supports.

$V_{support}$ =3.47 in^3
$M_{support}$ = 0.97 lb
Cost = \$14.67

Appendix A10: Finding Volume of the bottom attachment and approximating the volume for top attachment:

$V_{bottom\ attachment}$ = 4.01 in^3
$V_{top\ Attachment}$ = 4.01 in^3

Appendix A11: Finding Mass and Cost of the Attachments

$M_{bottom\ attachment}$ = 1.288 in^3
$M_{top\ attachment}$ = 1.288 in^3
$Cost_{top\ attachment}$ = \$8.85
$Cost_{bottom\ attachment}$ = \$8.85

Appendix A12: Determining and approximating total cost and finding the mass for the bottom assembly and approximating total mass

Cost Total = \$255.04
Mass Bottom Fixture = 12.31 lb
Mass Top Fixture = 11.5 lb
Total Mass = 23.81 lb

3. Method and Construction

Methods

The engineering discipline areas of interest comes from courses such as machining, mechanics of materials, mechanical design and material science. First and foremost, the initial design of the project is constrained by requirements such as cost, weight and performance. The initial design was conceived with the idea that the jig should be light enough to be easily installed onto the Instron. The initial requirement that the project must weigh under 20 pounds and per assembly as well as cost less than other readily available 4-point bend jigs was easily met through engineering analysis of volume, mass and cost (Appendix A5-A11). The analysis on the requirement that the jig must withstand 1000 pounds of force was performed in Appendix A3-A4. It was discovered that the normal stress acting on the base would only be about 83.33 psi which is much smaller than aluminum yield stress of 35,000 psi. Similarly shear stress on the base was 750 psi, which is much smaller than maximum shear of 30,000 psi. The project will further be optimized to reduce the weight, the initial idea is that the base of the jig can further be reduced in height to reduce the weight. More calculations of stress and deflection will need to be performed but realistically the ASTM standard specimens are so thin (0.05 inches maximum height) that reducing base by perhaps as much as two times the initial design wouldn't cause anywhere near the maximum yield and shear stress on the aluminum base.

3.1 Project Solution

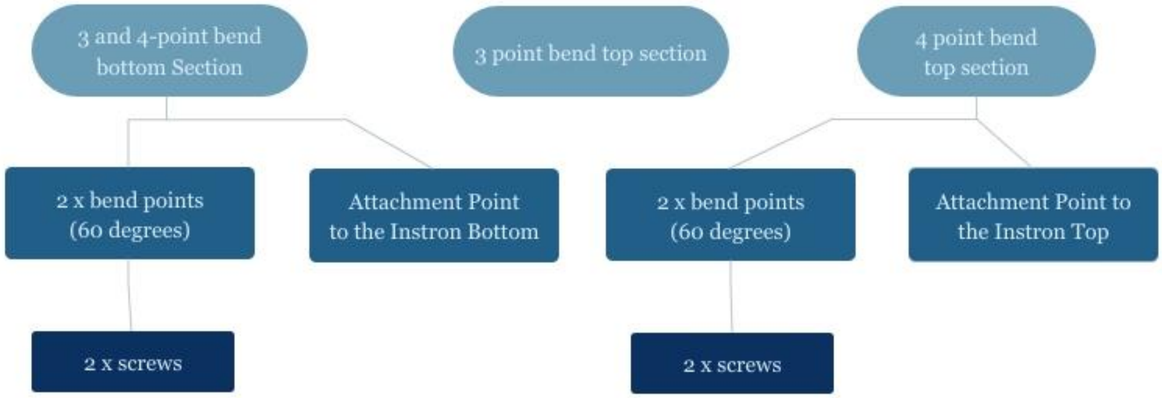
The 4-point bend jig project was planned, analyzed, and designed at Central Washington University. The project will be constrained to CWU resources and closely follow the requirements. The parts will be purchased in form of raw stock material and machined following ASTM standards and requirements.

Construction

3.2 Device Construction

The 4-point bend jig will be assembled from machined parts performed at CWU. The entire project will consist of 2 assemblies which is the bottom portion of the 4-point jig and the top portion of the 4-point jig as well as 1 part for the top portion of a 3-point bend jig. The parts will be obtained from suppliers in form of raw metal and machined to ASTM standards. The first assembly (Figure 5: 4-Point Bottom Jig) will include the stock body which will secure two 30°-supports to the stock body (secured with screws) as well as a bottom portion which connects to the stock body and the Instron. The second assembly will follow the same procedure as the first assembly, but the stock body will be smaller in length.

3.3 Drawing Tree



(Figure 1 Decision Tree)

3.4 Parts List

4-point bend base Bottom	The base of the entire jig supports the bottom assembly. Appendix B3
4-point bend base Top	The Base of the entire jig supports the top assembly Appendix B4
Supports x 4	30˚ Supports with a 0.005 radius. This will bend the material. Appendix B1
Hex Screw x 4	Hex Screws that will attach the supports to the base
Pins x 2	Will be used if design 1 is used. Will attach base to the Attachment point which will secure the bottom jig.
Instron to Base Attachment Top	Will secure the top base to the Instron. Appendix B6
Instron to Base Attachment Bottom	Will secure the bottom base to the Instron by using pins if initial design is used. Appendix B2.

3.5 Parts and Assembly

The 4-point bend jig will consist of 2 assemblies, which will be very similar. The bottom assembly consist of a base (Appendix B3), this acts as the frame of the jig. The base will attach to the piece which secures the base to the Instron (Appendix B2). The primary design is that the base and the attachment will be secured with a pin, or the secondary idea for the design is instead to just weld them together, and have it become a subassembly. The base will also hold two supports (Appendix B1). The supports will attach to the base with Socket Hex Screws which will be purchased from McMaster Carr. These will be partial threaded ideally ¼-28 with a total length of 2 inches. The complete assembly of the bottom jig can be viewed in Appendix B5. The

Top assembly will follow the same assembly, but the size of the base and attachment part will be slightly different to accommodate dimension requirements of the Instron.

Design Issues

Part 1

Some design issues that came up during manufacturing process was modifying the design because the raw material was a bit larger than the initial design, so in order to save time and not have to mill 0.5 inches from a 3.5-inch x 14.5 inches. It would be simpler to keep this size and finish the project first and the perhaps later mill of excessive material if there is time. Another problem that came up during milling, reducing the length of the steel from 2.5 inches to 2.18 inches on a (2 x 1.25) inch piece took more time than anticipated. The prediction was that it would take 4 hours, but because of multiple cuts and reducing size by 0.01 inches for each cut took way longer than expected, about 8 hours. Otherwise the project is moving along and getting close to finishing 4 parts.

Part 2

Design changes were made for the project in the past 4 weeks. These design changes include the following: reducing the height of the groove on top base and bottom base from 1 inch to 0.5 inches. Modifying the diameter of the slot hole where the attachment point is inserted from 1.25 inches to 1 inch – the reason for this change is because only one-inch end mills are available, to make the hole larger a different method would need to be used. This also means that the attachment point will now need to be turned to about 1 inch instead of 1.25 inches. The last design modification that occurred because of an issue. Since the A36 steel (Point Bends) material was hot rolled, it caused a problem when milling a 30-degree angle using a 30-degree angle tool. This made some angles turn out a bit less or more than 30 degrees, but it shouldn't be a problem when the fillet is created. The only problem is that the height of the parts at the longest section was different, so they had to be milled to the same size of 1.9 inches, which took about an extra 2 hours.

4. Testing Methods

4.1-4.3 Introduction, Approach, and Testing

The 4-point jig will be tested. Testing will be done on Instron at Central Washington University on an Instron machine. The test that will be performed is installing the jig onto the Instron and performing a bend test on a measured specimen of a known material such as steel or aluminum. Using the found values of flexural stress and flexural strain to determine the flexural modulus of elasticity of the specimen and comparing the to the known book value. The testing will follow the procedure outline in E855.

The 4-point fixture will also need to be weighed on a scale to make sure it does not exceed the maximum weight of 20 pounds for both assemblies.

Testing

The testing that will be performed includes the following. First weigh in all the pieces to check if it meets requirement for each part to weigh under 10 pounds. Check if every hole in top and bottom base can be properly secured with the bending points. There are 12 holes total that need to be checked. A bending point can be secured with a ¼-28 head cap screw and checked if the bending point sits flush. This also means that the socket head screw head should also sit flush in order to secure the point bend to the base. Next securing the attachment that holds the base to the intron will be checked. The attachment attaches to the base with a pin and must fit and sit flush for this to work. Same will be done with the Instron and the assembled part. Next the assembled part will be checked to see if it meets the weight requirement of less than 20 pounds per assembly. Lastly check if the both assemblies properly secure to the Instron and sit flush.

Testing Update 1

One of the requirements was to make sure that the jig assembly fits within the Instron in Hogue Hall 127. The test was performed by assembling the parts and attaching both the top and bottom assemblies onto the Instron with the pins. Both parts that fit onto the Instron were manufactured to the same length of 1.77 inches (Appendix 2B). Although the bottom piece fit in perfectly onto the Instron the top piece did not. The reason for this is that the setup with the Instron itself has two different bolts that attach onto the top and bottom. The one on the top has slightly larger length on the head of the screw. This means that when the jig is inserted the distance with the pin is slightly misaligned. This is fixable in two ways. One would be to face of both jig insertions. Since on the bottom it sits on its middle portion where on top the top face pushes off on the bolt. The other way would be to just face one of the insertions and label as top and bottom attachment. Another the requirements were that every component must weigh under 10 pounds, and that each assembly should weigh under 20 pounds. The first test that was performed was to check the weight of each component. All eight of the main components that was checked for mass includes the following and their respective mass: bending point 1: 1.2 lb , bending point 2: 1.2 lb, bending point: 3: 1.2 lb , bending point 4: 1.2 lb , base top: 10.1 lb , base bottom: 11 lb , jig attachment bottom: 0.4 lb, jig attachment top: 0.4 lb,. Next the top assembly was assembled with 2 bending points, top base, jig attachment top, 2 pins (ø-0.5 in x 3.5 in), ¼-28 head cap screws length 2.25 in. The mass was then of the top assembly was then checked and came out with 12.9 lb. Similarly, the bottom assembly was assembled in the same way and the mass was measured to be: 13.8 lb. The results can also be seen under appendix C.

Testing Update 2

During the second part of the testing phase for the project, some of the issues that occurred during testing includes testing for 1000 lbf requirement. As Central Washington University is currently closed, and the equipment needed for the test includes the Instron machine located in Hogue Hall. Previously TA Jim Helsius assembled the fixture onto the Instron for the testing the requirement of size constraint within the Instron. Both assemblies assemble onto the machine now. Another problem that occurred was to create video and test for the mass requirement the fixture had to be recovered and further testing had to occur outside of University.

5. Cost and Budget

5.1 Suppliers, Cost, and Issues

The project will be managed by first ordering the parts from sources such as Midweststeelsupply.com. These parts will come as a raw stock material in a form of plates and bars. The raw stock material will then be machined to the designed parts in drawings in Appendix B. Some of the parts such as hex screws or pins will be ordered from Mcmaster.com. These parts will be used to assemble the machined parts to create the 4-point jig. The list of all the parts and their cost can be seen in appendix D.

The most important part when creating the machined parts is that dimensions must be accurate and so there is very little to no room for error. A single mistake can make the part useless which means new stock will have to be ordered and that results in lost time and increases the cost of the project.

Actual Budget

As of January 7th, 2020, all raw material was purchased. The expected cost of raw material was \$214.5 plus shipping cost. The actual cost of the raw material was \$211.27 with shipping included in this cost. The reason why this price was lower than expected was because when ordering raw stock in bulk it costs less then the prices shown for individual item. The project requirement is that it must be less then \$600. So far only 2 pins are left to purchase which is approximated to be around \$10 plus shipping. Due to change of the design due to advising from Matt Burvee, instead of buying hex screws, the design was changed to socket cap screws (1/4-28). The approximated cost for these screws is about \$30 plus shipping.

So far the expected cost of the project is \$250-\$300. Which is way below the requirement of under \$600.

Budget Cost Issues

For the budget there was not much issue when it came down to meeting the cost requirement for the project. Majority of the research was done before ordering the parts and a rough estimate was made for the cost. It was previously predicted that the cost of the project was going to be between \$250-\$300 dollars. With an estimated guess of \$251.27, the project came out to be at \$241.36 which is even cheaper than the estimate. The reason for this is because some ordered parts were identical, and when ordering in ‘bulk’ from Mid-West Steel Supply meant that there were discounts on those parts, and they came out cheaper then initially expected.

6. Schedule

6.1 Tasks, Deliverables, And Total Project Time
The first task is to order raw stock for the project early, so that they are available for winter quarter. The stock will be ordered in early December. Next five parts must be machined by the end of week three in winter quarter. The project consists of eight parts totals excluding the socket hex screws and pins. This means that majority of the project shall be completed very early, this will help reduce the load later in the quarter or if some issues arise this can be resolved earlier rather than later. By week five 70% of the project must be completed which should not be a problem if 5/8 parts are made in week 3. This means that this means that only 1 part needs to be made to reach that requirement. By week 7, the entire project shall be completed and assembled. To fulfil the deadline requirement for the project listed above the parts that shall be completed by end of following weeks is listed in Appendix E.

The total time to complete the project is estimated to be 160.5 hours. This estimation is done from the Gantt chart in Appendix E for quarter 1 which took 53.5 hours to complete.

Scheduling Issues
Scheduling issues that occurred during manufacturing phase of the project include the following: estimating times for manufacturing parts vs making the parts can be completely different. For example, when making the first four parts it was estimated that it would take about 2 hours to make each part, when in fact it took nearly 7 hours per part. The main reason for this is because of changes made as well as reducing the length of the part from 2.5 to 2.18 inches with several passes and only .01 inches taken of per pass. This results in the part taking much longer to make than expected. Other scheduling issues that arose, include expecting to start making one part, but then due to complications a different part had to be made first. For example, the initial design of the base had a hole designed to 1.27 inches in diameter so that a 1.25 base attachment could fit inside. This had to be changed because making a hole of that size requires learning new techniques, so instead the hole was changed to 1.00 inch, this means that the base attachment now had to be turned by about .26-.27 inches more to fit inside, this takes more time then the initial design.

During the spring quarter, some scheduling issues that occurred for the project are mostly related to COVID19, as the University was closed during this time. One of the issues with this is performing the necessary tests for the project, which includes testing the requirement for the 1000 lbf. In order to perform this test, the Instron machine is required which is located at CWU. To perform other tests and take videos and pictures of the project, the project had to be recovered from the University by contacting Professor Pringle and allotting the time to make the drive from western WA.

7. Project Management

7.1 Resources

The most important resource is the person working on this project, so safety is number one priority. Safety of others is just as important as the safety of the engineer that is why it is important to be aware of dangers and surroundings so they can be avoided. Other resources include the following mentors: Doctor Johnson, Matt Burvee, Professor Pringle, Professor Choi, Jim Helsius, Ted Bramble and the Central Washington University resources of staff and equipment. This equipment includes computer labs and classrooms where the project is designed, analyzed, modified, and built. Other important resources include SolidWorks, Microsoft Word, Microsoft Excel, and Machining lab that are made available by CWU. The 4-point bend fixture project will be funded by engineering student. With all the available resources available, the project will be successful.

8. Discussion

8.1 Design Evolution

The proposal for the project was introduced during week 1 of Fall Quarter. The initial design started out as depicted under Design and Analysis. The initial design was going to be made entirely out of steel, but Dr. Johnson suggested that the base could be made from aluminum to make it lighter. During week four of quarter one the design was modified again (Appendix B5). The base of the project was modified with constrained walls on the sides. This was done with the idea that the when assembling the supports to the base they would be kept perfectly aligned at a 90-degree angle. Another thing that was modified was the supports, or more specifically how they attach to the base, it was decided that it would be best to secure them with a socket hex screw. The supports were also modified to fit the ASTM standards, the change that was made was to put 0.005-inch radius fillet on top which will bend the material. The attachment was also modified to be made out aluminum, so the only part that will be steel is the supports that will bend the material.

8.2 Project Risk Analysis

The two most important risks to consider is project management and schedule. The project is constrained to be completed in 10 weeks during winter quarter, this means that there is very little room for error when machining the parts. Mistakes will not only waste a lot of time but also increase the costs substantially. Some of the risks will include, making proper analysis, taking correct measurement so that the fixture can be assembled and attach to the Instron, Machining correct parts, taking relevant data during testing, and doing correct research to extend the knowledge and expertise on the project**.** The project will be successful if the outlined schedule in Appendix E is followed. As well as understanding risk analysis and planning with proper task to take during designing and machining of parts. Also, following the safety outlined in Appendix J will also mean the project can be done safely.

Manufacturing Issues/Modifications

There were several issues that occurred for the manufacturing phase of the project in the first half of the project. The first big issue that occurred was that the design had to be slightly altered become the raw stock material is slightly larger than that for which was designed. The 4 points that bend the material were designed for a width of 1.00 inch, but the stock material was 1.25 inches, because of this it was discussed with advisor Matt Burvee that it would be better to just keep the material at 1.25 inches to save time. The design for the length of the material was 2.18 inches, this had to be machined down from a length of 2.5 inches for raw stock. The issue that occurred here is that because the material is A36 steel it took quite a bit of time to do this. The main reason is because on the mill only 0.01 inch could be removed at a time, as well as 2 passes had to be made for each length reduction. It was predicted that this would take 4 hours, but it took more like 8 hours. Similarly making the 30-degree angle cut had the same issue, instead of predicted 2 hours, it took more like 4 hours. Since it took more time than expected the project fell a bit behind schedule. For the following week it is expected to bring in 50% of the finished parts. This may not be a problem since there is only 8 total parts, and four are nearly done.

During the second half of manufacturing the project some of the issues that occurred was mostly human error. For one of the cylindrical parts, the diameter has a very tight tolerance of 1.24 in +/- 0.003 in or so. Initially the part was turned to a diameter of 1.25 in, but it couldn't fit into the Instron. So about .01 in had to be taken of to be within tolerance. In the process of doing so something must have gone wrong when touching of the zero from the side of the cylinder because instead of the material being 1.25 in it went all the way down to 1.215 in. This must have happened because of some human error when setting up the part. So, what happens when this diameter cylinder is inserted into the Instron without a tight fit, it wobbles around side to side. In order to fix this problem, the first solution was to use knurling. This only added about .005 inches to the diameter although it helped it was still nowhere near the desired diameter. The next step that was taken to resolve this issue was to take an electrical tape and wrap it around to increase the diameter. This increased the diameter to about 1.238 which is in desired range. Although it is not perfect it works.

Aspects of Testing

The project was a success. It meets the first requirement of the ability to be installed onto the Instron. Although some dimension tolerances could be improved, such as reducing the height of the cylinder that attaches to the Instron, as this will allow the pin to slide in easier (Appendix B). The total cost of the project came to be $241.36 which easily met the requirement of $600 dollars. Most four-point flexure fixtures are around $700-$1000 dollars. In order to easily install the fixture each assembly had to be under 20 pounds. This requirement was also met with the bottom assembly having a mass of 13.8 lbm and the top assembly of 12.9 lbm.

Conclusion

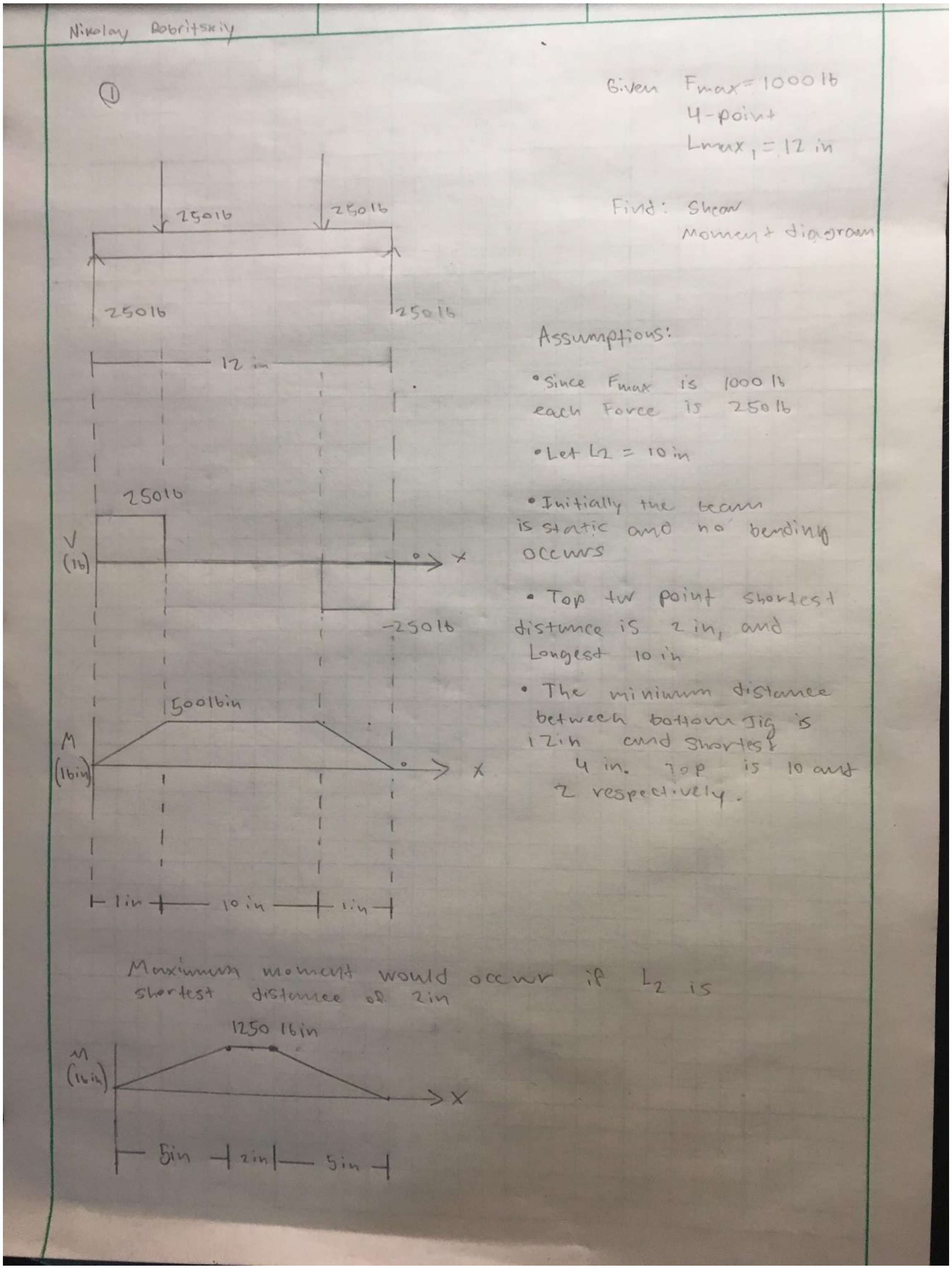
The 4-point bend fixture will be a successful project because the engineer has the resources readily available through Central Washington University. Mentors including Doctor Johnson, Professor Pringle and Professor Choi will guide him along the path to success. As well as the expertise developed throughout the time of coursework to make this project possible. The fixture will meet all the requirements through design and engineering analysis. The engineering analysis performed on the fixture contributes to meeting the requirements of cost, mass, dimensions, and structural integrity for the project to be successful. The 4-point bend fixture will fit onto the Instron and be ready to take measurements of 6 aluminum specimens.

10. Acknowledgments

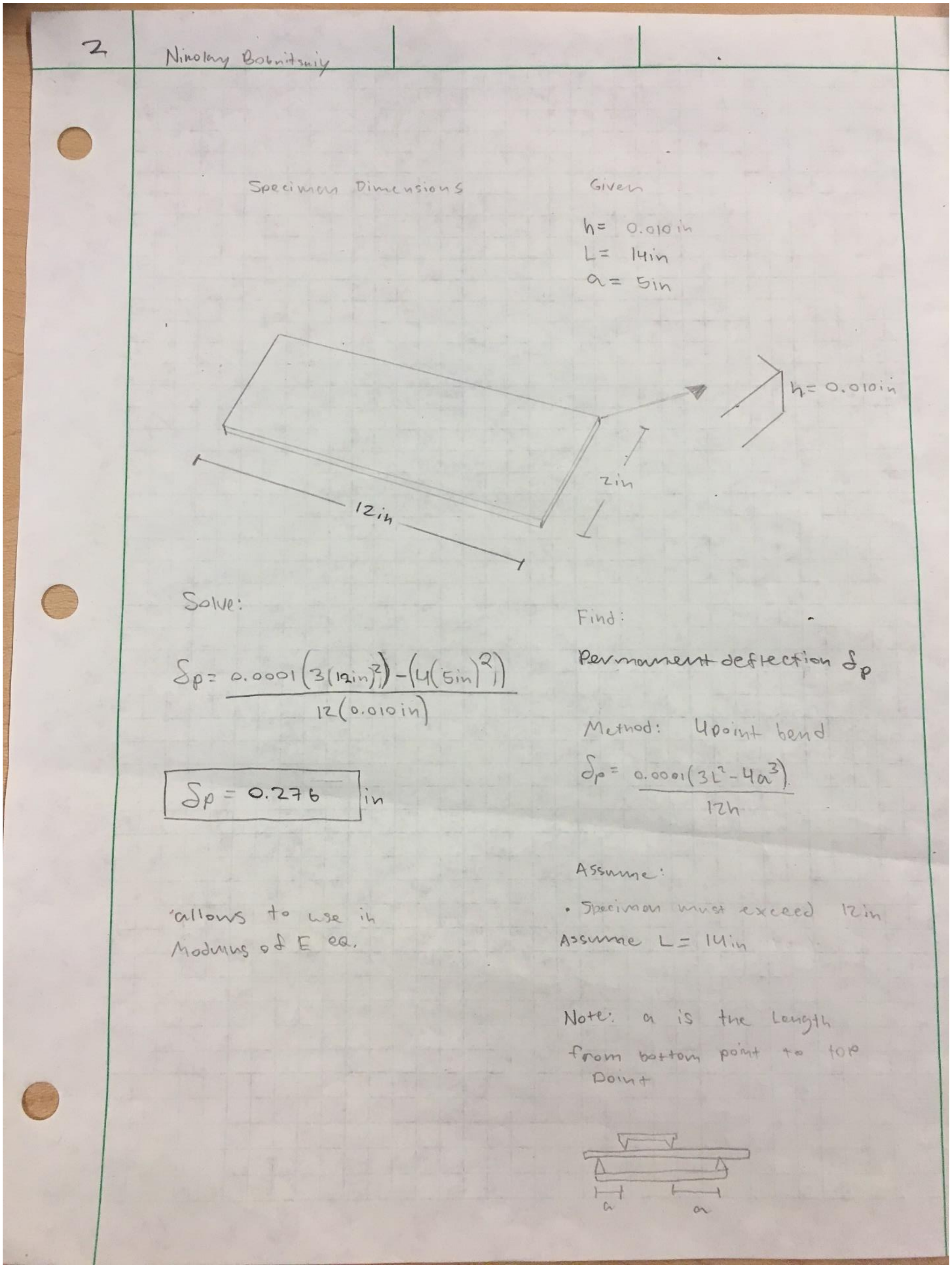
Advisors

Matt Burvee
Dr. Johnson
Professor Pringle
Professor Choi
Jim Helsius
Ted Bramble
Huy Dinh

Appendix A: Analysis



(Appendix A1: Shear and Moment diagram example)



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Specimen Dimensions

Given

h= 0.010 in
L= 14in
a= 5in

h= 0.010in

2in

12in

Solve:

$$\delta_p = \frac{0.0001\left(3(12in)^2\right)-\left(4(5in)^2\right)}{12(0.010in)}$$

$\delta_p = 0.276$ in

'allows to use in Modulus of E eq.

Find:

Permanent deflection δ_p

Method: 4point bend

$$\delta_p = \frac{0.0001(3L^2-4a^3)}{12h}$$

Assume:

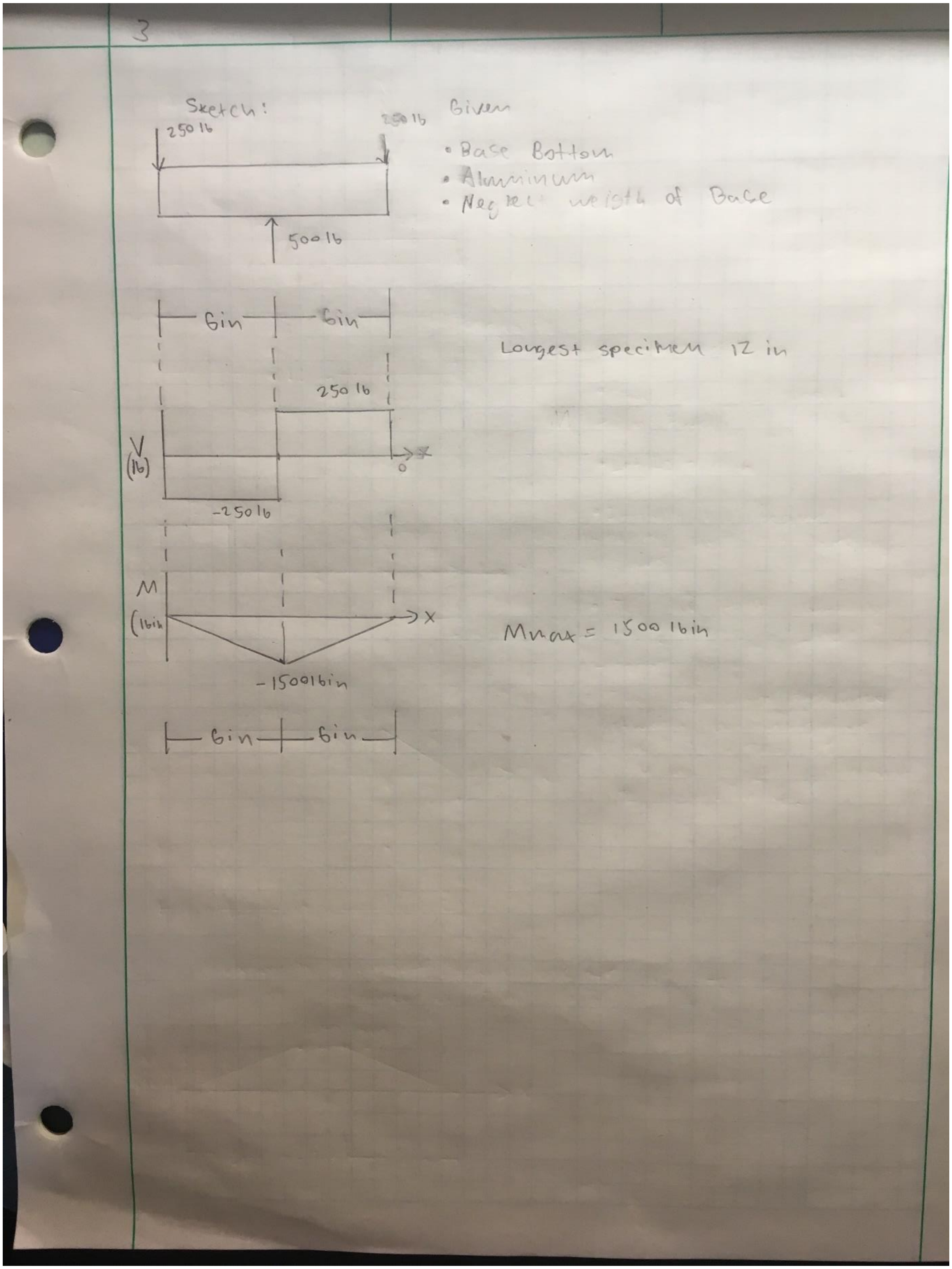
- Specimen must exceed 12in

Assume L= 14in

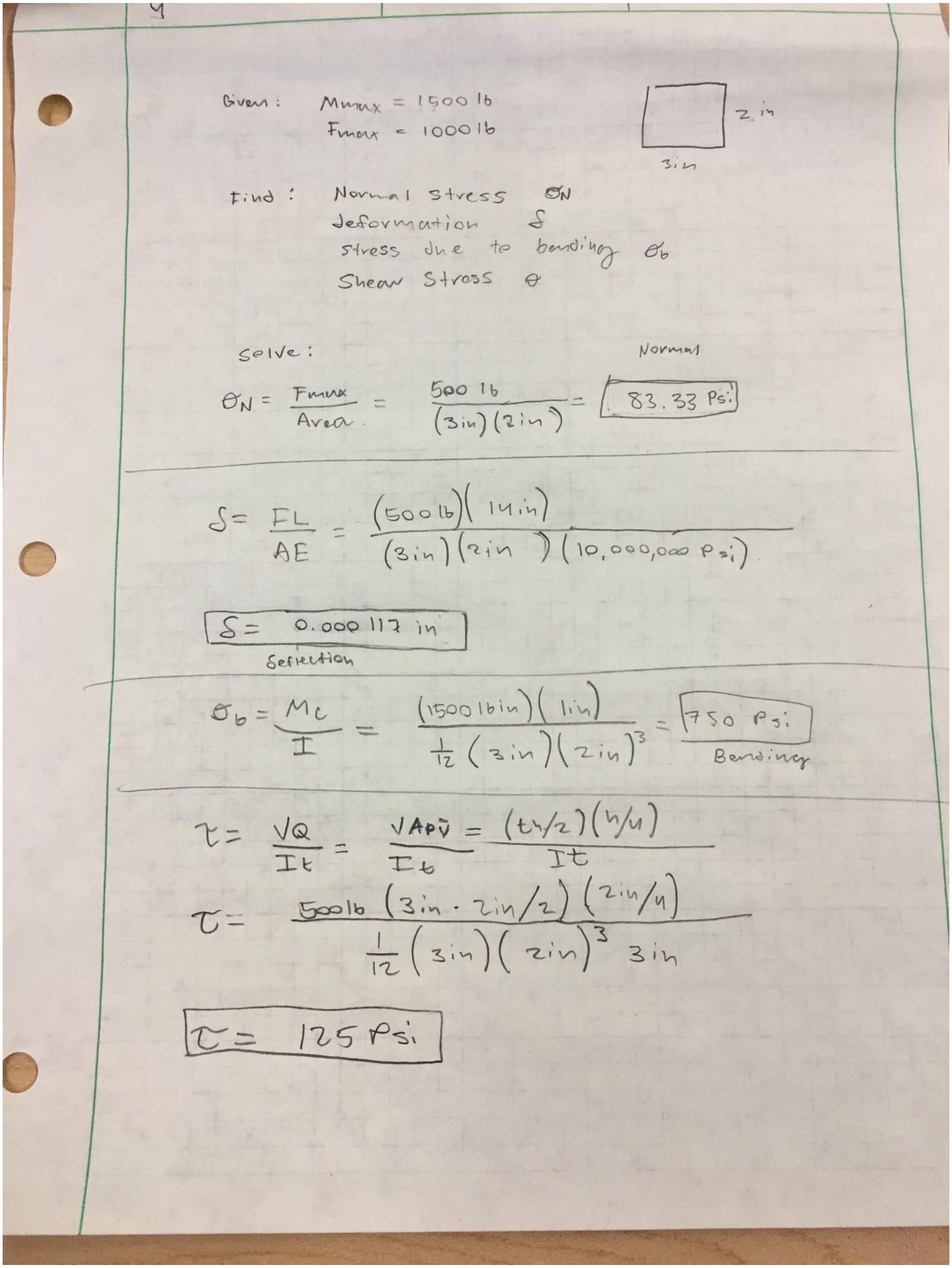
Note: a is the Length from bottom point to top point

a a

(Appendix 2A: Permanent Deflection)



(Appendix 3A: Base Shear and Moment Diagrams)



(Appendix 4A: Fining Normal, Bending Shear Stress, and Deflection)

5

Given

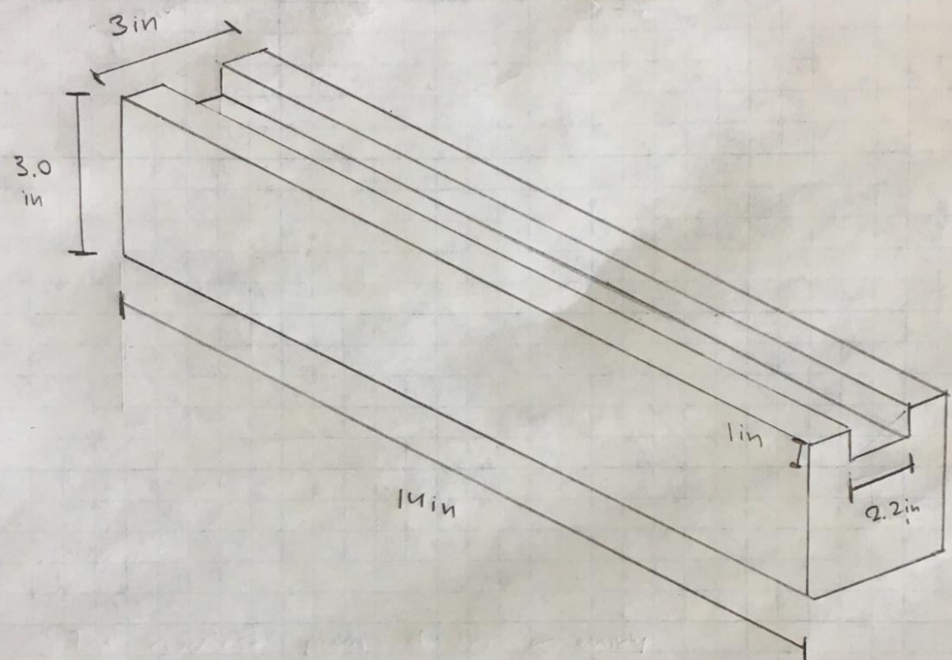
Each component weigh under 10 lbs

* withstand 1000 lb load (design to 1100lb)

Find: If design is suitable for material used

Volume:

Base Sketch



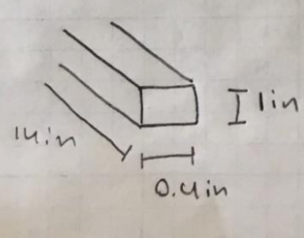
Assume: use Aluminum for base

: 6 taps treat as cylindrical 2inch wide specimens

Solve:

$V = (1in)(0.4in)(14in) = 5.6in^3$

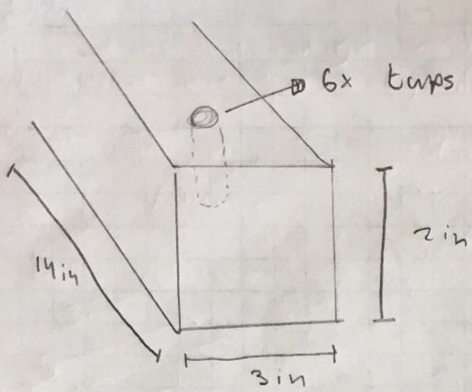
2x



V_{top} $5.6in^3 \times 2 =$ $\boxed{11.2in^3}$

(Appendix 5A: Determining Volume for Aluminum Base)

6



d = 0.5 in
h = 1 in
treat as cylinder

bottom portion

$V_B = (14in)(2in)(3in) = \boxed{84 in^3}$

(Screw Area) $V_A = \frac{1}{4}\pi d^2 = \frac{1}{4}\pi (0.5_{in})^2 = 0.19635 in^2$

Screw Volume $= Ah = (0.19635 in^2)(1 in) = \boxed{0.19635 in^3}$

V_{ST} = 6 screws = $0.19635 in^3 \times 6 = \boxed{1.17810 in^3}$

Total Volume of Part

$V_T = V_{top_{total}} + V_{bottom} - V_{ST}$

$V_T = 11.2 in^3 + 84 in^3 - 1.17810 in^3$

$\boxed{V_T = 94.02 in^3}$

(Appendix 6A: Base Volume Continued)

7

Find: mass of base

Given: Volume = 94.02 in^3

Material = 6061 Aluminum = 0.0975 lb/in^3

Solve:

$$m = \rho V = (94.02\,in^3)(0.0975\,lb/in^3) = \boxed{9.167\ lb}$$

Given: ordering stock of aluminum

Find: cost

Assume: midweststeelsupply.com

Plate

base

dimensions: $(14.5 \times 3.25 \times 3.25)\,in^3$

6061 Aluminum

Solve:

About $73.63

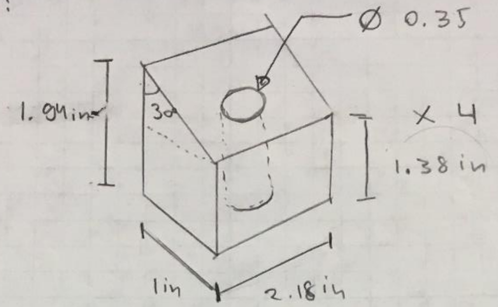
Top Jig will be $(12.5 \times 3.25 \times 3.25)\,in^3$

About $65.03

(Appendix 7A: Finding Base Mass)

8

Sketch:



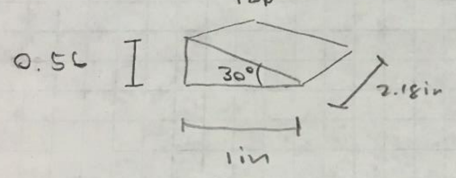
Given: Sketch

Find:

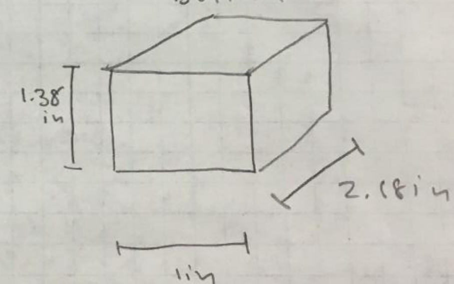
Volume
Mass
Cost

Assume: Steel
2 per assembly

Top



Bottom



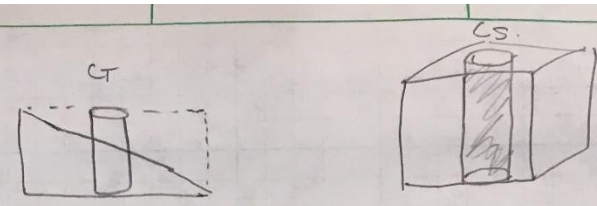
$$V_T = \frac{(0.56 \times 1 \times 2.18) in^3}{2} = 0.61\ in^3$$

$$V_B = (1.38 \times 2.18 \times 1in) = 3.01\ in^3$$

(Appendix 8A: Support Volume)

9

Vc



$$V_{CT} = \frac{\frac{1}{4}\pi(0.35\,in)^2(0.35\,in)}{2} = 0.0168\,in^3$$

$$V_{CS} = \frac{1}{4}\pi(0.35\,in)^2(1.38\,in) = 0.133\,in^3$$

$$V_T = V_t + V_b - V_c$$

$$V_T = 0.61\,in^3 + 3.01\,in^3 - 0.0168\,in^3 - 0.133\,in^3$$

$$V_T = 3.4702\,in^3$$

A36 steel $\rho = 0.28\ lb/in^3$

$m = \rho V = (0.28\ lb/in^3)(3.4702\,in^3) =$ **0.97 lb**

Given:
- Midwest supply.com
- Plate
- Support
- dimensions (2 in × 1.25 in × 2.5 in)
- A36 Steel

Find: cost

Solve: About **$14.67** 4 total

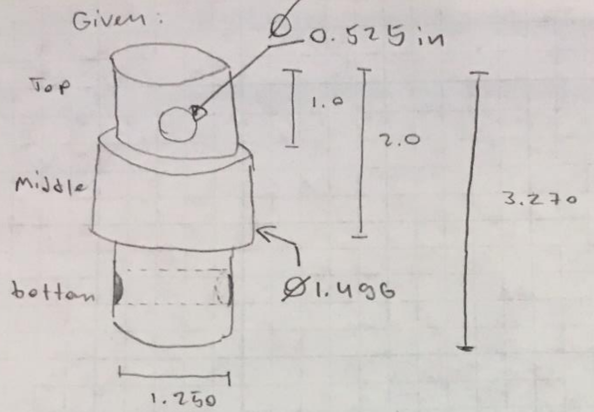
Total cost: **$58.68**

Note: will be less if ordering in bulk

(Appendix 9A: Support Mass and Cost

10

Given:



Assume:
* chamfer Volume is negligible.

Find: volume
mass
cost

Solve:

Top $V_t = \frac{1}{4}\pi(1.250\text{in})^2(1.0\text{in}) = 1.23\text{ in}^3$

mid $V_M = \frac{1}{4}\pi(1.496\text{ in})^2(1.0\text{ in}) = 1.76\text{ in}^3$

bottom $V_b = \frac{1}{4}\pi(1.250\text{in})^2(1.27\text{ in}) = 1.56\text{ in}^3$

Pin holes

$V_p = \frac{1}{4}\pi(0.525\text{in})^2(1.250\text{ in}) \times 2 = 0.54\text{ in}^3$

$V_T = V_t + V_M + V_b - V_p \Rightarrow$

$V_T = 1.23\text{in}^3 + 1.76\text{in}^3 + 1.56\text{in}^3 - 0.54\text{in}^3$

$\boxed{V_T = 4.01\text{ in}^3}$

(Appendix 10A: Attachment Volume)

11

Find: mass of connector

Given: Volume =

Assume: A36 Steel $\rho = 0.28\ lb/in^3$

Solve: $m = \rho V = (0.28\ lb/in^3)(4.01\ in^3)$

$\boxed{m = 1.1228\ lb}$

Given:
- midweststeelsupply.com
- Bar
- Aluminum
- Instron/Base Attachment
- dimensions ($\varnothing$1.625 x 3.3) in

Find: cost

Solve: About $\boxed{\$8.85}$

Assume: Although Top and Bottom Jigs will have slightly different attachments will assume they are the same so the total cost will be double

or: $\boxed{\$17.7}$

(Appendix 11A: Mass and Cost of Attachments)

12

Given: Entire Assembly

Find: Approximate cost

Solve: Top base = $65.03
Bottom base = $73.63
4-Supports = $58.68
2 attachments = $17.7
4 Hex screws = $20.0
4 Pins = $20.0

Total cost

T_c = $255.04

* requirement met

Find: mass Total for Bottom Assembly

Mass Base = 9.167 lb
Mass support × 2 = 1.94 lb
Mass attachment = 1.2 lb

Total mass = 12.31 lb

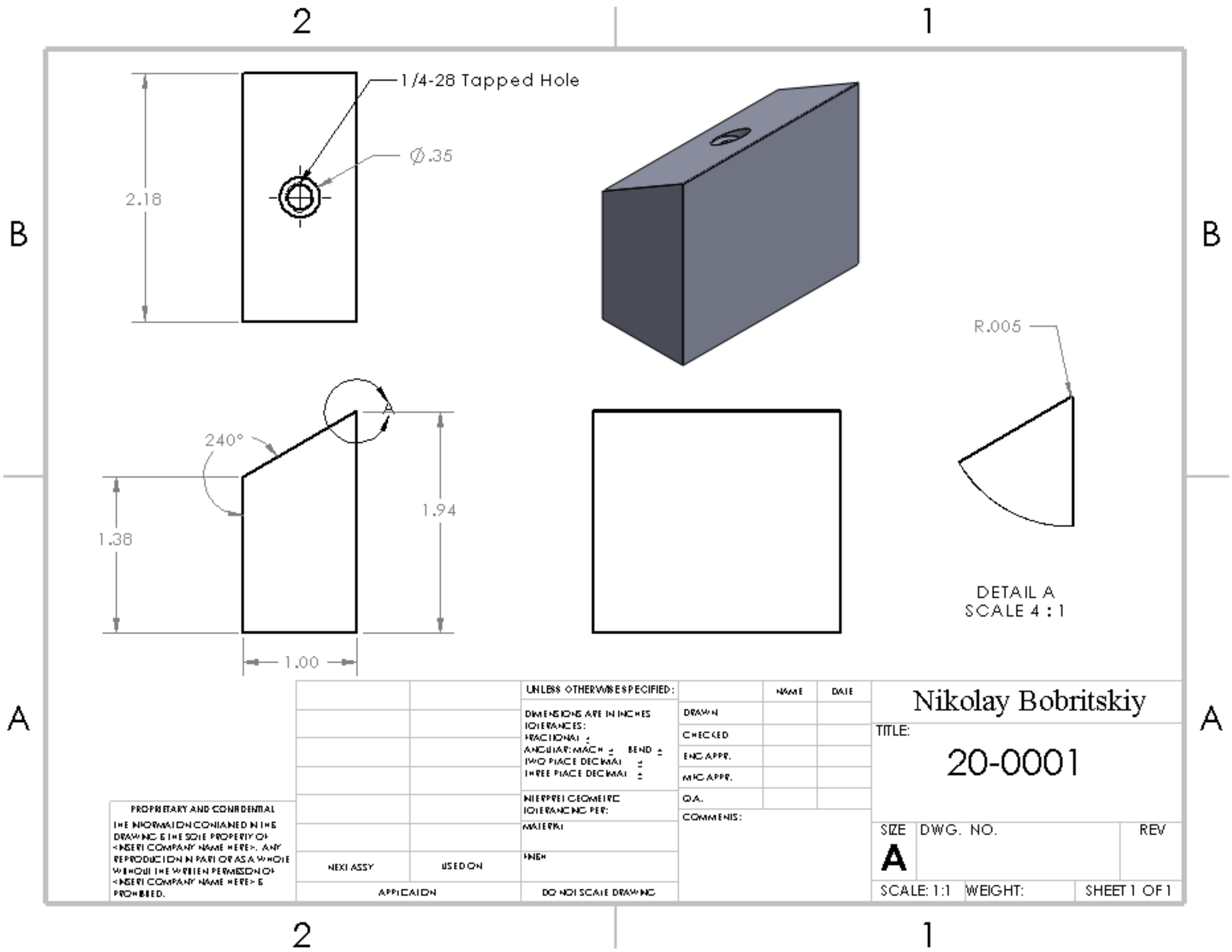
Assume hex screws and pins are negligible

- Assembly under 20 pounds
- Top assembly less than bottom

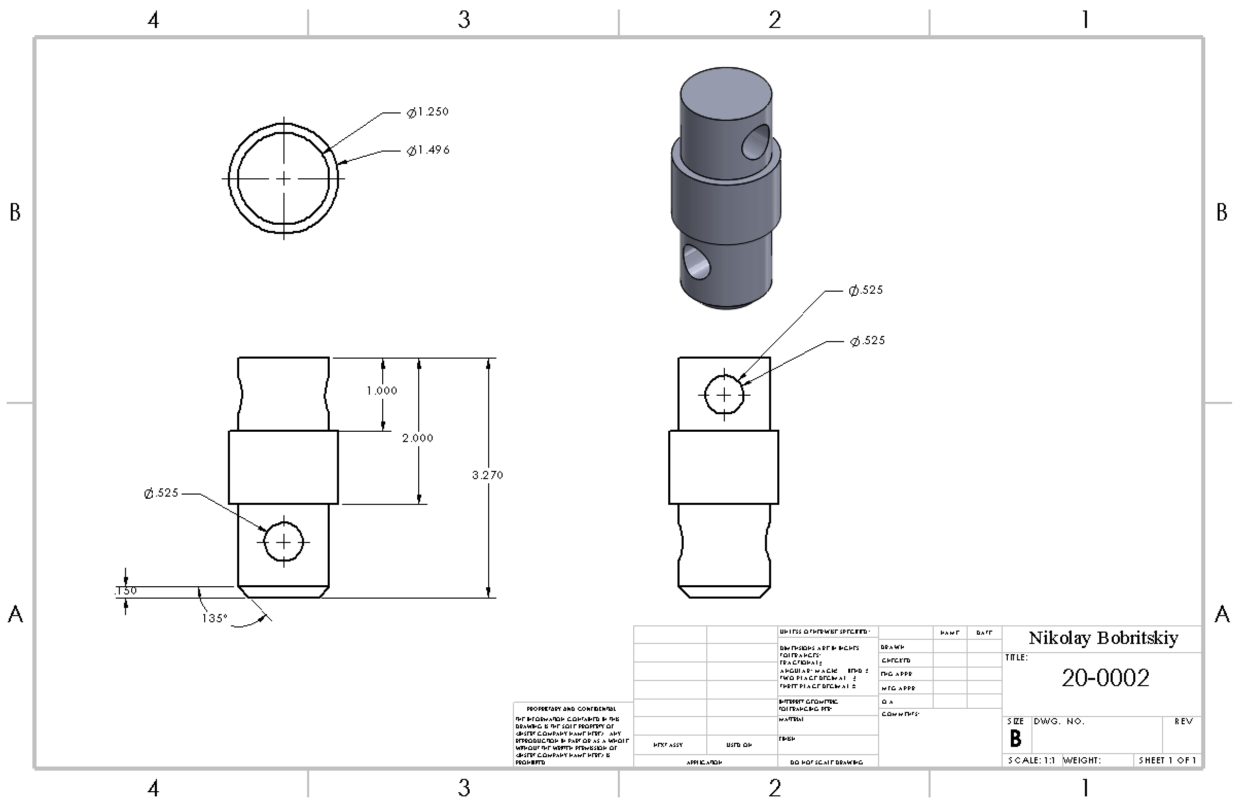
* requirement met

(Appendix 12A: Total Cost of Materials)

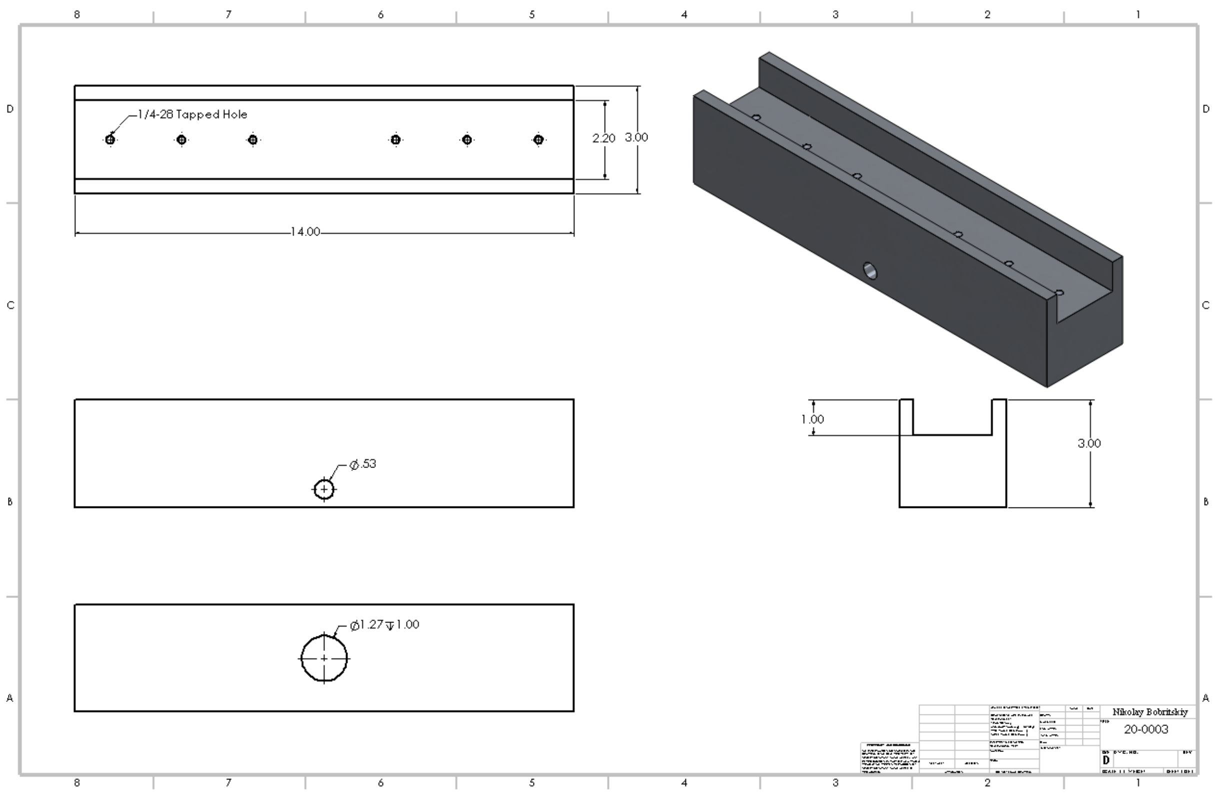
Appendix B: Drawings



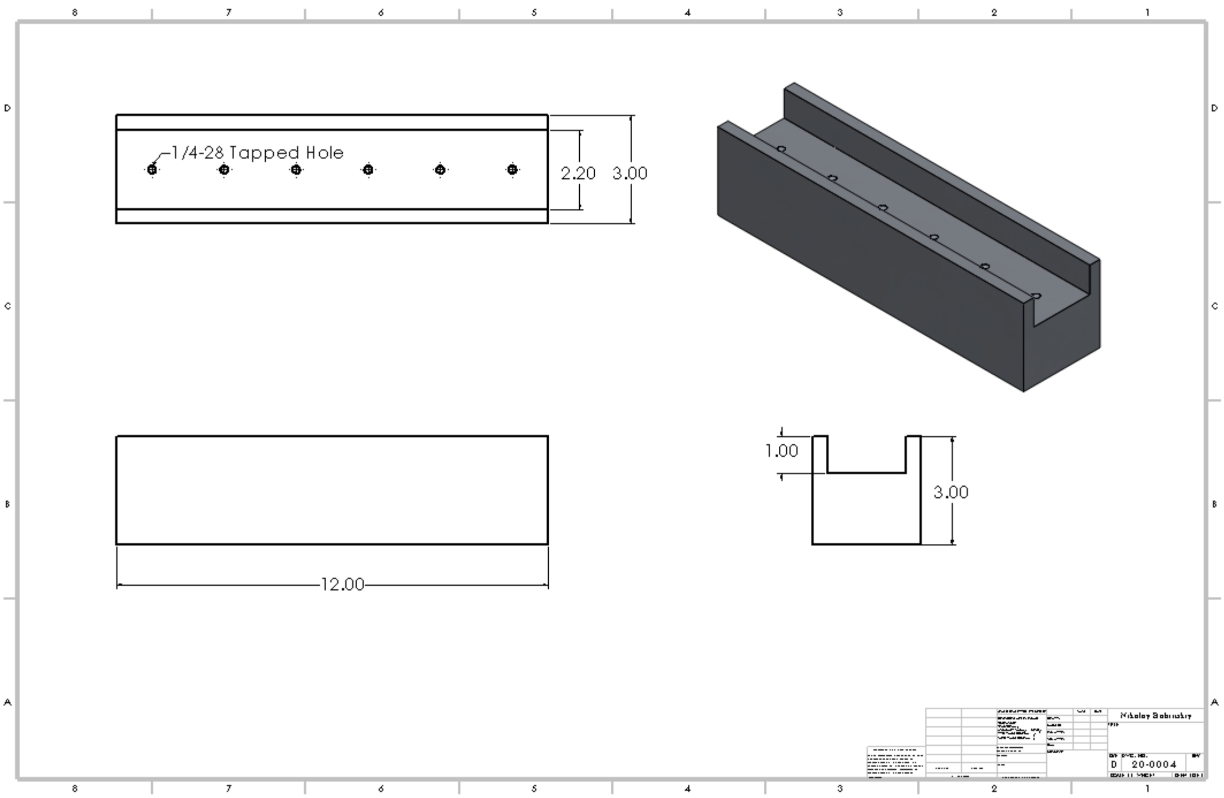
(Appendix B1: .005 in point bend)



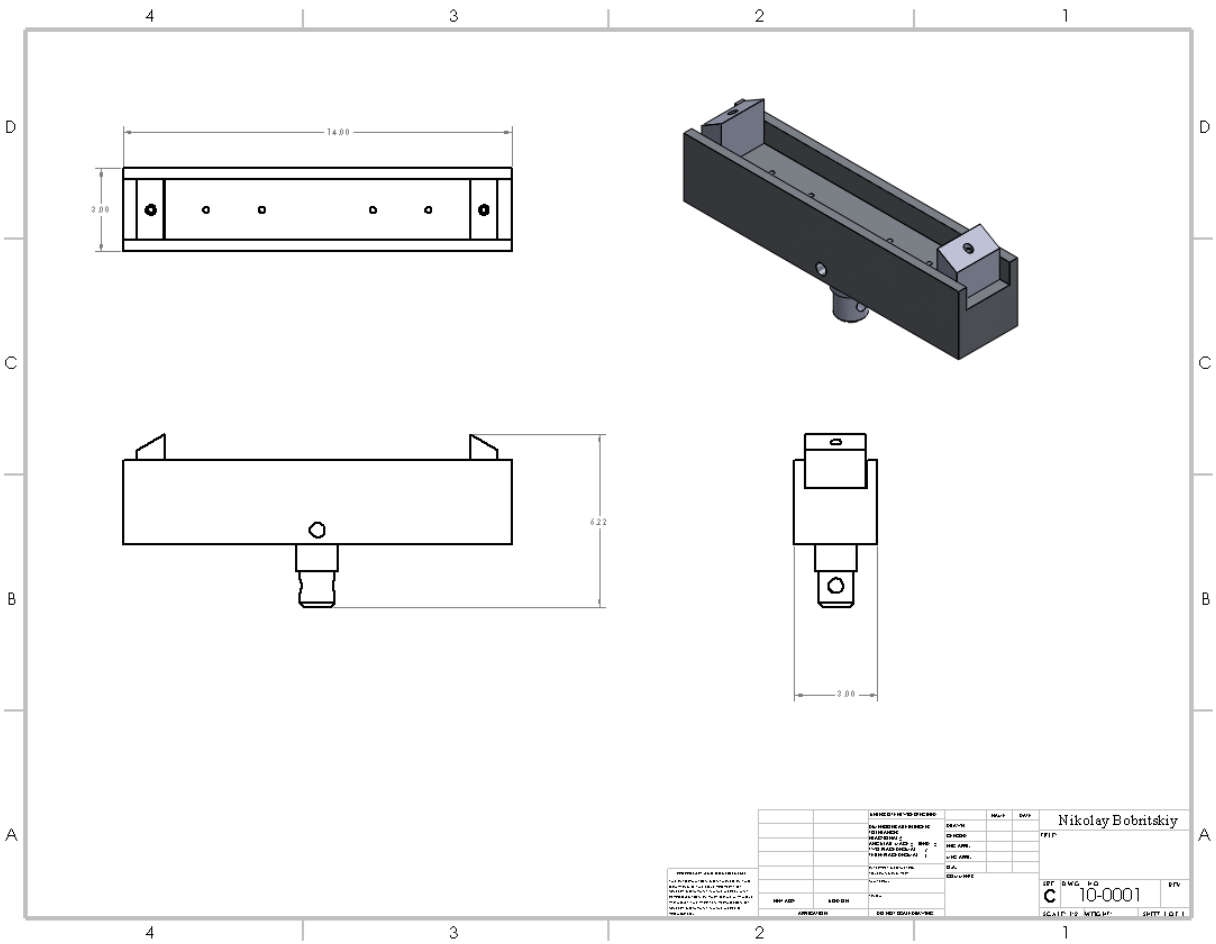
(Appendix B2: Instron to jig attachment)



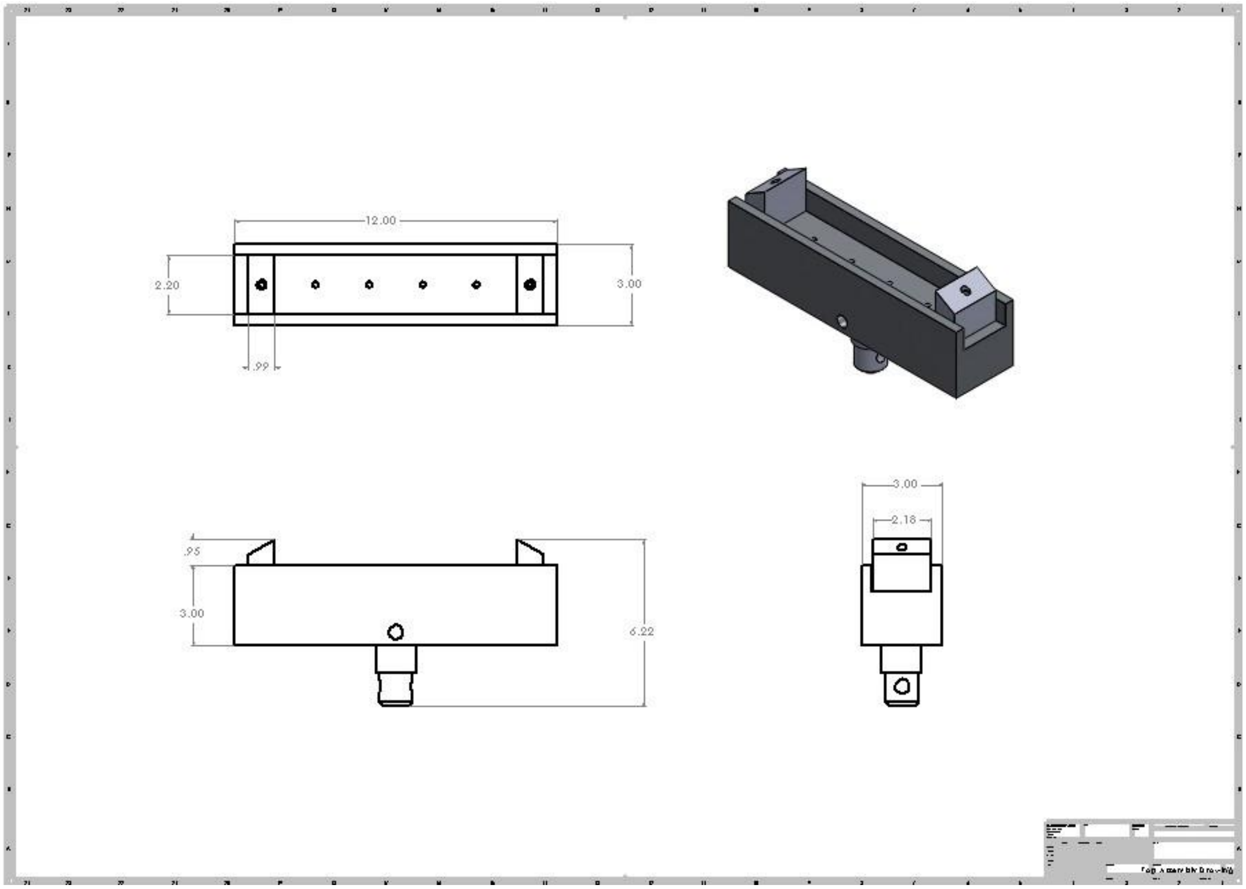
(Appendix B3: Bottom Frame)



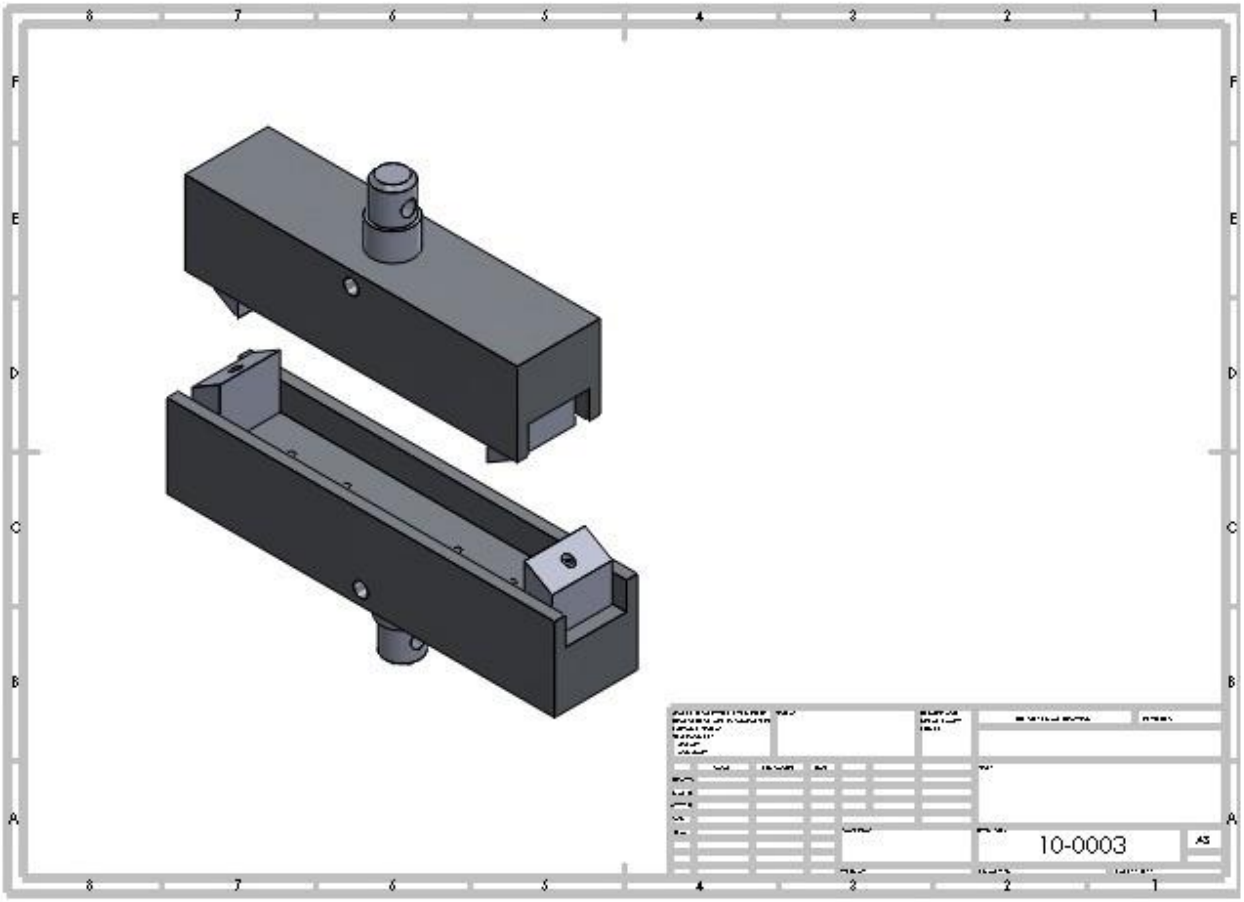
(Appendix B4: Top Frame)



(Appendix B5: Bottom Assembly)



(Appendix B6: Top Assembly)



(Appendix B7: Top and Bottom Assembly)

Appendix C and D: Parts List and Budget

Parts List and Budget

Part	Ordering Part	Cost
4-point bend base Bottom	(14.5 x 3.25 x 3.25)in Aluminum Plate	$ 73.63
4-point bend base Top	(12.5 x 3.25 x 3.25)in Aluminum Plate	$ 65.03
4 x Supports	(2.5 x 2.0 x 1.25)in Steel Plate	$ 58.14
Instron to Base Attachment Top	(ø1.625 x 3.3)in Aluminum Bar	$ 8.85
Instron to Base Attachment Bottom	(ø1.625 x 3.3)in Aluminum Bar	$ 8.85
Dowel Pin	4140 Alloy Steel, 1/2" dia, 3-1/4 L, x(5 pack)	$ 10.12
Socket Head-Stainless Steel	1/4-28, 2-1/2 L, x (10 per pack)	$ 5.86
Socket Head-Black Oxide Alloy Steel	1/4-28, 2-1/4 L, x (25 per pack)	$ 10.88
	Total Cost	$ 241.36

Appendix E: Schedule

Task Dates
• Week 1: Machine Base Bottom
• Week 2: Machine 2 Supports
• Week 3: Machine 2 Supports
• Week 4: Begin Machining Top Base
• Week 5: Finish Machine Bottom Base, Begin Machining Attachment Bottom
• Week 6: Finish Attachment Bottom, Start Machining Attachment Top
• Week 7: Finish Machine Attachment Top, Assemble Project
• Week 8: Machine Single Support for 3-Point Bend

(Appendix E1 Tasks Dates)

EXAMPLE SCHEDULE FOR SENIOR PROJECT:

NOTE: STUDENTS MUST MAKE THEIR OWN SCHEDULE!!!!!!!!!!!!!

PROJECT TITLE: 4-Point Bend Fixture

Principal Investigator: Nikolay Bobritskiy

Note: March x Finals
Note: June x Presentation
Note: June y-z Spr Finals

TASK: ID	Description	Duration Est. (hrs)	Actual (hrs)	%Com	S October November Dec January February March April May June	Notes
1	Proposal*					
1a	Outline	2	3			Started on time eneded on time
1b	Intro	3	3			Started on time ended on time
1c	Methods	5	4			Started on time ended late
1d	Analysis	11.5	13			Started late ended on time
1e	Discussion	7	2			started late ended on late
1f	Parts and Budget	4	3			Started on time ended time
1g	Drawings	8.5	11.5		X	Started on time not ended
1h	Schedule	4	4			Started late ended late
1i	Summary & Appx	4	10		X X X	Started time ended on time
	subtotal:	49	53.5			
2	Analyses					
2a	Shear/Moment Spec	0.5	0.5			Started on time ended on time
2b	Permanenet Defelction	1	1			Started on time ended on time
2c	Shear/Moment Base	0.5	0.5			Started on time ended on time
2d	Stress on Base	0.5	1			Started on time ended on time
2e	Volume Base	1	2			Started on time ended late
2f	Volume Base 2	1	1			Started on time ended late
2g	Mass/Cost Base	1	1			Started on time ended on time
2h	Volume Support	1.5	1.5			Started on time ended on time
2i	Mass/Cost Support	1	1			Started on time ended late
2j	Volume Attach	1.5	1.5			Started on time ended late
2k	Mass/Cost Attach	1	1			Started on time ended late
2l	Total Cost	1	1			Started on time ended late
	subtotal:	11.5	13			
3	Documentation					
3a	Support	1	3			
3b	Attach Bottom	1	1			
3c	Base Bottom	1	2			
3d	Base Top	1	1			
3e	Assembly Bottom	1	1			
3f	Attach Top	1	1			
3g	Assembly Top	0.5	0.5			
3l	ANSIY14.5 Compl	1	1			
3m	Make Object Files	1	1			
	subtotal:	8.5	11.5			
7	Part Construction					
7a	Buy Parts	1	2			Started on time ended on time
7b	Part: Point Bend 1	2	6.2			Started on time ended late
7c	Part: Point Bend 2	2	6.2			Started on time ended late
7d	Part: Point Bend 3	2	6.2			Started on time ended late
7e	Part: Point Bend 4	2	6.2			Started on time ended late
7f	Part: Instron Attachment 1	4	3			
7g	Part: Instron attachment 2	4	3			
7h	Part: Top Base	4	10			Started on time, finished on time
7i	Part: Bottom Base	4	7			Started on time, finished on time
	subtotal:	25	49.8			
9	Device Construct					
9a	Assemble Bottom	0.1	0.1			
9b	Assemble Top	0.1	0.1			
9c	Fix onto Instron	0.1	0.1			
	subtotal:	0.3	0.3			
10						
10a	Device Evaluation					
10b	List Parameters	1	0.1			
10c	Design Test&Scope	2	3			
10d	Obtain resources	5	5			
10e	Make test sheets	1	0.2			
10f	Plan analyses	1	0.5			
10g	Test Plan*	2	6.5			
10h	Perform Evaluation	1	0.5			
10i	Take Testing Pics	0.1	0.1			
10j	Update Website	10	3			
	subtotal:	23.1	18.9			
11						
11a	495 Deliverables					
11b	Get Report Guide	2	2			
11c	Make Rep Outline	30	30			
11d	Write Report	8	8			
11e	Make Slide Outline	2	2			
11f	Create Presentation	4	4			
11e	Make CD Deliv. List	1	1			
11f	Write 495 CD parts	1	1			
11g	Update Website	2	2			
	Project CD*					
	subtotal:	50	50			
Labor$	Total Est. Hours=	167.4	197		=Total Actual Hrs	

(Appendix E2: Gantt Chart)

Appendix F: Expertise and Resources

Senior project was designed, analyzed, manufactured, and tested at Central Washington University during 2020 as a Senior Student.

Appendix G: Test Report

Introduction
The requirements and design of the project will follow ASTM standard for a 4-point jig. Along with the following requirements

- Each component weight under 10 pounds
- Part assembly less than 20 pounds

The parameter of interest for mass of the parts and assembly is to maintain a light jig for a person to install onto the Instron without much effort. The predicted value is that each assembly is around 12-pound mass and heaviest part around 10-pound mass. The data will be collected using a mass scale.

- Cost under $600

The total cost of the project is $241.36 which is well under $600 requirement.

- Size constraint within the Instron

The parameter of interest for size constraint is that the assembly can be assembled and fit onto the Instron in a timely fashion of 5 minutes. The predicted value is that both assemblies can be assembled and fit onto the Instron in around 3 minutes. The data will be collected by having both assemblies unassembled and timed with a stopwatch for how long it takes to assemble both fixtures.

- Withstand 1000 pounds of force

The parameter of interest is to check if the jig can withstand 1000 pound of force (maximum Instron force) without any damage. The aluminum jig is most likely to fail at the attachment part of the Instron where it is held just above the pin. The predicted value is around 31000 pounds of force from stress/area calculation.

Method/Approach
The testing predictions is that the jig is easy to lift and install for a single person, the entire assembly assembles without any issues, and can withstand at least 1000 pounds of force to perform the four-point bend test. The calculated parameters are mass, time to assemble the jig, and withstand a load of 1000 pounds of force. The mass scale will have an accuracy of +/- 0.1 pounds. The time will be measured with human error with a +/- 1 second. To measure if the jig can withstand 1000 pounds of force an object will need to be placed in between that can withstand 1000 pounds and tested on the Instron to +/- 1 lbf. The tools/resources that will be needed to perform the requirement test are a mass scale, stopwatch, Instron, L-key 3/16, 4 pins, and two jig assemblies consisting of base, 2 contact points, and cylindrical attachment. The data will be recorded with videos or pictures. The numerical data will be recorded into data tables

where it will be stored and analyzed. Some operational limitations such as using the Instron might not be available to perform as the University is closed for spring quarter.

Test Procedure

Summary

- Duration for Setup: The entire setup can take between 5-10 minutes, Time to complete test an additional 2-3 minutes.
- Place: Hogue 120
- Resources: Instron Machine, Hex L-key 3/16, 4x (¼-28 thread, 2-1/4 length socket head screw). Mass Scale.
- Risk, Safety: The entire assembly is around 20-30 lbs. That is why one should be careful when attaching it to the Instron. Securing all the parts properly is a must. Otherwise the device could fall and cause injury or damage the machine.
- Discussion: During the Initial setup it turned out that the bottom base of the Instron and top base of the Instron where the assembly is attached has slight variation in height (Figure 3). This is because the bolt head height is different which attaches the on the Instron itself. When inserting the cylindrical part (Figure 2) into the bottom base (Figure 3) of the Instron and putting in the pin produces good results, it sits perfectly, but taking the same cylindrical piece an inserting it onto the top section of the Instron base causes it to stick out more, so the pin cannot be inserted. This means that either one of the two-cylinder heights must be faced slightly more, or both must be faced slightly.
- Setup

  Note: Figure 4 provides how the entire assembly should look like attached to the Instron. The shorter base goes on top, and the longer base on the bottom.

  1. Use 3/16 L-hex key to and ¼-28 thread, 2-1/4 length socket head screw to attach bending point to the base in desired location. The longest length of the bending point facing inward (Figure 1).

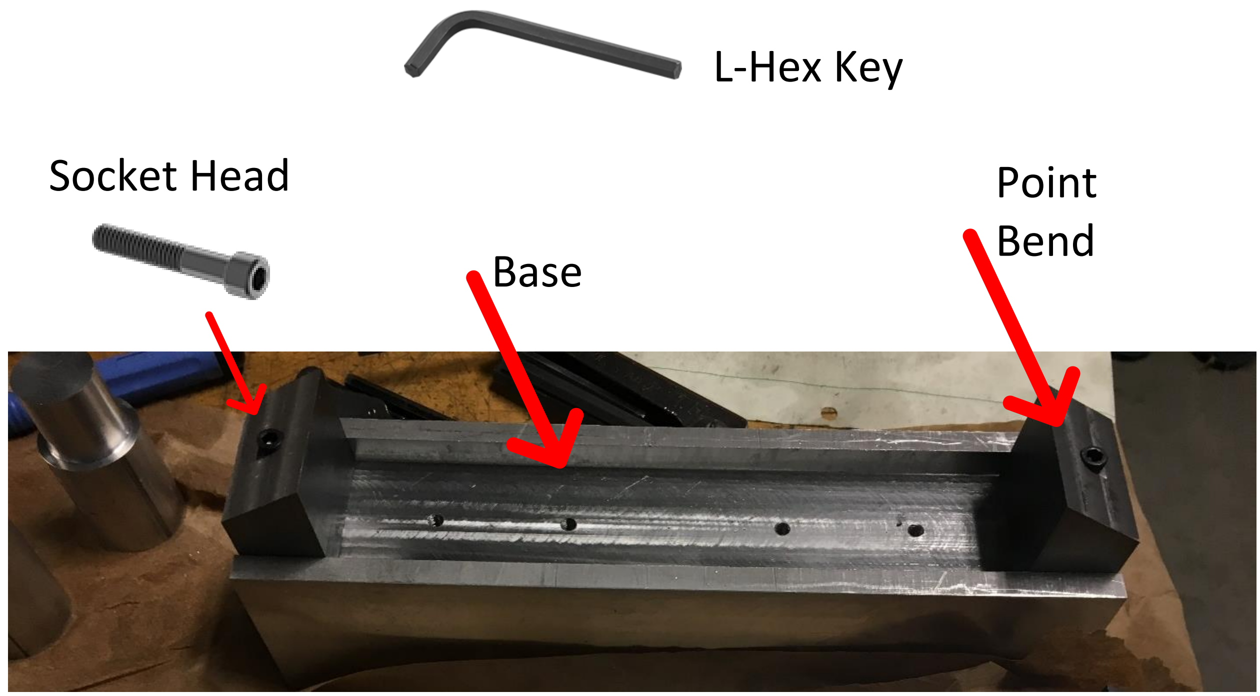


Figure 1: Base and Bending points assembly

2. Attach the cylindrical part with the largest diameter side onto the Instron with a short pin. (Figure 2 and 3)

Figure 2: Cylindrical Part

Figure 3: Instron Base Bottom

3. Attach the base onto the cylindrical part that was inserted in step 2 using a 0.5 in diameter pin with a length of 3-1/4 in Should look similar to Figure 4 but with pins and inside the Instron.


Figure 4: Base attached to the cylindrical part.

4. Perform the 4-point bend test at 1000 pounds force load limit
5. Disassemble
6. Weigh individual parts on the mass scale

Deliverables

In conclusion the project can be assembled quickly and single handedly, it is easy to assemble and install onto the Instron. The top base and bottom base did not meet the requirement of being under 10 lb, but the entire assembly did meet the requirement of 20 lb. The time to assemble both fixtures took 3.2 minutes. Testing for 1000lbf cannot be completed as CWU is closed.

Report Appendix

Appendix G1: Procedure Checklist

- L-hex key 3/16
- 4 pins ø-0.5 in, 3.5 in length
- 4 hex cap screws ¼-28, 2.25 in length
- Stopwatch
- Mass Scale in lb
- Instron

Appendix G2: Data Sheet

Data Form

Part	Mass
Top Assembly	
Bottom Assembly	
Top Base	
Bottom Base	
Bending Points	
Cylinders	

Assembly Time	
Withstand 1000 lbf (Yes/No)	

Appendix G3: Raw Data

Parameter Values:

Part	Mass
Top Assembly	13.8 lb
Bottom Assembly	12.9 lb
Top Base	11.0 lb
Bottom Base	10.1 lb
Bending Points	1.2 lb each
Cylinders	0.4 lb each

Assembly Time	3.2 minutes
Withstand 1000 lbf (Yes/No)	-

Calculated Values:

Part	Mass
Top Assembly	12.31 lb
Bottom Assembly	12.31 lb
Top Base	9.17 lb
Bottom Base	9.17 lb
Bending Points	0.97 lb each
Cylinders	1.12 lb each

Assembly Time	3 minutes
Withstand 1000 lbf (Yes/No)	-

Success Criteria Values:

Top Assembly	20 lb	Success
Bottom Assembly	20 lb	Success
Top Base	10 lb	Fail
Bottom Base	10 lb	Fail
Bending Points	10 lb	Success
Cylinders	10 lb	Success

Assembly Time	5 minutes	Success
Withstand 1000 lbf (Yes/No)	-	-

Appendix H: Resume

Nikolay Bobritskiy
2214 119th Ave SE, Lake Stevens, Washington 98258
Cell: 425-322-9828
Email: Nikolay_5@yahoo.com

OBJECTIVE: Pursuing Bachelor of Science in Mechanical Engineering and Technology and working towards mechanical engineering 1 position.

EDUCATION:

Everett Community College, Everett, WA
Associate of Science in Engineering (Graduated 2018)

Central Washington University, Ellensburg, WA
Bachelor of Science – MET (Expected Graduation June 2020)

PROJECTS:

Balsa Bridge Wood Project

- Built Balsa Wooden Bridge for class competition
- Explored Strongest bridge structures

Electronic Robot

- Built Robot using Arduino board and MATLAB for self-driving robot to place medicine boxes in rooms specific rooms
- Won 1st place for most effective robot.

Electric Motor

- Made small electric motor and measured its efficiency for class project/presentation.

WORK EXPERIENCE

Sharp Electric - Electric Apprentice: Everett WA (Summer 2016)

VOLUNTEER EXPERIENCE

- Helped clean high school campus
- Volunteered at Snohomish Library
- Helped teach Tae Kwon Do Class
- During elections helped Representative Hans Dunshee
  - Make posters for school campus
  - Hand out flyers

COMPUTER SKILLS

- Proficient with Microsoft Word, Power Point, Excel
- Experience with SOLIDWORKS and AutoCAD

Appendix J: Safety

Safety Procedure

The safety procedure of operating and performing a 4-point bend test requires the user to wear safety goggles, and perhaps steel toed boots. Although a 4-point bend test is not very dangerous to perform, safety goggles should still be used as a precaution in the lab. The steel toed shoes should be used in case an operator drops the part or something else while installing it onto the Instron.

Designing the part Safety

For design of the 4-point bend same rules apply to the safety procedure. One must always wear goggles and steel toed shoes. As well as hearing protection if operating loud machinery. Majority of the project will require to operate the mill, CNC, and drills which can all release metallic fragments that can be dangerous to the eye. Steel toed shoes are required in case the operator drops the material.

JOB HAZARD ANALYSIS

Prepared by: Nikolay Bobritskiy	Reviewed by: Approved by:

Location of Task:	Machine Shop
Required Equipment / Training for Task:	Safety Goggles, Appropriate Footwear, Hearing Protection
Reference Materials as appropriate:	

Personal Protective Equipment (PPE) Required (Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)						
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☐	☐	☒	☐	☒	☒	☐
Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.						

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	Drilling	Eye injury from metal debris Injury caused by breaking the bit	Wear eye protection. Do not use compressed air. Feed with the appropriate pressure. Use the appropriate bit for the type of metal. Wear eye protection.
	Milling	Possible eye injury from wire stitches thrown out by milling blade	Wear safety glasses during operation
	Turning	Injury to hands Possible eye injury from wire stitches thrown out	Never disconnect safety Shields Wear safety glasses during operation.
	Facing	Injury to hands Possible eye injury from wire stitches thrown out	Never disconnect safety Shields Wear safety glasses during operation.

(Figure 12: Safety Chart)

References

ASTM 3-4 Point Bend Standards (E855) Reference Material

0.01, 0.05, and 0.10 % should be determined, provided this does not require that the maximum allowable deflection angle of 30° be exceeded.

NOTE 2—These values of offset yield strengths in bending are not necessarily equal to either the yield strengths in tension, the cyclic bending yield strength, or to bending proof strengths determined by other methods.

11. Precision and Bias

11.1 *Precision:*

11.1.1 The precision of the values of the modulus of elasticity in bending and the offset yield strength in bending will depend on the precision of each of the values used in the calculations, as well as the mean and standard deviation of the values determined for each of the replicate tests. It is suggested that the report include an estimate of the precision of the values reported.[6]

11.1.2 The following parameters will affect the results and can be quantified as precision of the applied weights, precision of the span length measurement, deviation of width measurements from the average value, deviation of thickness measurements from the average value, and precision of the deflection measurements.

NOTE 3—A round-robin test program is currently being conducted to quantify these parameters.

11.2 *Bias*—A statement of bias requires a reference standard or a true property value based on many measurements of the property of the same material. Such standards or true values are presently not available for bending properties of metallic flat spring materials. Therefore, the bias of the method is unknown.

12. Report

12.1 The following shall be included in the report.

12.1.1 Complete description of the material tested, including alloy, temper, and manufacturer's identification number,

12.1.2 Specimen dimensions and orientation relative to the rolling direction,

12.1.3 Test temperature, and

12.1.4 The modulus of elasticity in bending and an estimate of the precision of the value reported.

12.1.5 Offset yield strengths in bending, for strains of 0.01, 0.05, and 0.10 % within the limitation of a maximum deflection angle of 30°, plus an estimate of the precision of the values reported.

METHOD B: THREE-POINT BEAM TEST

METHOD C: FOUR-POINT BEAM TEST

13. Scope

13.1 These methods cover the determination of the modulus of elasticity in bending and the bending proof strength of flat metallic strips or sheets for spring applications. The methods consist of deflection tests of a simple beam configuration subjected to either three- or four-point symmetrical loading. The thickness range covered is 0.010 to 0.050 in. (0.25 to 1.3 mm).

NOTE 4—Thickness ranges outside of those specified may be agreed upon between suppliers and users.

14. Summary of Methods

14.1 The test specimen is loaded as a simple beam in either three- or four-point symmetrical loading. The modulus of elasticity in bending is obtained by load-deflection measurements at stresses below the elastic limit. The bending proof strength is obtained by a stepwise increasing loading–unloading sequence carried out until a specified permanent set is measured on unloading.

NOTE 5—In these methods the specified permanent set corresponds to a maximum outer fiber strain after springback of 0.0001 in./in. (mm/mm).

15. Significance and Use

15.1 These methods are useful for obtaining values of proof strength in bending and modulus of elasticity in bending. These values are useful to spring designers to determine spring constants and maximum permissible deflection of flat springs. It should be recognized, however, that the proof strength in bending determined by these methods is not necessarily equal to either the yield strength in tension or to the cyclic bending yield strength.

15.2 These tests can also serve the following purposes:

15.2.1 For research and development to study the effects of metallurgical variables such as composition, heat treatment, fabrication operations and alloy development.

15.2.2 For information or specification purposes, to provide a manufacturing quality control where suitable correlations have been established with service behavior.

[6] See M. G. Natrella, "Experimental statistics", NBS Handbook 91 available from National Bureau of Standards, Washington, D.C.

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15.3 For most loading systems and test specimens, effects of backlash, initial specimen curvature, and grip backlash introduce significant errors in the deflection or curvature measurement when applying a small load to the test specimen. Therefore, bending modulus measurements should be made between a preload high enough to minimize these effects, and a higher load known to be below the proportional or elastic limit. For linear elastic materials, the slope of the straight line portion of the bending–stress versus bending–strain curve should be established. For non-linear elastic materials the chord or tangent modulus may be established for stress values ranging from the appropriate preload to the elastic limit.

15.4 Because of difficulties associated with accurately establishing the origin of the stress-strain curve, due to the problems mentioned in 15.3, the use of secant modulus or initial tangent modulus is not recommended.

16. Apparatus

16.1 The apparatus consists of two adjustable supports and a means for measuring deflection or curvature and for applying load.

16.1.1 *Supports*—The supports should have a 60° angle with a radius of 0.005 in. (0.13 mm) at the supporting edge. One knife edge should be straight and the other convex (0.50 in. (13 mm radius of curvature)). Their mutual separation should be adjustable along the specimen longitudinal axis (Fig. 3).

16.1.2 *Load Application:*

16.1.2.1 *Applicator Geometry*—The load applicator shall have a 60° angle with a radius of 0.005 in. (0.13 mm). In the case of three-point loading the load is applied at midspan, using one such applicator as shown in Fig. 3. In the case of four-point loading, two load applicators are used, symmetrically spaced from the supports as shown in Fig. 4 and the distance between the load applicators shall equal 2/3 of the span length. One of the load applicators shall have a convex (0.50 in. (13 mm)) radius of curvature.

16.1.2.2 *Dead Weights*—Calibrated dead weights may be used with the load applicator. Any cumulative error in the dead weights or the dead weight loading system shall not exceed 1.0 %.

16.1.2.3 *Testing Machines*—in determining the suitability of a testing machine, it is advisable to calibrate the machine under conditions approximating those under which the tests will be made, together with the load applicators, in accordance with Practices E 4. Corrections may be applied for systematic errors in load. Any cumulative error in the machine loading system shall not exceed 1.0 %.

16.1.3 *Deflection Measurement Devices*—It is recommended that a deflectometer, or a cathetometer be used to determine the specimen deflection, δ, at midspan as shown in Figs. 3 and 4.

NOTE 6—If, in the case of universal testing machines the relative crosshead displacement is used as a measure of specimen deflection, proper correction must be made for machine and load cell stiffness.

16.1.3.1 The elastic deflection used in determining the modulus of elasticity in bending, and the permanent set used in determining the bending proof strength, shall be measured between outer supports to midspan. Interference forces from the measuring device must not exceed 0.05 % of the applied force during the test. Deflection shall be measured to an accuracy of ± 0.002 in. (0.05 mm).

17. Test Specimens

17.1 Rectangular test specimens shall be used. Specimen orientation relative to the rolling direction must be identified. Specimen curvature due to coil set shall be permitted if the ratio of the radius of curvature to thickness exceeds 500. However, the specimen shall not be twisted or wavy. No attempt shall be made to flatten or straighten specimens prior to testing. Care shall be exercised not to alter the microstructure during specimen preparation. All burrs shall be removed before testing.

17.2 The recommended minimum specimen thickness shall be 0.010 in. (0.25 mm). The thickness shall be measured at the four corners and at the center of the specimen's gage section. Specimens having measured thickness variations in excess of 2 % of the average (of these five measured thicknesses) are not acceptable. The instrument used to measure the specimen's thickness shall have a precision of within 2 % of the average thickness.

NOTE 7—In Eqs 5 and 6 in 18.2.4 it is shown that the value of the modulus of elasticity in bending varies as the third power of thickness. Hence, thickness is by far the most critical measurement in the determination of the modulus. For example, for an error in the thick-

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ness measurement of ±0.0001 in. (0.0025 mm) for a specimen having the minimum recommended thickness of 0.010 in. (0.25 mm), the thickness measurement is reproducible to within 1 % and the error in modulus attributable to the reproducibility of the thickness measurement is 3 %. Further, if the thickness actually varies by 2 % over the gage section or by 0.0002 in. (0.0050 mm), the error in modulus attributable to actual thickness variation is 6 % and the total error attributable to both measurement and actual variation is 9 %. Additional sources of uncertainty are the precisions of determining the span length, the specimen width, and the beam deflection.

17.3 The span length shall be 150 times the nominal thickness in the range 0.010 in. to 0.020 in. (0.25 to 0.51 mm), inclusive, and 100 times the nominal thickness in the range exceeding 0.020 in. (0.51 mm). Specimen width shall be 0.150 in. (3.81 mm) in the thickness range 0.010 to 0.020 in., inclusive, and 0.500 in. (12.7 mm) in the thickness range exceeding 0.020 in. The total specimen length shall be 250 times the nominal thickness in the range of 0.010 to 0.020 in. and 165 times the nominal thickness in the range exceeding 0.020 in.

17.4 The width shall be measured at both ends and the center of the specimen. Specimens having width variations greater than 0.2 % of the average width are not acceptable.

17.5 A minimum of six specimens shall be tested, half of which shall be tested with the concave surface facing upwards and half with the convex surface facing upwards.

17.6 Replication required for evaluating material variability within either the same sample or among several suppliers shall be covered in product specifications or upon agreement between supplier and user.

18. Procedure

18.1 *Measurement of Specimens*—Measure the thickness as specified in 17.2 using any means of measuring which is repeatable and precise to within 2 %.

18.2 *Modulus of Elasticity in Bending:*

18.2.1 The supports shall be spaced per Figs. 3 or 4. The specimens shall be placed symmetrically on the knife edges.

18.2.2 A preload corresponding to approximately 20 % of the bending proof strength shall be applied.

NOTE 8—This value of proof strength can be estimated by means of a preliminary test.

18.2.3 The specimen shall be then gently tapped by hand to minimize friction at the supports. Both load and displacement at midspan shall be measured either incrementally or continuously up to 50 % (maximum) of the estimated proof strength value (see Note 8). In the case of the dead weight or incremental loading, at least five measurements shall be taken from the preload to the maximum load for each specimen.

NOTE 9—Friction effects may further be reduced by lubricating the supports.

18.2.4 The modulus of elasticity in bending is obtained as follows:

Three-Point Loading

$$E_b = PL^3/4bh^3\delta \quad (5)$$

Four-Point Loading

$$E_b = [Pa(3L^2 - 4a^2)/4bh^3\delta] \quad (6)$$

where:

E_b = modulus of elasticity in bending, lbf/in.^{2} (Pa),
L = span length between supports, in. (m),
b = specimen width, in. (m),
h = specimen thickness, in. (m),
P = load increment as measured from preload, lbf (N),
δ = deflection increment at midspan as measured from preload, in. (m), and
a = (for four point loading) the distance from the support to the load applicator when the specimen is straight (see Fig. 4), in. (m).

18.2.5 The average modules of elasticity in bending shall be determined for a minimum of six specimens, half of which shall be tested with the concave surface facing upwards and half with the convex surface facing upwards.

18.3 *Bending Proof Strength*:

18.3.1 The procedures of 18.2.1, 18.2.2, and 18.2.3 shall be followed. The specimen then shall be loaded to within 90 % of the estimated proof strength value and unloaded to the preload. The load then shall be increased to 92, 94, etc. % of the proof strength until a permanent strain in the outer fiber of 0.01 % is observed on unloading. This corresponds to a permanent deflection, δ_P, at the center of the span:

Three-Point Loading

$$\delta_P = 0.0001L^2/6h \quad (7)$$

Four-Point Loading

$$\delta_P = 0.0001(3L^2 - 4a^2)/12h \quad (8)$$

NOTE 10—Equations 7 and 8 are obtained by substituting Eqs 9 or 10 into Eqs 5 and 6, respectively, and setting $\sigma_p/E_b = 0.0001$.

The load, P_p, which produces permanent set, δ_p, is calculated from a linear interpolation of the two value pairs of (*1*) load and (*2*) permanent set above and below the exact value of δ_p desired (Eqs 7 or 8).

The bending proof strength, σ_p, lbf/in.^{2} (Pa), is then determined as follows:

Three-Point Loading

$$\sigma_p = 1.5P_pL/bh^2 \quad (9)$$

Four-Point Loading

$$\sigma_p = 3P_pa/bh^2 \quad (10)$$

NOTE 11—These values of proof strength are not necessarily equal to either the yield strength in tension or the cyclic bending yield strength.

18.3.2 The average bending proof strength shall be determined for a minimum of six specimens, half of which shall be tested with the concave surface facing upwards and half with the convex surface facing upwards.

19. Interpretation of Data

19.1 *Modulus of Elasticity in Bending:*

19.1.1 If a plot of load versus deflection is obtained by means of an autographic recorder, the value of the modulus of elasticity in bending may be obtained by determining the slope of the straight portion of the line. Choice of the lower load point depends on the limitations set forth in 15.3. The modulus of elasticity in bending is calculated from the load increment and the corresponding deflection increment between two points on the straight line as far apart as possible, using either Eqs 5 or 6, depending on whether three or four point loading is utilized.

19.1.2 If the load versus deflection data are obtained in numerical form, the errors which may be introduced by plotting the data and fitting graphically a straight line to the experimental points may be reduced by determining *P* by using the method of least squares, or the strain deviation method (see Test Methods E 111).

19.1.3 For non-linear elastic material, the load points and corresponding deflection points used in calculating chord or tangent modulus should be reported. In the case of tangent modulus, the method for establishing the tangent to the curve should be reported.

19.2 *Proof Strength in Bending:*

19.2.1 Deflection, δ_p, which produces the specified permanent set shall be determined as outlined in 18.3.1.

19.2.2 Load, P_p, corresponding to deflection, δ_p shall be determined as outlined in 18.3.1.

19.2.3 The proof strength in bending shall be calculated as outlined in 18.3.1.

20. Precision and Bias

20.1 *Precision:*

20.1.1 The precision of the values of the modulus of elasticity in bending and the bending proof strength will depend on the precision of each of the values used in the calculations, as well as the mean and standard deviation of the values determined for each of the replicate tests. It is suggested that the report include an estimate of the precision of the values reported.[6]

20.1.2 The following parameters will affect the results and can be quantified as: precision of load cell calibration, precision of span length measurement, deviation of width measurement from average value, deviation of thickness measurement from average value, and precision of deflection measurement.

NOTE 12—A round-robin test program is currently being conducted in order to quantify these parameters.

20.2 *Bias*—A statement of bias requires a reference standard or a true value based on many measurements of the property of the same material. Such standards or true values are presently not available for bending properties of metallic flat spring materials. Therefore, the bias of the method is unknown.

21. Report

21.1 The report shall include the following:

21.1.1 Complete description of the material tested, alloy, temper and manufacturer's identification number,

21.1.2 Specimen dimensions and orientation relative to rolling direction,

21.1.3 Test temperature,

21.1.4 Type of loading (Method B or C) and stress range for which data were used,

21.1.5 Type and sensitivity of test equipment,

21.1.6 A measure of the variability of the load deflection data,

21.1.7 Modulus of elasticity in bending, and an estimate of the precision of the value reported, and

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21.1.8 Bending proof strength and an estimate of the precision of the values reported.

METHOD D—CYCLE REVERSE BEND TEST

22. Scope

22.1 This method covers the determination of the modulus of elasticity in bending and the cyclic bending yield strength of flat metallic strip material for spring applications. The test procedure involves measurement of energy dissipation in a specimen undergoing cyclic reverse bending. The thickness range covered is 0.010 to 0.050 in. (0.25 to 1.3 mm).

23. Summary of Method[7]

23.1 The test specimen is coupled into a 1 degree of freedom oscillating system such that the specimen undergoes cyclic reverse bending. Energy is added to the system to compensate for losses, thus allowing a steady state to develop. In this steady state condition, the maximum kinetic energy of the oscillating system equals the maximum strain energy in the specimen which allows the modulus of elasticity in bending to be determined. Furthermore, the work added per cycle must be equal to the energy dissipated by the specimen per cycle which is used to calculate the cyclic bending yield strength.

24. Significance and Use

24.1 The cyclic reverse bend test is used to determine the cyclic bending yield strength and the modulus of elasticity in bending, as a function of plastic strains, $\Delta\epsilon_n$, over the range from 10^{-5} to 5×10^{-4}. These bending properties can be used to provide design information on flat spring materials subjected to repeated reverse loading. It should be recognized, however, that the cyclic bending yield strength determined by this method is not necessarily equal to either the yield strength in tension or the proof strength in bending determined by other methods.

24.2 The test can serve the following purposes:

24.2.1 For research and development to study the effects of metallurgical variables such as composition, heat treatment, fabrication operations, and alloy development.

24.2.2 For evaluation of flat spring material for cyclic service, and for specific applications where cyclic bending yield strengths at given plastic strains are desired.

24.2.3 For information or specification acceptance purposes, to provide a manufacturing quality control where suitable correlations have been established with service behavior.

25. Apparatus

25.1 An example of the cyclic reverse bend test apparatus meeting the requirements of this test method is shown in Fig. 5. The test device consists of the following components:

25.1.1 *Upper Jaws*—consisting of two flat faces rigidly attached to a pendulum. The center of rotation of the pendulum, of known mass moment of inertia, coincides with the center of the gage length of the specimen. The pendulum provides a uniform bending moment to the specimen.

25.1.2 *Lower Jaws*—consisting of two flat faces which become rigidly attached to the table as they are tightened to hold the specimen. The table is forced to rotate through angle $\Delta\phi_n$ and thus rotate the lower jaws through angle $\Delta\phi_n$. Rotation causes a decrease of specimen curvature and an increase in its stored energy.

25.1.3 *Table*—The forced rotation of the table is controlled by a mechanism attached to both ends of the table. This mechanism is controlled by a switch that is activated every time the pointer, attached to the pendulum, passes through the sensor (see Fig. 6).

25.1.4 *Switch*—An optical switch, in conjunction with a pointer of known width, is used to establish the velocity of the pendulum. The period of oscillation and the measured time are determined by electronic timers.

25.1.5 *Gage Length Spacer*—used to establish the gage length, L, of the specimen. It fixes the distance between the upper and the lower jaws. After the specimen is clamped in the jaws, the spacer is removed.

26. Test Specimens

26.1 Test specimens shall be rectangular and flat. Dimensions shall be approximately 2.0 in. (50 mm) long by 0.5 in. (12.7 mm) wide. Specimen thickness will be limited by the gage length and the pendulum of the particular test machine chosen for the test. Care shall be exercised not to alter the microstructure during specimen preparation. All burrs shall be removed before testing.

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[7] Weissmann, G. F., "Determination of Mechanical Design Properties of Materials" J. of Testing and Evaluation, JTEVA, Vol. 1, No. 2, March 1976, 133–138.

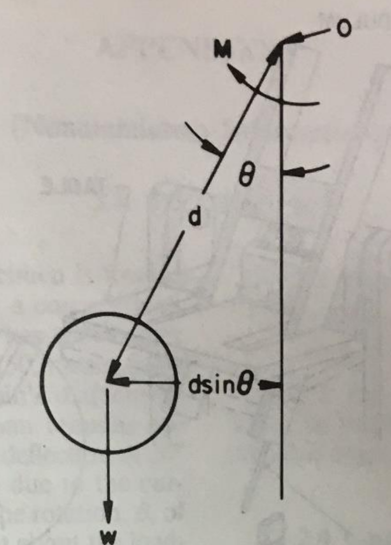

FIG. 2 Schematic of Pendulum System

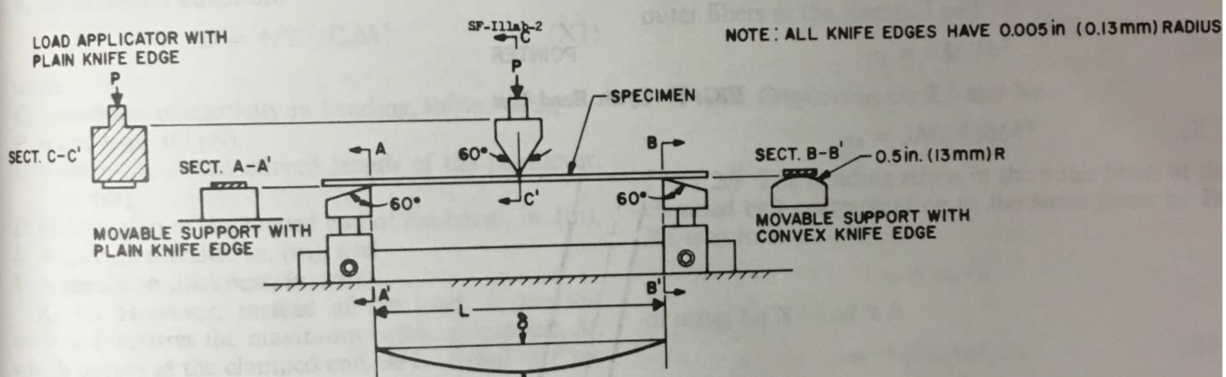

FIG. 3 Three-Point Bend Test

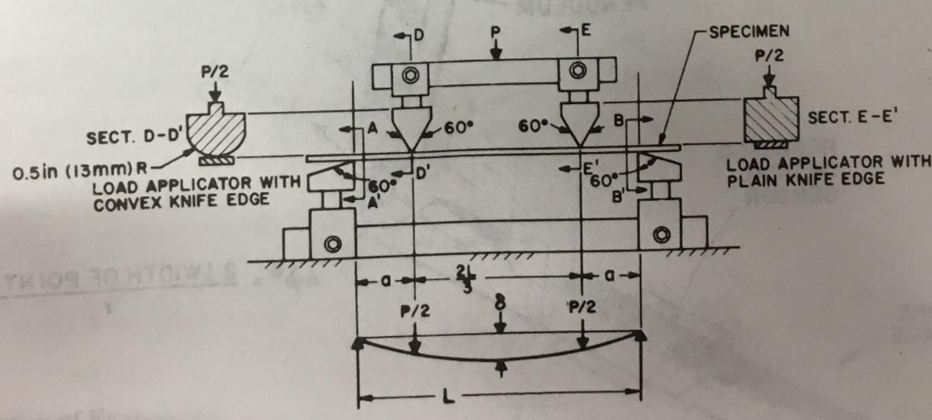

FIG. 4 Four-Point Bend Test