Spring 2021

JCATI Carbon Fiber Recycling Shredder

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By

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Abstract

Once carbon fibers are cast into a resin and used in a composite material, retrieving those fibers can be a difficult task. However, it is beneficial to recycle and reuse the fibers from old unneeded components rather than pay the cost of acquiring new ones. The Joint Center for Aerospace Technology Innovation (JCATI) carbon fiber recycling device condenses the multistep process of extracting the fibers by integrating all steps into one automated device. In the previous version of the device, the cutting blades turned the long composite strips into thin fingers but did not sever them across the width.

The goal of the cutters is to create composite pieces small enough to undergo pyrolysis in the next section of the device, so the long thin fingers must be severed along the width at intervals to create composite chips containing long enough fibers to reuse. To sever the strips across the width, the number of blades on the cutter shafts was increased and the blades were moved closer together. The blades being closer together allows the system to act as a crosscut shredder and cut the strips along the length and width at the same time. This results in composite chips that contain fibers between 0.25” and 0.5”. These chips are small enough that they can undergo pyrolysis in the next step of the device to extract the fibers, and large enough that the fibers inside are reusable.

Contents

1. INTRODUCTION

a. Description

The JCATI funded project at CWU has the purpose of reclaiming carbon fibers from used carbon fiber components. The large composite parts are cut into strips which are fed into the device, where they get delaminated and cut into chips. The current blades on the device cut those long strips into thinner fingers, but do not cut along the width to turn the fingers into chips small enough to enter the pyrolysis portion of the device. The purpose of this project is to redesign the cutting section of the device to turn the inputted carbon fiber strips into chips small enough that the fibers can be separated and reused through pyrolysis. The spacing of the existing blades will be reduced so that the blades behave like a shredder and sever the strips into chips, not just slice them into long ribbons.

b. Motivation

Motivation for this project comes from the financial and environmental benefit of recycling and reusing carbon fibers. Recycling the fibers saves the cost of production of new ones, and saves emissions and other pollution associated with the production process. Reusing the fibers also keeps old and excess material from ending up in a landfill, which has been an issue with carbon fiber since it does not easily break down or lend itself to repurposing in its used form. Composite parts from cars, planes, windmills, and more end up in landfills too often. If a large percentage of the carbon fibers in a composite material can be reused, there will be less production of new fibers and less synthetic waste in landfills.

c. Function Statement

A device will be designed that cuts continuous strips of carbon fiber into smaller segments.

d. Requirements

Requirements for this project are concerned with getting the cutting blades fully functional by the end of the year and using only a fair portion of the budget for the device.

- Costs under $2500
- Blades are replaceable
- A clutch system prevents further damage to the device if the blades get stuck
- Blades will last a minimum of 2000 hours before becoming too dull to use
- Drive must be compatible with the current electric motor
- Creates carbon fibers between 0.5”-1” in length

e. Engineering Merit

This project requires calculating the diameters of shafts and analyzing material properties to determine whether the selected parts will hold up under the stress caused by operation. Calculations were also completed for the necessary shaft rpm and gear reduction, as well as the option for a belt drive system that was forgone. Measurements were taken and applied to determine the size and spacing of blades and spacers on the shafts. GD&T was followed in creating CAD drawings of every assembled part, and some pre-existing parts.

f. Scope of Effort

This project is concerned with only the cutting section of the carbon fiber recycling process, not the delamination or resin removal. The constructed cutting mechanism will apply to this specific device, with implications for a larger scale device that could be used in the aerospace industry or the recycling field.

g. Success Criteria

A successful cutting device will be capable of continuous operation, cutting the composite into chunks small enough to fit into the pyrolysis device, and containing fibers that are between .25”-0.5” in length.

2. DESIGN & ANALYSIS

a. Approach: Proposed Solution

The proposed solution to cutting the carbon fiber strips along the width is to increase the number of the current blades and spacing them closer together. This will form a crosscut shredder-style blade system that severs the strips with the blade edge and individual blade teeth.

b. Design Description

The blade setup will be modeled after an industrial shredder. The assembly will consist of a set of meshing wheel blades separated by spacers on the shaft, which will chip the composite as it passes through. The blades will be mounted on two shafts and driven by an electric motor.

c. Benchmark

The cutters will be benchmarked by keeping up with the feed rate of the delamination process and performing continuous chipping like a crosscut shredder, which it is modeled after. However, the main criteria for success will be the ability to produce fibers between 0.25" and 0.5".

d. Performance Predictions

The blade is predicted to cut through the carbon fiber while maintaining its edge. A predicted issue is that not all carbon fibers would be severed, but instead get pulled through the small gaps between the blades. Another predicted issue is the relatively large number of teeth on the current blades (compared to shredder models) producing fibers that are smaller than the desired 0.25"-0.5".

e. Description of Analysis

Analysis of this project covers the requirements from the motor that determine gearing, and the feasibility of using different setups and blade types based on the ability to cut the composite strips. The calculations concerning the motor were about power, torque, and rpm, to make sure the current motor could deliver the desired results. The torque and speed from the motor can be adjusted with motor controllers or through gearing. Analysis of the blade styles determined which blade setup is the most capable and how much force/torque is needed for them to make successful cuts.

f. Scope of Testing and Evaluation

Testing will confirm the ideas from completed analyses and illuminate the need for more analysis by bringing up unexpected problems. If the device is evaluated as not performing at the desired level, then recalculations will be necessary. Testing will include the ability of the blade to cut the carbon fiber into the desired size, the rpm of the blade shafts, and the space between the blades allowing uninterrupted rotation.

g. Analysis

Note: Some of analyses 1-12 are for the initial wood-chipper-inspired design that was abandoned in favor of the shredder-style blades. See the Discussion section and section 2-h for more on the initial design and the reason for the design change.

i. Analysis 1

Analysis 1 is to determine the amount of torque needed for the wheel chipper-style blade to cut the composite strips using the shear stress formula. The average shear strength of a carbon fiber composite, according to Matweb, is around 12,400psi. This was rounded to 15,000psi for added safety factor and used as the stress in the shear stress equation. The shear force required to generate that stress was calculated to be 1250lb, and the torque to create that reaction at an average distance from the axis of 3in was 3750in-lb. (Appendix A-1 for calculations)

ii. Analysis 2

Analysis 2 is to determine the rotation speed of the chipper-blade in order to cut the strips in 0.5” to 1” intervals. A length of 0.75” was chosen for this analysis to get an average value. The feed speed was found to be 1ft/min, and the necessary rotation speed of the blade was calculated to be 16rpm.

iii. Analysis 3

Analysis 3 is an attempt to find how discover how long the blade will need to contact the strip to sever it with the force calculated in analysis 1. The properties of momentum were used to determine the time required to contact the blade with the strip before it was cut. Further analysis needs to be done in this area because the result was questionable.

iv. Analysis 4

Analysis 4 determines the required gear reduction based on the 16rpm found in analysis 2 and the motor rating of 1750rpm. The goal was to find possible gear combinations to reduce the rpm from the motor shaft to the blade shaft, but the rpm difference is too great for a two-gear system to reduce by itself. Either a controller must be used to lower the speed of the motor shaft, or a gearbox must be used as an intermediary to greatly reduce the gear ratio. This was determined after calculations assuming a 7-tooth gear on the motor shaft found that the single gear on the blade shaft would have to be over 750 teeth. That number is not reasonable for the functioning model because the gear would be far too large in diameter to be integrated into the machine.

v. Analysis 5

Analysis 5 covers the design of a V-belt drive that would effectively reduce the rpm of the motor shaft and handle the power and shock loading required. Heavy shock loading was assumed, and an input rpm after a gearbox was assumed to be 100rpm. The target output was 16rpm. The V-belt chosen was a 5V, with one belt required, at a standard length of 212in.

vi. Analysis 6

Analysis 6 revisits the gear reduction needed to reduce rpm from the 1750rpm motor shaft to the desired 16rpm at the device. This time a gearbox with a 30:1 speed reduction is assumed after the motor, and the further gear reduction needed after the gearbox was calculated. After the 30:1 reduction the speed is 58.33rpm, leaving a further 3.65:1 reduction needed from the pulley system.

vii. Analysis 7

Analysis 7 deals with material requirements of the shaft that drives the blade. Using the required torque calculated in analysis 1, the shear stress of the shaft was calculated assuming a diameter of 0.75”. The shear stress in the shaft was calculated to be 45270.7psi, and by comparing the yield shear stress of different steels, it was determined that the material AISI 5160 or higher carbon steel is desired. The yield strength was used instead of the ultimate strength to ensure that the shaft will not permanently deform or weaken.

viii. Analysis 8

Analysis 8 determines the amount of torque required at the motor shaft and compared it with the torque rating of the motor to make sure it will support continuous operation. Using the relationship between gear ratio and torque ratio, and the output torque found in analysis 1, the torque required by the motor was found to be 2.86ft-lbs. From the manufacturer website, the motor is rated at 14.9ft-lbs during continuous operation. This satisfies the torque requirement with a safety factor of more than 4.

ix. Analysis 9

Analysis 9 assessed the shaft diameter required to withstand the shear and bending stresses imposed by the v-belt drive on the end of the blade shaft. A material of AISI 5160 steel was assumed. The yield stress was used instead of the ultimate stress to prevent any plastic deformation of the shaft that would hinder performance and require replacing parts. A 6in distance was assumed from the pulley location on the shaft (the force application point) to the nearest support (pillow block). The shear yield stress was calculated from the axial yield stress, and the minimum required diameter of the shaft was found to be 0.5in.

x. Analysis 10

Analysis 10 confirmed that the proposed shaft diameter would be sufficient to withstand the bending and shear stresses induced by the v-belt drive. A material of AISI 5160 steel was assumed. Like analysis 9, the axial yield stress was found, and the shear yield stress was calculated. Then the shear and bending stresses were calculated using the proposed 0.75in diameter cross section, and the results were compared to the yield values. Both the shear and bending stresses were found to be less than the yield values, and therefore the diameter was considered acceptable.

xi. Analysis 11

Analysis 11 selected the type of bearing required in the pillow block shaft supports. The shaft inner diameter must be 0.75” to accommodate the shaft diameter, and the bearing will experience radial load. A thrust loading of 10lb was assumed for a safety measure, which was found to be negligible, and a radial load of 185lb was used from analysis 9. A design life of 30000 hours was used to ensure a safety factor, and bearing 6204 was found to closely match the required dimensions.

xii. Analysis 12

Analysis 12 ensured that the designed key would support the induced shear stress from the blade and shaft. The cross-sectional area of the designed key is 0.1425in^2, and the average carbon steel tensile strength from Matweb is 230000psi. The average shear stress was calculated to be 172500psi, and the applied shear force of 1250lb was used from analysis 1. The stress in the key was calculated to be 8772psi, which is far less than the ultimate shear value of 172500psi, so the designed key is acceptable provided it is made from average medium carbon steel.

h. Device: Parts, Shapes, and Conformation

The design of the blade system comes from a crosscut paper shredder, or more similarly, an industrial fabric shredder. Two shafts will be driven by an electric motor, each shaft having several slotting saw blades on it. The blades from each shaft will alternate in position and mesh together, slicing the composite strips between them. The crosscut will come from the teeth on the blades severing the fibers along the width.

The size of the resulting chips may not conform to the targeted size, due to the tight spacing of the blade teeth. This issue may need to be resolved in the future by switching to saw blades with fewer teeth. The tolerances with shaft alignment must be tight so that the gears or blades don't bind together, and operation can continue smoothly. Tolerances for the space between the blades must be tight enough that gaps are not left for strips of fiber to pass through and jam up the blades, but large enough that the blades will never contact each other during operation.

Original design idea: The wheel shape of the blade was originally chosen for the slow ability to cut once per rotation with the cuts spaced out. The hollow in the wheel was to allow the material to pass through before being cut, to create appropriately sized cuttings. An issue with the wheel shape is that the rotation takes the blade outside the housing, so it must be covered for safety and ergonomics. The cutting shelf was designed to provide a surface against which the blade can shear the fibers. The blade tolerances are tight, as are the placement of the shafts due to the required precision of the cutting surfaces. The housing tolerances are looser because they are not a part of the moving assembly. A safety factor of 2 was used for the assembly because the stresses are not anticipated to exceed the predicted stress by nearly that amount, so 2 times the design stress will be a safe buffer.

i. Device Assembly

The extra blades will be added to the carbon fiber recycling device, along with smaller spacers than were previously installed. Those will be installed on new shafts that allow more space for blades, and the shafts will be mounted on pillow block bearings that are bolted to the existing housing. The problem presented for this project was that the composite strips need to be cut along the width to create chips, not just long fingers. The shredder blade layout satisfies this problem by cutting along the width to create chips of a specified size. Guards and covers will be added last to lessen safety risks while the device is running.

j. Technical Risk Analysis

A risk of this blade design is that the individual blades need to be very close to each other to properly shear the composite. This presents the risk of the blades jamming together if proper spacing is not kept, and the cutting being ineffective if the spacing is too large. If the blades contact each other without binding, there is also the risk of prematurely dulling the cutting edges.

k. Failure Mode Analysis

The entire assembly is made of steel, so if any components fail it will likely be in ductile fashion. However, there are some additional failure risks. The key in the shaft would fail in direct shear, the blade wheels could fail in torsion, and the blade edges would fail from fatigue due to impact or friction. Torsional stress analysis was done on the shafts to ensure that they won't fail in torsion if the system binds, and the system is designed so that the key will shear before the blades or shafts are destroyed.

l. Operation Limits and Safety

No objects besides the predetermined size of carbon fiber composite can be run through the cutter. For safety reasons, the drive chain must be covered to avoid exposure to that pinch point and the entirety of the blades must be covered to prevent exposure to the cutting surface by human hands. There is also a risk of electrical shock when near the motor or motor controller when they are turned on. The power must be fully off, ensured by lockout-tagout, when wiring is being done or adjusted. Safety glasses must be worn at all times when working with the device.

3. METHODS & CONSTRUCTION

a. Methods

The methods used in analysis were shear and normal stress analysis, v-belt design, bearing design, rpm and gear ratios, torque, and bending moments. These methods were used to answer questions of how much power is required at the blade and from the motor, the required material and diameter of the shaft, and the required rotation speed and gear reduction to achieve the desired power and cut length. V-belt design and bearing design procedures were also utilized to select the ideal v-belt and bearings that will support the load.

The primary manufacturing method used in construction was machining. Machining was the logical conclusion because the assembly is made entirely of metal. The housing plates required cutting to shape, hole layout, drilling, and thread tapping. With the redesign considered, the old housing that is already manufactured was be used, but additional holes needed to be drilled to mount the flange bearings, and some dimensions have been altered to ensure fitment without binding the gears. If appropriate spacers for the blades cannot be obtained off the shelf from a distributor, then they will be machined in house from stock material such as steel plate or rod. The blades will be ordered from a manufacturer to ensure that a tight dimensional tolerance and consistency is achieved. The efficiency of the blade is the crux of this project, so it is essential that the blade functions properly. To accomplish this, the blades must be a hard enough material that the edge does not wear prematurely, round enough so that a complete cut is made consistently, and straight enough to avoid interference between blades or the spacers. Therefore, the blades may also be sent off if the edge needs to be honed, as a professional would get the highest performance out of the cutting edge and be able to keep to the necessary tolerance.

The testing method was observing the function of the device. Initially the shafts were turned by hand to make sure there was no binding, and the electric motor was introduced when normal function of the blades and shafts was demonstrated. Then a small amount of composite material was fed through, and the cutting results were observed. If the composite strips were severed completely without jamming the blades, then the process continued as designed with continuous operation.

The design will be optimized through stress analysis. The shaft, blades, pulleys, and other rotating components were examined for premature wear, and as examination continues if wear is found, then analysis will be done to find the source of error that causes it. Now that the device has demonstrated proper and sustainable functionality, weight and excess material may be cut from parts that can afford it while still meeting design parameters. Other optimization can be done through trial and error, such as adjusting the rotation speed and blade spacing. Fitment needed to be augmented once everything was assembled and real-world inconsistencies revealed themselves, such as grinding housing edges to achieve better fitment and enlarging bolt holes so they line up with the threaded holes underneath. The alignment of the housing affects the alignment of the shaft (although the new bearings help with this issue) and by necessity the rotation of the blades, and therefore the housing bolting up square and without deflection is important to the design of the cutting device.

The method used to locate the mounting holes for the flange bearings was originally to be measuring the distance of the holes in the flange from the center of the bore, scribing a circle of that radius on the plate concentric with the shaft hole, and locating the mounting holes on that circle. This was determined to not be an efficient strategy because the holes in each bearing flange were not all at the same location. So instead, each of the four bearings was designated to a specific shaft end location and then marked, placed on the shaft to locate it, aligned horizontally, and then a drill bit was used to mark where the flange holes were on the housing plate.

b. Construction

i. Description

The current housing plates were disassembled to locate and drill holes to mount the flange mounted bearings that support the shafts. The custom spacers were machined using the lathe and the milling machine. The rest of the parts were machined or otherwise manufactured elsewhere, such as the bearings, blades, and drive gears. The first thing to be assembled was the housing, leaving off the cap. The base and sides were bolted together, and the shaft was fed through the holes with the blade and spacers in the middle and the bearings on the outside of each housing wall. The blades and spur gears were secured between the walls of the housing by spacers and collars, and the shaft was held in proper configuration by set screws in the bearings. Set screws will suffice for holding the shaft in proper orientation because the axial load is extremely minimal. Then the drive sprocket was fastened to the portion of a shaft that remains sticking out on the side of the motor.

ii. Drawing Tree, Drawing ID's

See Appendix B – Drawing Tree for drawing tree figure, including references to individual part drawings in Appendix B. Also see Appendix B for the assembly drawing.

iii. Parts

The blades and shaft were machined as needed. The blades were machined by the manufacturer, and the shaft was received with a keyway, so one did not need to be milled. The plate for the housing was drilled and tapped to receive the bolts that mount the bearing flanges. The drive sprocket, pillow block bearings, spacers, and shaft collars were installed as purchased.

iv. Manufacturing Issues

The blades and spacers required precise machining because the blades must come very close together without contacting in order to shear the fibers. This requires the blade surfaces to be straight, flat, and parallel with each other and the housing plates. The shafts need to be perpendicular to the housing plates they are mounted in, and the blades need to be perfectly concentric with them for uniform rotation.

The bolt holes in the housing plate have a tight location tolerance because the plates must line up straight to ensure the shafts and blades line up with each other. A change in shaft and blade geometry would cause less effective cutting and even contact between the blades and spacers, or more likely binding between the spur gears that link the cutter shafts. The layout for the holes drilled in the plate must be precise, and have a precise location with little variance because the shaft cannot be allowed to move or shift. This was made difficult by the holes in the bearing flanges not being in controlled locations form the manufacturer, so each hole in the housing plate had to be located individually. This was mitigated by using mounting bolts that are slightly smaller in diameter than the holes in the flange, allowing a small amount of play in the shaft location until the bolts are fully tightened. Assembly takes longer as each bearing needs to be held in position while bolted down, but this lessened the effect of an errant hole location on the permanent shaft alignment.

In the design by previous engineers, brass sleeves were pressed into the housing and used as bearings by precisely mounting the shaft while supporting it. While this allowed for immediate and definite shaft location, it did not leave room for adjustment if the holes were drilled slightly off center from each other. Those brass inserts were originally planned to stay in the plate to provide an extra cushion should the shafts contact the side of the holes. This idea was scrapped when it was determined that the inner diameter of the sleeves was less than one inch, and the new shafts with a 1” diameter would not fit through. The sleeves had to be removed after they were used in conjunction with the old shafts to locate the bearing mount holes.

v. Discussion of Assembly

The first thing assembled was the housing, minus the cap so the internals could still be viewed. The shafts were inserted into the housing and the shaft assemblies were put together from the shaft, blades, drive gears, collars, and spacers. Then the housing cap was installed to complete the housing assembly. Finally, the flange bearings were installed to attach the shaft and housing assemblies together, supporting and locating the shaft assembly. Each bearing needed to be held in place while the bolts were tightened, and if the shaft alignment was incorrect then one side of that shaft was loosened and adjusted until the shafts and blades lined up straight.

4. TESTING

a. Introduction

The testing required checking the clearance between the blades, the rpm of the blades to ensure synergy with the rest of the device, and the material output of the device for the desired fiber size. The main goal that the device must meet in testing is producing appropriately sized fibers.

b. Method/Approach

The method of testing the blade clearance was securing the blades in the location where they would be used, and then measuring between the blades. Blade RPM was tested by using a contact tachometer pressed against the end of one of the blade shafts. The method of testing the chip size and full operation was running the machine with material going through it and observing the results. The machine ideally needs to run continuously for hours at a time, so a long-term observation will be necessary to make sure that continuous operation is successful. Running the machine at full capacity and noting the continued success of the blades will be the testing approach for the blades. After the device is run, the blades will be inspected to ensure they kept their edge, and the produced chips will be analyzed again for conformance to the desired size.

c. Test Procedure

Formal Procedure of Test 3

Chip Size:

Summary: This procedure documents the process of powering, running, and operating the cutting blades of the JCATI carbon fiber recycling device. This cutter blade assembly was designed and manufactured by Mechanical Engineering Technology students for senior projects. The blades are designed to be powered by the electric motor on the device and run continuously without supervision, while severing the composite feed into chips containing 0.25”-0.5” long fibers.

Time: The test was conducted on 5/4/21 from 10:00 am to 11:00 am in Hogue 127. There was a half an hour of collecting equipment and setting up prior to the test. After the test, 15 minutes was required to remove the leftover fibers and resin from the cutter housing and return the device to a safe powered-off state.

Place: Room 127, Hogue Hall, Central Washington University campus in Ellensburg, WA.

Required equipment includes:

• Camera (cell phone)

• Carbon fiber composite strip (approximately 4” wide, 0.5” thick)

• Hand crank

• Allen wrench set

• Ruler

• Carbon fiber crusher

Risk: This test cannot be conducted without high voltage electrical power. The device under electrical power involves components rotating at high speed. There is a risk of injury to hands or fingers when hands are near the blades.

Risk to successful completion of the test would be a loose or interfering fit between the blades that causes binding or fracturing.

Safety glasses were required at all times while conducting the test. Additional personnel were not required but could be on hand as observers and in case of emergency.

The test procedure is as follows:

1) Collect equipment:

a. Source a cell phone or other video camera-equipped device.

b. Hand crank and composite strip from cart of device parts next to Hogue 127 work bench.

c. Allen wrench set from Hogue 127 work bench.

d. Ruler from Hogue 127 or Hogue machine shop.

2) Go to Hogue 127 and carbon fiber recycling device (North end of the room).

3) Place all the equipment on a table or bench nearby.

4) Ensure that power to the device is off and the machine will not run with lock out/tag out. *(image)*

5) Observe the cutting gears and check that there is space between the blades. Jiggle the blades in the axial direction of the shaft to ensure there is no play. If the blade sets on each shaft are touching each other, or if there is motion in the axial direction, loosen the locking collars and move each blade set until they are no longer contacting each other and are tight against the housing wall. Tighten the collars after adjusting. *(image)*

6) Remove hands and extremities from the blade area, and attach the hand crank to the input shaft of the device. *(image)*

7) Slowly rotate the crank and observe the rotation of the blades. If rotation becomes difficult or there is visible contact between the blades, stop and remove the crank immediately, and repeat from step 5.

8) Once the blades have been rotated without binding or contacting, remove the hand crank and place it back on the table.

9) Go to the power switch and turn on the power to the device. *(image)*

10) Turn on the switch that runs the electric motor and powers the device. *(same image)*

11) Observe the blades for contacting or runout of the shafts. If none is present, continue to the next step.

12) Pick up the composite strip and place it into the device at the location shown: *(image)*

Insert the strip as follows: hold it by one end and feed the opposite end into the crushing gears pictured. *(image)*

13) Observe the strip as it goes through the crushing gears and into the cutting gears.

14) After a pile of composite chips has accumulated on the other side of the cutting gears, stop the device and completely shut the power off with lock out/tag out. Use a brush to remove the chips from the housing.

15) Measure the fibers visible in the chips to determine whether they are in the acceptable 0.25”-0.5” range.

d. Deliverables

The distance between the blades was difficult to directly measure. Due to the blades being recessed in the housing, a caliper could not fit inside to measure the inside distance. For the first test, stacks of paper were inserted between the blades until no more could fit, and then a measurement was taken of the thickness of the paper. The distance between blades was estimated to be the width of a spacer minus the width of a blade taken in half, or 31 thousandths of an inch. Measured from the blades on the lower shaft, the distance to the next blade left was measured to be 34 thousandths, and to the right was 23 thousandths. The difference likely stems from the spacers between each blade bank and the housing slightly differing in width as machined. However, the clearance is high enough that the machine can be run. Due to the inaccuracy of using paper, which can be bent or compressed, another test will be administered using a clearance gauge when one becomes available.
The blade RPM necessary for the cutters to function in sync with other components of the device was calculated at 9.6 RPM. However, based on the unloaded motor speed and the gear ratio, a speed of 613 RPM was estimated for the actual operating value. The measured speed at the blade shaft was 620 RPM, so 613 was a good estimate, and the speed needs to be geared

down considerably before the cutting device can be properly used with the rest of the device. Another option to overcome the speed difference would be to use a motor controller to lower the input speed.

After the device was run under power and composite was fed through, the fiber size in the resulting composite pieces was measured. The average fiber size was 0.4”, which falls between the 0.25”-0.5” desired range, so the test was considered a success. There were outliers as large as 3” long and shorter than 0.125”, but the average result was used and the test was considered a success. If, in the future, it is determined that larger fibers must be attained to be reusable in industry, the blades and blade speed will need to be altered to meet that new goal.

5. BUDGET

a. Parts

The cost of this project was reduced with the redesign, because the new design utilizes many of the preexisting parts from the old cutter assembly, including the housing and half of the blades, which constitute the bulk of the expense. Thus far the no extra cost has resulted from manufacturing mistakes, and every precaution is being taken to keep it that way. The final cost of each item after shipping and taxes will be added to the table below.

	Part	Unit Cost	Quantity	Total Itemized
1	Blade	48.34	10	483.4
2	Brass washer	6.45	2	12.9
3	Flange bearing	15.08	4	60.32
4	Shaft	38.39	2	76.78
5	Blade spacer	6.72	23	154.56
6	Shaft Collar	3.13	1	3.13
7	Offset Chain Link	1.92	2	3.84
8	Chain Breaker Tool	24.99	1	24.99
9	5/16"-18 Hex Screw	0.1702	8	1.3616
			Tot Est.	821.28
	After tax + shipping		Total	843.53

The blades are the most costly part of the project, costing almost $50 each. This was mitigated by sourcing half the blades from the previous iteration of the project, but 10 blades still needed to be ordered. The other parts, including spacers, shafts, and bearings, did not constitute a bulk amount of the total cost like the blades did.

An order was placed on 1/16/21 consisting of blades, blade spacers, shafts, and flange bearings. The complete order was received on 2/4/21, with the correct parts and in a timely manner.

An order was placed on 3/3/21 for hardware, consisting of a single shaft collar. That order arrived during the second week of spring quarter.

Bolts to mount the bearings to the housing were selected from stock in the CWU machine shop, and an order was placed to replace them in the machine shop stock. These parts shared an order with an offset link for the drive chain.

A chain breaker tool was ordered at the start of spring quarter when the chain was installed, to edit the length of the chain further than adding master links or offset links. The order was received on April 25. The order also included a half link for the chain.

There were no extra costs due to production or testing. Care was taken to not damage parts and do things correctly on the first try to avoid remanufacturing with new parts.

b. Outsourcing

All purchased parts were either used as they came off the shelf or were machined in-house, so no outsourcing of labor was necessary for this project.

c. Labor

Labor was done 100% in-house for parts that needed to be machined or manufactured from raw stock. All work was completed in the Hogue machine shops, so there was no cost associated with labor.

d. Estimated Total Project Cost

$500 for blades
$150 for spacers
$150 for hardware
Total: $800

e. Funding Source

This project is funded by the school through a grant from JCATI. The grant is given for the purpose of prototyping a method of carbon fiber reclamation, and split among the students working on the project each year.

6. Schedule

a. Design

The initial design process was scheduled to end after fall quarter. The cause for delay of the design process was having to start over with a new idea at the beginning of winter. The open-ended nature of the project meant essentially starting from scratch, and several brainstormed ideas did not work out, so some analyses and sketches had to be done again. That was only a slight delay because the redesign happened early in the process. A major cause of delay was having to redo several analyses. With analyses completed every week, and tweaks to the design happening constantly, some old analyses became incorrect or even irrelevant. Other schedule issues include putting certain aspects of the design process off until the end of the quarter, such as different elements of analysis, assembly drawings, and any additional required CAD models.

As addressed in the Gantt Chart (in Appendix E), all aspects of the design slated for fall were completed by the start of winter quarter. An estimated total hour amount for the design process is 130 hours.

The redesign of the blades from the chipper style to shredder style caused a delay of several days in the design process, and set back the manufacturing and ordering of parts by a week.

b. Construction

Construction began the week of 1/25/21 with the disassembly of the old cutter housing. Parts were ordered the same week because of the redesign, so the construction started later than planned. Construction was originally scheduled to begin the first week of winter quarter, two weeks before. Manufacturing of custom parts began the week of 2/1/21, with the fabrication of the 1/32" spacer on the lathe. The housing plates were also edited to change the fitment to the mounting point by removing excess material from the front plate. The construction process is slated to continue as parts arrive, with initial assembly being finished by the week of 3/1/21. Issues that delayed the process of final tweaks and assembly were parts not arriving, additional parts having to be fabricated, and fitment issues during assembly. If an error was made in parts ordering or on the assembly drawing and the ordered parts do not fit, production was delayed until the correct parts could be made or ordered, potentially by a week or even two. To reduce the impact that this had on the schedule, other parts of the assembly were worked on while waiting for orders. To make use of the waiting period for the initial parts order, work began first on the existing housing plates.

c. Testing

Test planning began at the end of march with the planning of test 1. The first test was completed on schedule during the second week of April. Although alternate tools had to be used to complete the test, the testing time was only set back a manner of minutes and was still completed on schedule. The second test was conducted on Monday morning, April 26, on schedule and without scheduling complications. The third test was completed the week of May

3 of Spring quarter. This test was conducted several days later than originally scheduled, because the motor controllers were switched from on/off switches to PWM speed controllers by CWU electricians. Each test was set apart by about one week due to the time necessary to complete the data processing and testing reports after each one. For the second and third tests, it was necessary for the device to be fully assembled and operational before testing took place, so it could be hooked up to the motor and run under power. This requirement kept the tests from being completed earlier, before the device was ready to be powered on.

7. Project Management

a. Human Resources

Human resources for this project include the Central Washington University mechanical engineering technology faculty, namely Dr. Pringle and Dr. Choi, and contacts at JCATI. The principal engineer provided analysis and final say on design decisions, along with expertise in materials science. The principal engineer's resume is located in Appendix H.

b. Physical Resources

A key physical asset for this project was the Central Washington University machine shop and the equipment therein, including lathes, milling machines, drill presses, and other machining process tools. The physical resources required by this project were the milling machine, the drill press, saws and files, grinders, and the lathe. The risk in relying on the CWU machine shop was having limited access to the building, but that was not anticipated to be (nor was it) a problem.

c. Soft Resources

Modeling for this project relied heavily on Solidworks for part models and drawings. MDSolids was also used to check calculations for stresses in some components. The risk associated with using MDSolids is that there is no guarantee about the accuracy of results, but the software is reputable and the risk of an incorrect calculation from that source is low. The risk with Solidworks is a continued reliance on the file compatibility with hardware and the ability to share files with advisors. This risk is also negligible because the MET staff and students have access to this software.

d. Financial Resources

The bulk of the financial resources for this project came from the JCATI grant to Central Washington University. The grant is committed to fund the material and labor costs for the entire carbon fiber recycling device. Other funds came from the mechanical engineering technology department and small out-of-pocket expenses by the principal engineer. Over budget expenses not cleared by the MET department would be paid out of pocket by the principal engineer, but none occurred.

8. DISCUSSION

a. Design

During the idea phase several design possibilities were considered. A worm gear, a single large gear with wide teeth, and a shredder-style blade were the first ideas. In the worm gear setup, the gears would have traveled when they meshed together, and therefore the worm gear idea was not feasible. The large gear would be difficult to mesh against a cutting surface to completely sever the strip. A similar design is used for the delamination of the composite strips prior to them being fed into the cutter, and it only bends the strip without severing many of the fibers. The shredder was thought to risk leaving some of the fibers uncut, because they are small enough to fit between the shredder teeth. The choice was made to move to a chipper-style blade because the speed involved would enhance the ability to cleanly shear the fibers. The large size of the blade wheel will allow the single blade on the wheel to rotate at a speed fast enough to shear the fibers. The chipper blade will also be able to slice along the width of the strips more easily than the other cutter designs. The crosscut chipper blade would be added on to the process behind the current blades.

The design problems to overcome for the chipper blade were the size of the blade wheel and the orientation of the shaft. For the strip to fit through the wheel and be sliced, a radius larger than the strip width was necessary. That meant the housing must be large, or part of the wheel would be sticking out of the housing. Either way a cover must be made to shield the wheel from operators. The simplest solution was to enlarge the housing to cover the entire wheel. A perk of the chipper design is that it is oriented perpendicular to the strip and can therefore cut across in a direct manner, but that means by necessity that the rotation is perpendicular to the feed rollers and the other cutting gears. The rotation direction must be rotated 90 degrees from the motor to the wheel shaft for the proper transmission of motion to occur. The solution to this problem was a twisted v-belt drive or a 90-degree gearbox. Another issue was that the blade must be oriented in a specific way for the chipper setup, and must be machined as such. Machining the blade at the wrong angle could meant the blade not cutting because the edge is not shearing the fibers against the cutting shelf. If the blade is angled away from the cutting shelf instead of against it, the fibers may be bent under the blade instead of sheared. Also, the housing must be large enough to not only fit the shaft and cutting surfaces inside, but also have room on the outside to mount the pillow block bearings. Another issue with the chipper blade was the extremely slow rpm required for the single blade to make cuts at the desired intervals, which detracted from the perceived benefit of a fast, clean severing of the strip.

The chipper blade was abandoned in favor of a shredder blade setup, utilizing the current housing and shaft structure already in place. The rotation speed of the chipper blade was determined to be too slow for effective cutting, and the tolerances would be difficult to achieve between the cutting shelf and the blade. The shredder blades will be cheaper because many of the blades are already purchased and in use, and the same housing can be used with some edits. This style will also allow the blades to be completely enclosed in the housing, erasing the need for a larger cover for the exposed chipper blade. This design will also save space by building on the current setup instead of adding the crosscut blade onto the process in a different housing.

b. Construction

Deconstruction of the old blade assembly presented some challenges, including the tight spacing of the chain sprocket to the cutter housing limiting access to the set screws. This problem is being remedied by adding the longer shaft and further spacing out the sprocket hub from the housing. An assembly issue that presented itself early was that a small portion of the front panel of the housing sticks down below the baseplate, making it difficult to mount the assembly flat on the larger device. This was remedied by removing the excess material sticking below the baseplate, so the box can be mounted flatter on the baseplate.

One challenge presented by construction was aligning the shafts parallel to each other so they can both spin freely without binding, and so the blades can rotate without contacting each other. To make sure that the shafts line up from bearing to bearing, the bearings were bolted in loosely while the shafts were fed through, and after the shaft reached through both bearings they were tightened up. Then the shaft alignment with respect to each other was checked, and the bearings were loosened and moved one end at a time until the shafts lined up.

Next the blades and spacers were fed onto the shaft. This process took over an hour because the blades had to be in the correct orientation, and the blades had to be put on both shafts at the same time, alternating one after another, because of the tight clearance between them. The blades and spacers had to be held in place during assembly so the key didn't back out and allow rotation of the blades. Once all the blades were installed, the need for a shaft collar became evident, because if the blades and spacers were allowed the slightest slack in their placement against the housing wall, the blades would slightly contact each other during rotation. Until the second shaft collar arrived from a parts order, extra spacers were used to keep the space between the spur gears and the blades.

c. Testing

The first test conducted was measuring the clearance between the blades. The test was originally planned to be conducted using inside calipers between the blades, but because the blades are recessed inside the housing when assembled, calipers could not reach them. Instead, paper was stacked between the blades until no more could fit, and then the stack of paper was measured by the calipers to determine the clearance. The test would have been more accurate with feeler gages, but feeler gages could not be located on short notice, and so the paper was used as a substitute. Paper provided a close enough approximation, and still showed a clear difference in the clearance from one side of the blades to the other.

The next test was determining the rpm of the blade shafts. To keep up with the linear feed speed of the composite from the crushing wheels, the necessary rpm was calculated to be much lower than the measured rpm. The measured rpm was 620, compared with the “required” rpm of 9.6. The rpm was difficult to measure because the reading on the mechanical rpm gauge kept fluctuating, but the steadiest reading was taken as the correct one. Because the measured rpm was much too high to synchronize with the rest of the device, the rpm will have to be lowered. Because the motor struggled with providing torque to shred the full-size composite, the best option for rectifying the rpm is gearing down the rotation instead of slowing the motor speed, which would lower rpm and simultaneously increase torque.

The final test was measuring the length of fibers after the material was shredded. The predicted average value was between 0.25” and 0.5”, and the measured average fell in that range, at 0.4”. The goal of the project is to end up with fibers around 1” in length, so the test failed on that front. But the test was based on the predicted value given the current blades, and so it succeeded. One caveat to the success of the test is that the composite that resulted in the shredding was not fed from the crushing section or at the ideal speed. The composite was instead fed into the blades with plyers at the full speed of the blades. A c-clamp was used to attempt to hold the composite in place while the blades chipped it, but the composite was pulled out of the clamp by the blades. Because of the high rpm the shredding blades currently operate at, the fiber length may have been longer or shorter than it would be if the blades were moving slowly and being fed directly from the crushing gears.

9. CONCLUSION

The carbon fiber cutting section of the JCATI composite recycling device has been successfully designed according to senior project standards. The design demonstrates engineering merit in the analysis of various components, which include stress, torque, and rotational analysis, and through the complex calculations of the flange bearings and v-belt drive. The shaft material has been chosen to resist deforming when under torsion, and the blade design has been chosen to fit the directional and cutting-size needs. A key on the cutter shafts has been specified so that if a blade binds, the key will shear to ensure that the rest of the device remains intact in the event of a stuck blade. All parts contingent to the success of the project have been identified and sourced, and are within budget. The components are all within the capability of the principal engineer and the mechanical engineering department to source, whether bought, machined from raw material, or borrowed from extra stock. In addition to being of great interest to the principal engineer, the project has been devised and assembled solely by the principal engineer, and therefore reflects the engineering ability of the principal engineer. The device successfully met the chief requirement of producing fibers between ¼” and ½” in length.

10. ACKNOWLEDGEMENTS

JCATI sponsored this project through a grant to the CWU MET department, making the construction of the composite recycling device possible.

Central Washington University has provided access to the labs and equipment on campus which allowed the design and manufacturing processes for this project to take place.

Dr. Charles Pringle has provided guidance to the principal engineer on analysis techniques, engineering procedures, and the feasibility of different manufacturing strategies, as well as instruction on the subjects needed to complete the analysis and design of the project.

Dr. John Choi has provided instruction on engineering principles, analysis, and standards, in addition to advice on the completion of this report.

PE Andrea Cooley assisted in gathering general industrial processes and strategies from various manufacturing industries to assist in the design development of the composite cutting blade system.

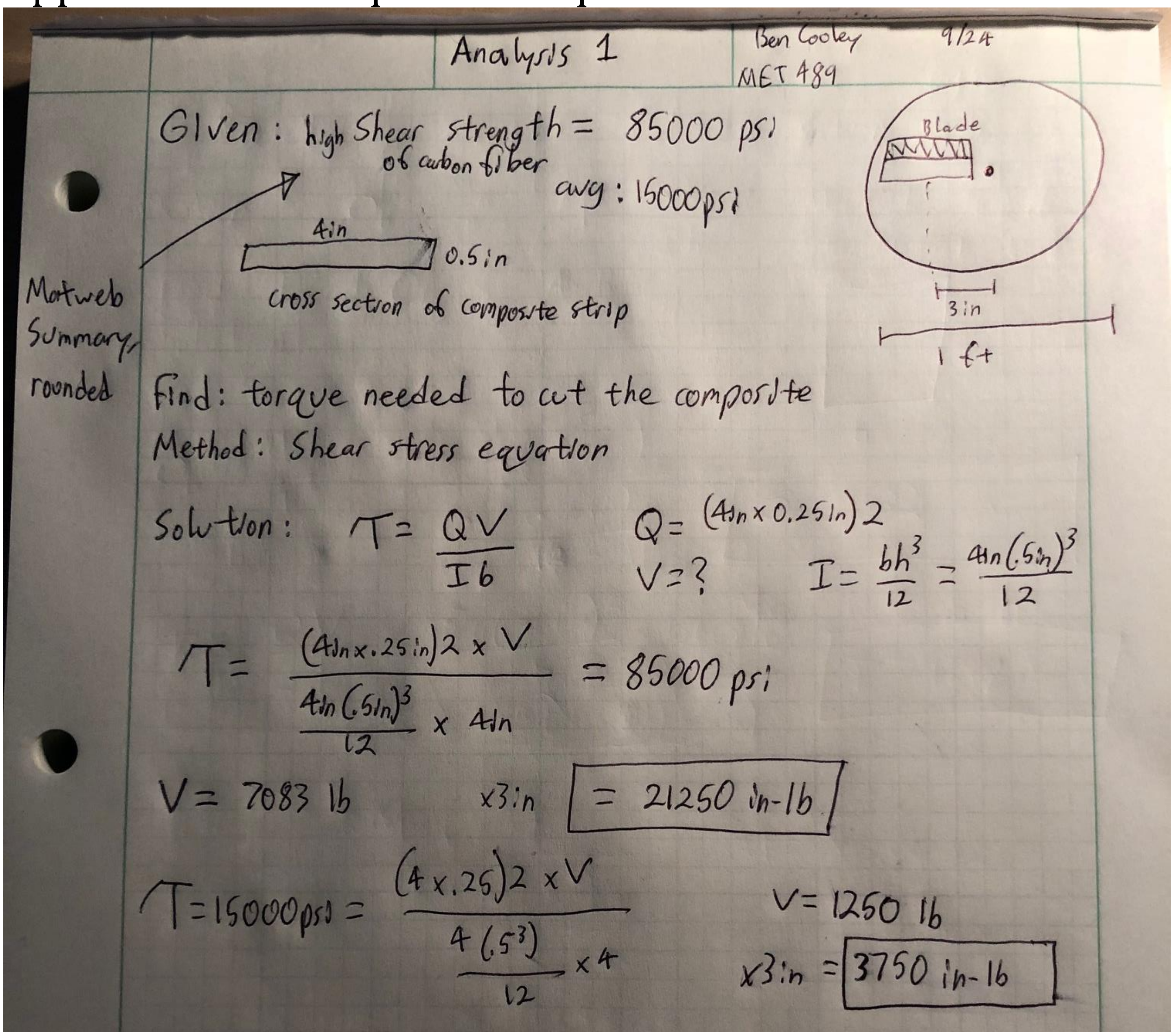
References

"Medium Carbon Steel." *Metal, Plastic, and Ceramic Search Index*, 2020, www.matweb.com/search/MaterialGroupSearch.aspx.

Mott, Robert L., et al. *Machine Elements in Mechanical Design*. Pearson, 2017.

APPENDIX A - Analysis

Appendix A-1 – Required Torque



Analysis 1 — Ben Cooley, MET 489 — 9/24

Given: high Shear strength = 85000 psi of carbon fiber (Matweb Summary, rounded)

avg: 15000 psi

4 in × 0.5 in — cross section of composite strip

Find: torque needed to cut the composite

Method: Shear stress equation

Solution: $\tau = \frac{QV}{Ib}$ $\quad Q = (4in \times 0.25in)2$ $\quad V = ?$ $\quad I = \frac{bh^3}{12} = \frac{4in(.5in)^3}{12}$

$$\tau = \frac{(4in \times .25in)2 \times V}{\frac{4in(.5in)^3}{12} \times 4in} = 85000 \text{ psi}$$

$V = 7083$ lb $\quad \times 3in$ $\boxed{= 21250 \text{ in-lb}}$

$$\tau = 15000 \text{psi} = \frac{(4 \times .25)2 \times V}{\frac{4(.5^3)}{12} \times 4}$$

$V = 1250$ lb

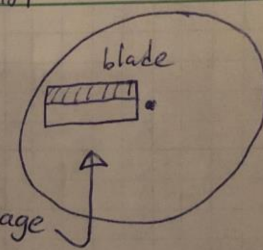
$\times 3in = \boxed{3750 \text{ in-lb}}$

Appendix A-2 – Required RPM

Analysis 2 | Ben Cooley, MET 484 | 10/1

Given: Feed rate = 1 ft/min = 12 in/min

Blade ⇒ 1 revolution = 1 cut



Find: rpm of the blade to cut 0.75 in fibers

Method: rpm vs feed rate, unit conversion

Assume: feed rate is constant

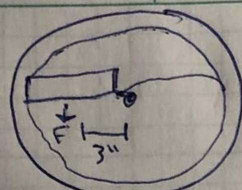
Solution:

$$\frac{12\ \text{in}}{\text{min}} \times \frac{1\ \text{rev}}{.75\ \text{in}} = \boxed{16\ \text{rpm}}$$

Appendix A-3 – Blade Contact Time

Analysis 3 — Ben Cooley, MET489 — 10/8

Given:



$F_{req} = 7083$ lb to cut the carbon fiber strips

$V = r\omega \qquad H_o = d\,mv \qquad P_o = mv$

Find: How quickly will the blade cut the strips?

Methods: momentum, angular momentum

Assume: r and d are avg = 3"
rpm is constant
$m_{blade} = 10$ lbm

Solution: $H_o = 3''(10\,lb_m)(3'' \cdot 16\,rpm) = 1440$ lb-in²/min

$= 24$ lb-in²/s

$P_o = mv = 10\,lb_m(3'' \cdot 16\,rpm) = 480$ lbm-in/min $= 8$ lbm-in/s

$mv = Ft \qquad 8\,lb_m\text{-in/s} = 7083\,lb_f\,t \qquad \boxed{t = 0.0011\,s}$

With the given rpm, the blade will not be able to cut the strips as quickly as 0.0011s.

Appendix A-4 – RPM Reduction

Analysis 4 | Ben Cooley MET 489 | 10/8

Given: Cutter Speed$_B$ = 16 rpm
motor speed A = 1750 rpm

$$\frac{rpm_A}{rpm_B} = \frac{\#\,teeth\,B}{\#\,teeth\,A} = GR$$

Find: necessary gear ratio, possible teeth #s
Method: ratios and gear reduction
Solution:

$$\frac{1750\ rpm}{16\ rpm} = 109.375 = GR$$

Say gear A has 7 teeth

$$109.375 = \frac{t_B}{7} \qquad t_B = 765.625\ \text{teeth}$$

Not feasible.

A lower motor rpm must be used, or another gear box that provides further reduction. Two gears will not be large enough to adequately reduce speed.

Appendix A-5 – V-Belt Design

Analysis 5 — Ben Cooley, MET 489 — 10/15 — 1/2

Given: AC Motor 1750 rpm 5 hp 8 hr/day

After gearbox: ~~60~~ 1000 rpm nominal output: 16 rpm

reduction

Find: design V-belt drive

Assume: heavy shock loading, $v =$ ~~4000 ft/min~~ 2500 ft/min

V-belt is appropriate

Method: V-belt design parameters

Solution:

$P_{des} = SF \times Hp = 1.4 \times 5\,hp = 7\,hp$

Belt size from chart: **5V**

$VR = \frac{\omega_{driving}}{\omega_{driven}} = \frac{1000\,rpm}{16\,rpm} =$ ~~3.75~~ $\boxed{62.5}$

$PD_1 = \frac{v\,2}{\omega} = \frac{2500\,ft/min\,(2)}{1000\,rpm} \times \frac{12\,in}{1\,ft} \times \frac{1\,rev}{2\pi\,rad} =$ ~~25.4.65~~ $9.55\,in$

$\boxed{std: 9.65\,in}$

Power rating $\boxed{13\,hp}$

Trial $VR = \frac{24.8\,in}{9.65\,in} = 2.57$ closest std → $\boxed{PD_2 = 24.8\,in}$

Trial CD

$24.8\,in < CD_T < 3(24.8\,in + 9.65\,in)$

Say $CD_T = 80\,in$

$L_p = 2(80\,in) + 1.57(24.8\,in + 9.65\,in) + \frac{(24.8\,in - 9.65\,in)^2}{4(80\,in)}$

$L_p = 214.66\,in$ $\boxed{std\ size = 212\,in}$

Cont | Analysis 5 | Ben Cooley MET 489 | 10/15 | 2/2

Actual CD

$$CD = \frac{B + \sqrt{B^2 - 32(D_2 - D_1)^2}}{16}$$

$$B = 4L_p - 6.28(D_2 + D_1)$$

$$B = 4(212in) - 6.28(9.65in + 24.8in) = 631.65$$

$$CD_A = \frac{631.65 + \sqrt{631.65 - 32(24.8in - 9.65in)^2}}{16}$$

$$\boxed{CD_A = 40.24in}$$

$$\theta = 180° - 2\sin^{-1}\left(\frac{24.8in - 9.65in}{2(40.24in)}\right) = 158.30°$$

Correction factors

$C_L = 1.08$

$C_\theta = 0.94$

$$P_{cor} = P_{rated} C_\theta C_L = 13\,Hp \times 1.08 \times 0.94 = \boxed{13.20\,Hp}$$

# of belts

$$\frac{13\,hp}{13.20\,hp} = 0.98$$

$\boxed{1 \text{ belt}}$

Appendix A-6 – RPM Reduction 2

Analysis 6

Ben Cooley
MET 499

10/16

goal: 16 rpm

Given: 1750 rpm motor
speed reducer gearbox: 30:1

Find: further speed reduction required

Assume:

Solution:

$$\frac{1750 \text{ rpm}}{30} = 58.33 \text{ rpm}$$

$$\frac{58.33 \text{ rpm}}{16 \text{ rpm}} = 3.65$$

A pulley system with a speed reduction of 3.65:1 is needed.

Appendix A-7 – Shaft Strength

Analysis 7 | Ben Cooley MET 489 | 10/22

Given: diameter = 0.75" Torque = 3750 in-lb

safety factor = N/A

AISI 1045 S_y = 84800 ~~70300~~ psi Matweb

AISI 5160 S_y = 94300 psi

Find: torsional strength desired, suitable material

Method: Shear stress due to torsion,

Solution:

$$\tau_{max} = \frac{Tc}{J} \qquad c = \frac{0.75"}{2} = 0.375"$$

$$J = \frac{\pi}{32}(.75")^4 = 0.031\ in^4$$

$$\tau_{max} = \frac{3750\ in\text{-}lb \times 0.375"}{0.031\ in^4}$$

$$\boxed{\tau_{max} = 45270.7\ psi}$$

$$S_{ys} = \frac{S_y}{2} \qquad S_{ys} = \frac{84800\ psi}{2} = 42400\ psi$$

$$S_{ys} = \frac{94300\ psi}{2} = 47150\ psi$$

AISI 5160 or higher carbon steel

Appendix A-8 – Motor Torque

Analysis 8 | Ben Cooley, META89 | 10/22

Given: Output torque = 3750 in-lb; RPM required = 16 rpm; Motor power = 5 hp; Motor RPM = 1750 rpm; Motor Torque = 14.9 ft-lb

Find: ~~Output power and motor torque.~~ Does the motor have enough power? (torque)

Assume: 3750 in-lb is near max torque required

Method: ~~Power~~ Gear ratio, velocity ratio, ~~power/torque relationship~~

Solution:

$$T_{out} = T_{in} \times \frac{\pi D_{out}}{\pi D_{in}} \qquad \frac{D_{out}}{D_{in}} = \frac{n_{in}}{n_{out}}$$

$$T_{out} = T_{in} \times \frac{n_{in}}{n_{out}} \qquad 3750\text{ in-lb} \times \frac{\text{ft}}{12\text{ in}} = 312.5\text{ ft-lb}$$

$$312.5\text{ ft-lb} = T_{in} \times \frac{1750\text{ rpm}}{16\text{ rpm}} \qquad \underline{T_{in} = 2.86\text{ ft-lb}}$$

~~$T = P/n \qquad 2.86\text{ ft-lb} = \frac{P}{1750\text{ rpm}} \qquad P =$~~

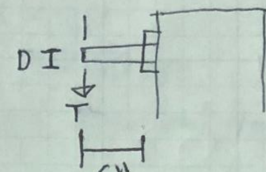
> 14.9 ft-lb > 2.86 ft-lb
> The motor will supply enough torque.

Appendix A-9 – Shaft Diameter

Analysis 9 | Ben Cooley, MET489 | 10/29

Given:

AISI 5160 Steel



matweb: $\sigma_Y = 94300\ psi$

gates calculator: $T = 185\ lb$ (standard)

$\tau_Y = \sigma_Y / 2$

Find: shaft diameter

Assume:

Method: σ_Y, τ_Y, bending and pure shear stress

Solution:

$$\sigma_b = \frac{My}{I} \qquad M = Td = 185\,lb(6\,in) \qquad M = 1110\ lb\text{-}in \qquad y = \frac{D}{2}$$

$$I = \frac{\pi D^4}{64}$$

$$94300\,psi = \frac{1110\,lb\text{-}in\left(\frac{D}{2}\right)}{\frac{\pi D^4}{64}} = \frac{11306.37}{D^3}$$

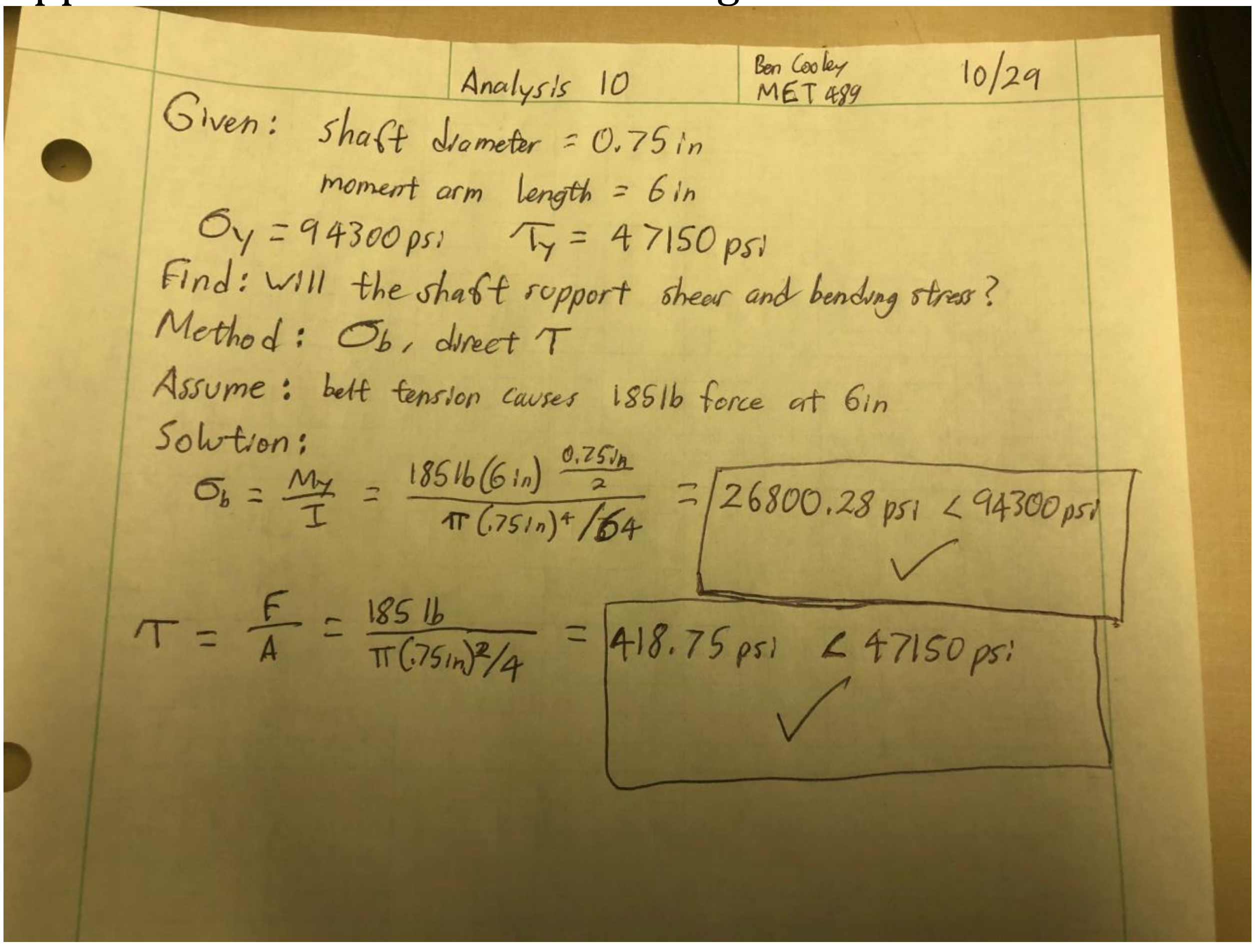
$$D^3 = \frac{11306.37\,lb\text{-}in}{94300\,psi} = 0.120\,in \qquad \underline{D = 0.493\,in}\ ✓$$

$$\tau_Y = \frac{94300\,psi}{2} = 47150\,psi \qquad \tau = \frac{F}{A}$$

$$47150\,psi = \frac{185\,lb}{\frac{\pi D^2}{4}} \qquad \frac{\pi D^2}{4} = \frac{185}{47150} \qquad \underline{D = 0.071\,in}$$

D = 0.5 in or greater

Appendix A-10 – Shear and Bending Stress



Analysis 10 | Ben Cooley MET 489 | 10/29

Given: shaft diameter = 0.75 in

moment arm length = 6 in

$\sigma_y = 94300$ psi $\quad \tau_y = 47150$ psi

Find: will the shaft support shear and bending stress?

Method: σ_b, direct τ

Assume: belt tension causes 185 lb force at 6 in

Solution:

$$\sigma_b = \frac{My}{I} = \frac{185\,lb\,(6\,in)\,\frac{0.75\,in}{2}}{\pi(.75\,in)^4/64} = 26800.28\ psi < 94300\ psi\ ✓$$

$$\tau = \frac{F}{A} = \frac{185\,lb}{\pi(.75\,in)^2/4} = 418.75\ psi < 47150\ psi\ ✓$$

Appendix A-11 – Bearing Calculations

Analysis 11 | Ben Cooley MET489 | 11/4

Given: The shaft bearing will experience radial and thrust loads. Thrust loading is minimal.

ID = 0.75 in   1000 hr desired life

Find: select bearing to use

Assume: radial load = 185 lb   Thrust load = 10 lb

Method: bearing selection procedure (from text)

Solution:

$Y = 1.5$ (Assume)

$X_{assume} = 0.56$

$K = 3$

$P = VXR + YT$

$P = 1.0(0.56)\,185\text{ lb} + (1.5)\,10\text{ lb} = 118.6\text{ lb}$

$C = P\,(L_d/10^6)^{1/k} = 118.6\text{ lb}\,(0.96)^{1/3}$

$C = 116.997$

Bearing selected from C value = 6004

$C_o = 1124$

$T/C_o = 10\text{ lb}/1124\text{ lb} = 0.009$

closest $e = 0.19$

$T/R = 0.054$ $T/R < e$, switch to $P = VR$

$P = VR = (1.0)\,185\text{ lb} = 185\text{ lb}$

L_d = Design life = 20000–30 000 hours (table 14-4)

$C = P_d\,(L_d/10^6)^{1/3} = 185\text{ lb}\,(30000/10^6)^{1/3} = 57.48$

All bearings meet specified C value in table 14-3

Bearing 6204 closely matches dimensions

Single row, deep groove

Appendix A-12 – Key Stress

Analysis 12 | Ben Cooley MET489 | 11/6

Given: ~~Torque =~~ Shear force = 1250 lb

cross sectional area of key = 0.75" x 0.19" = 0.1425 in^2

Martweb: avg carbon steel tensile strength = 230000 psi

Find: will the key support shear stress induced?

Methods: direct shear

Assume: direct shear across the key, carbon steel key

Solution:

$$\tau = \frac{V}{A}$$

$V = 1250 \text{ lb}$ ← from Analysis 1

$A = 0.1425 \text{ in}^2$

$$\frac{1250 \text{ lb}}{0.1425 \text{ in}^2} = 8771.93 \text{ psi}$$

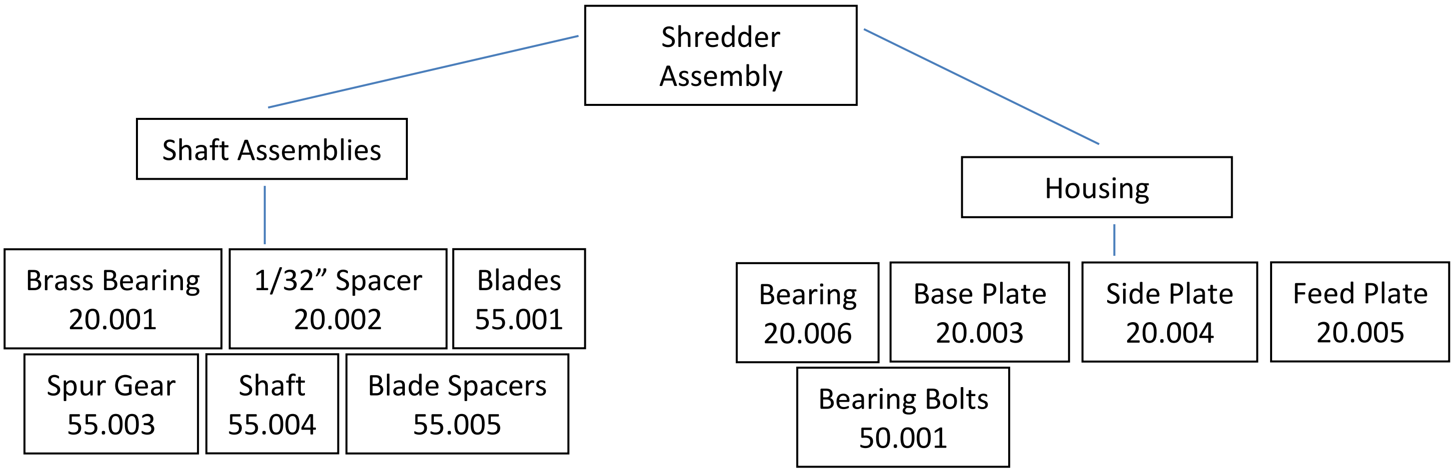
$USS \approx UTS(0.75)$ $\quad$ $230000 \text{ psi}(.75) = 172500 \text{ psi}$

172500 psi >> 8771.93 psi

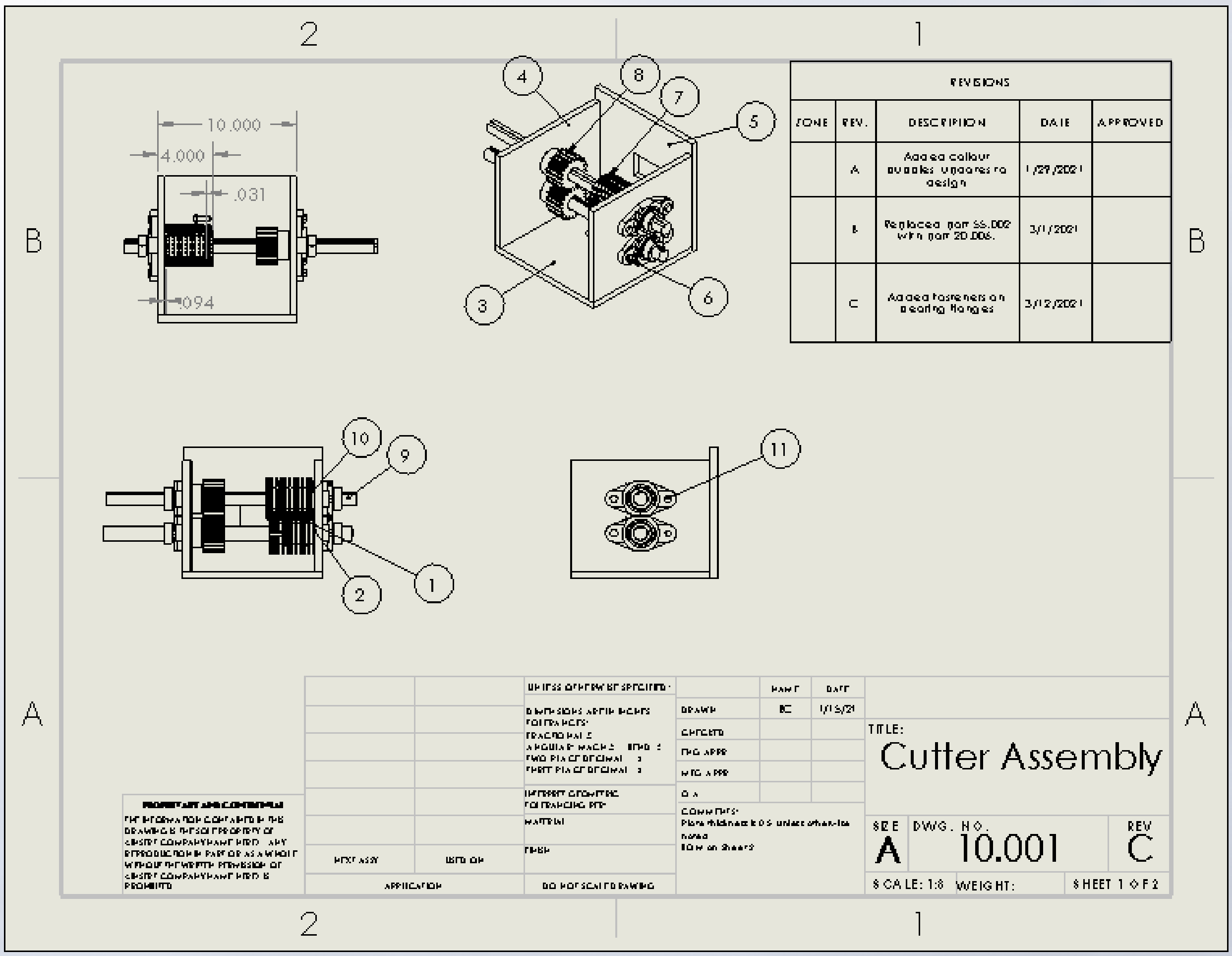
The key will support the stress.

APPENDIX B - Drawings

Appendix B – Drawing Tree



Appendix B – Assembly



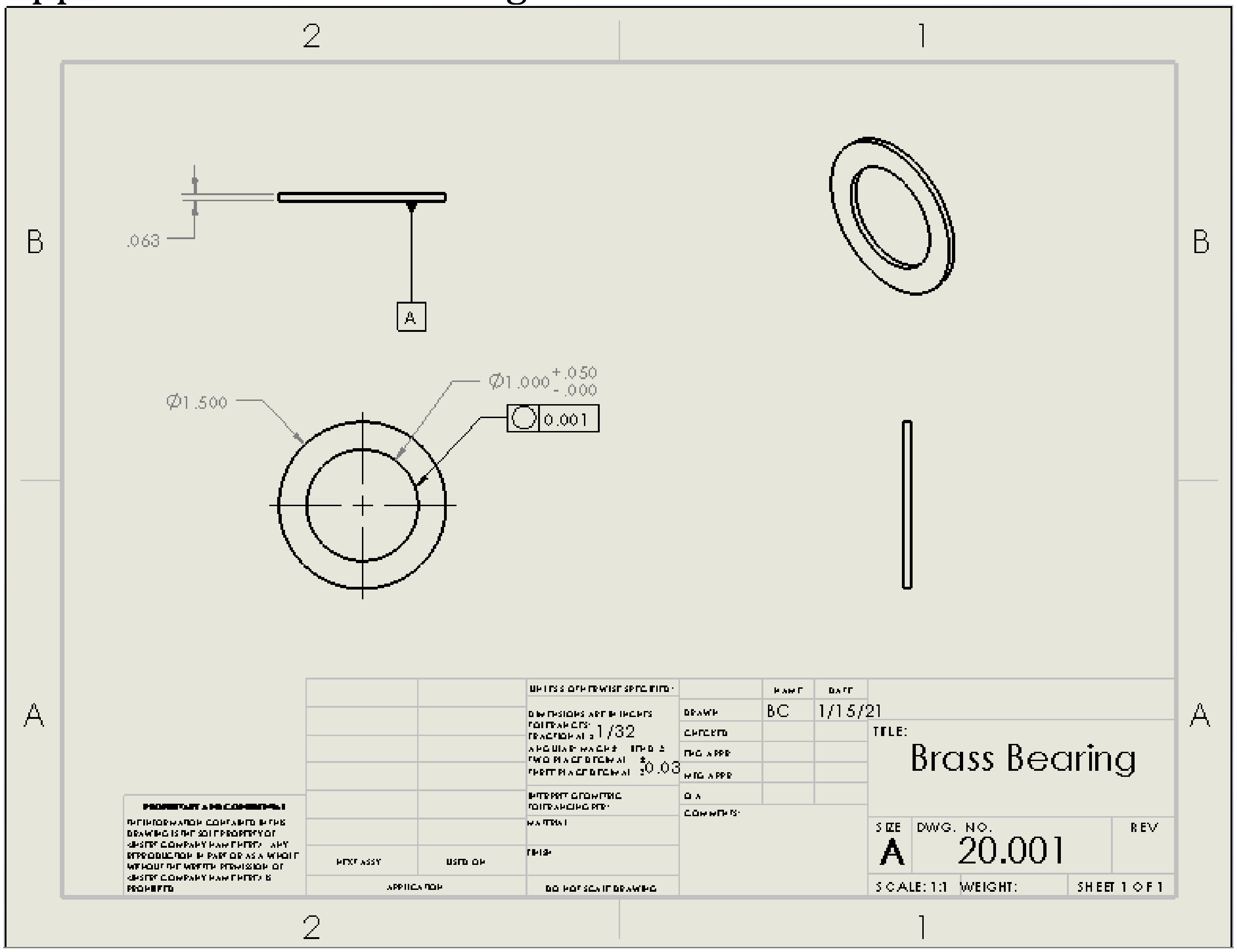
ITEM NO.	PART NUMBER	/PART TITLE	QTY.
1	20.001	BRASS BEARING	2
2	20.002	1/32" SPACER	1
3	20.003	BASEPLATE	1
4	20.004	SIDEPLATE	2
5	20.005	FEED PLATE	1
6	20.006	FLANGE BEARING	4
7	55.001	SAMPLE BLADE	22
8	55.003	SPUR GEAR	2
9	55.004	SHAFT	2
10	55.005	3/16" SPACER	21
11	50.001	BEARING BOLT	8

TITLE: Bill Of Materials

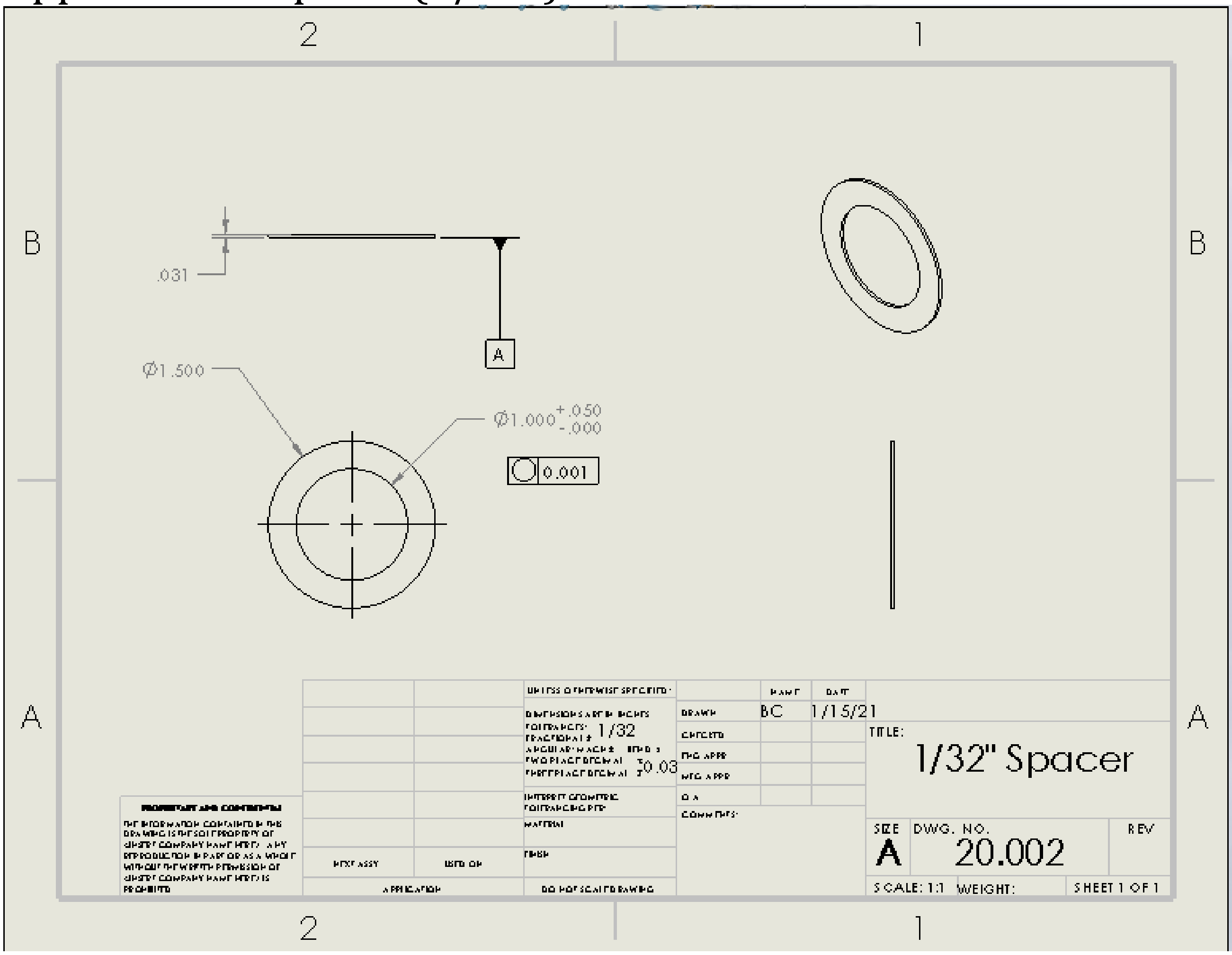
SIZE A DWG. NO. 10.001 REV C

SCALE: 1:8 WEIGHT: SHEET 2 OF 2

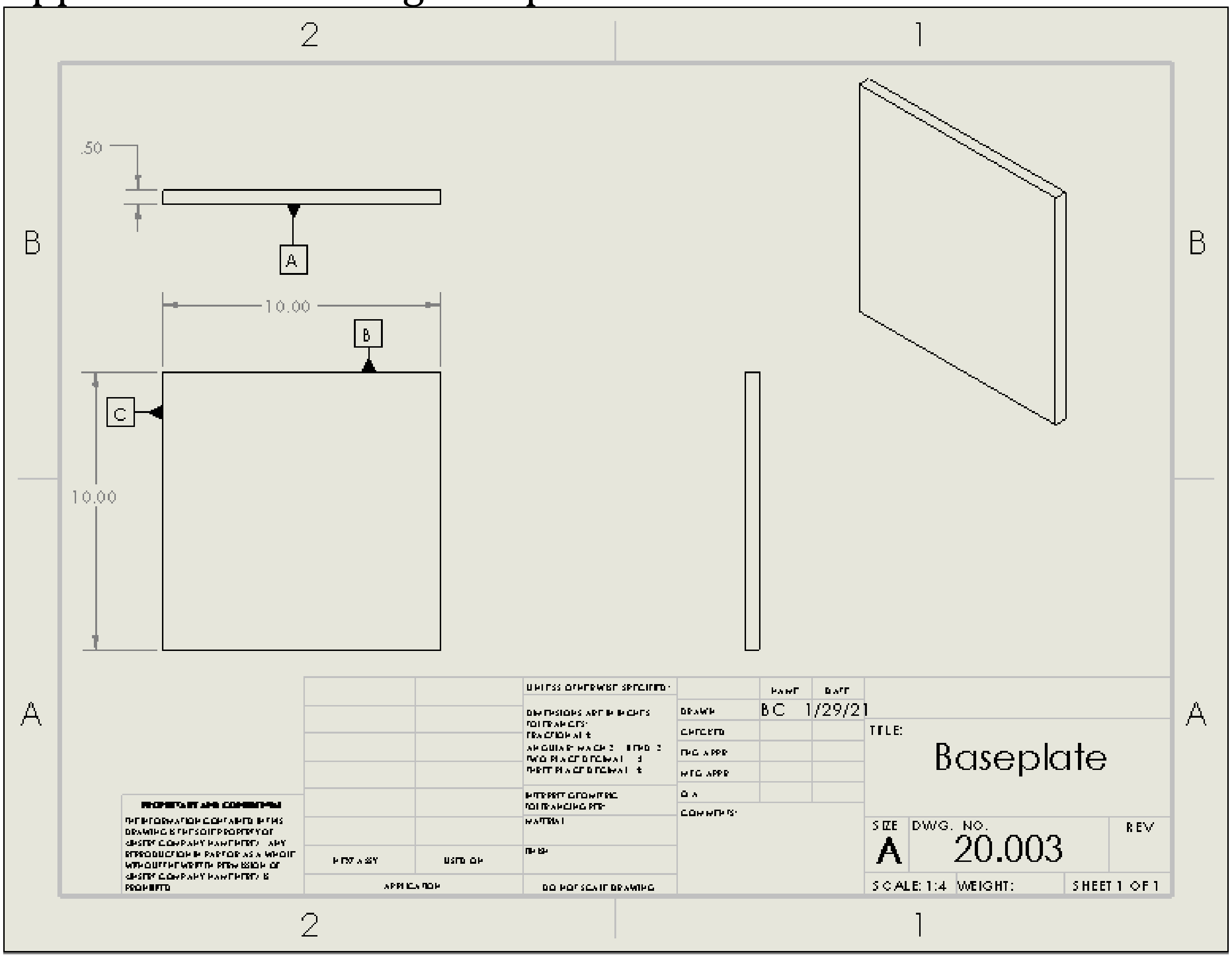
Appendix B – Brass Bearing



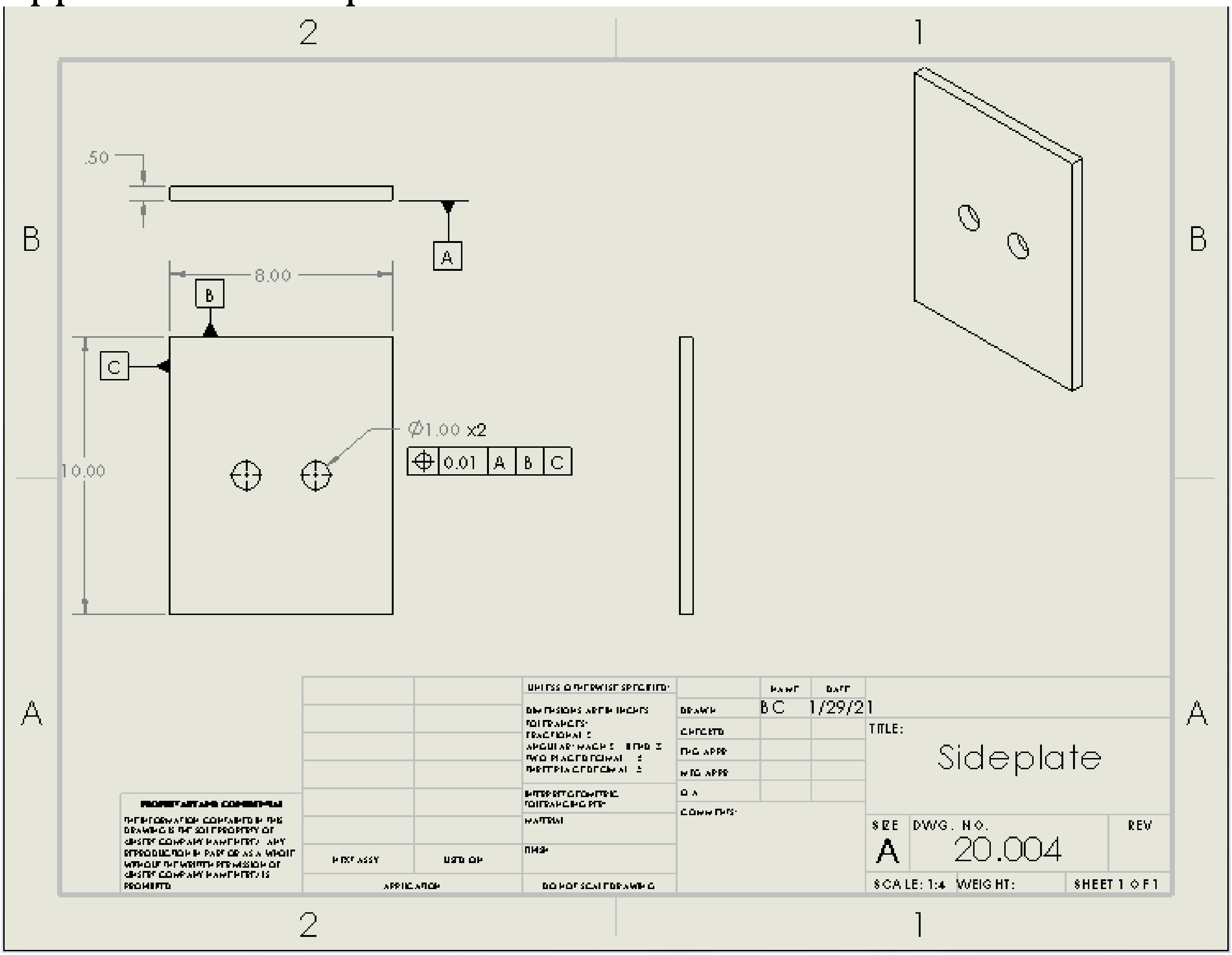
Appendix B – Spacer (1/32")



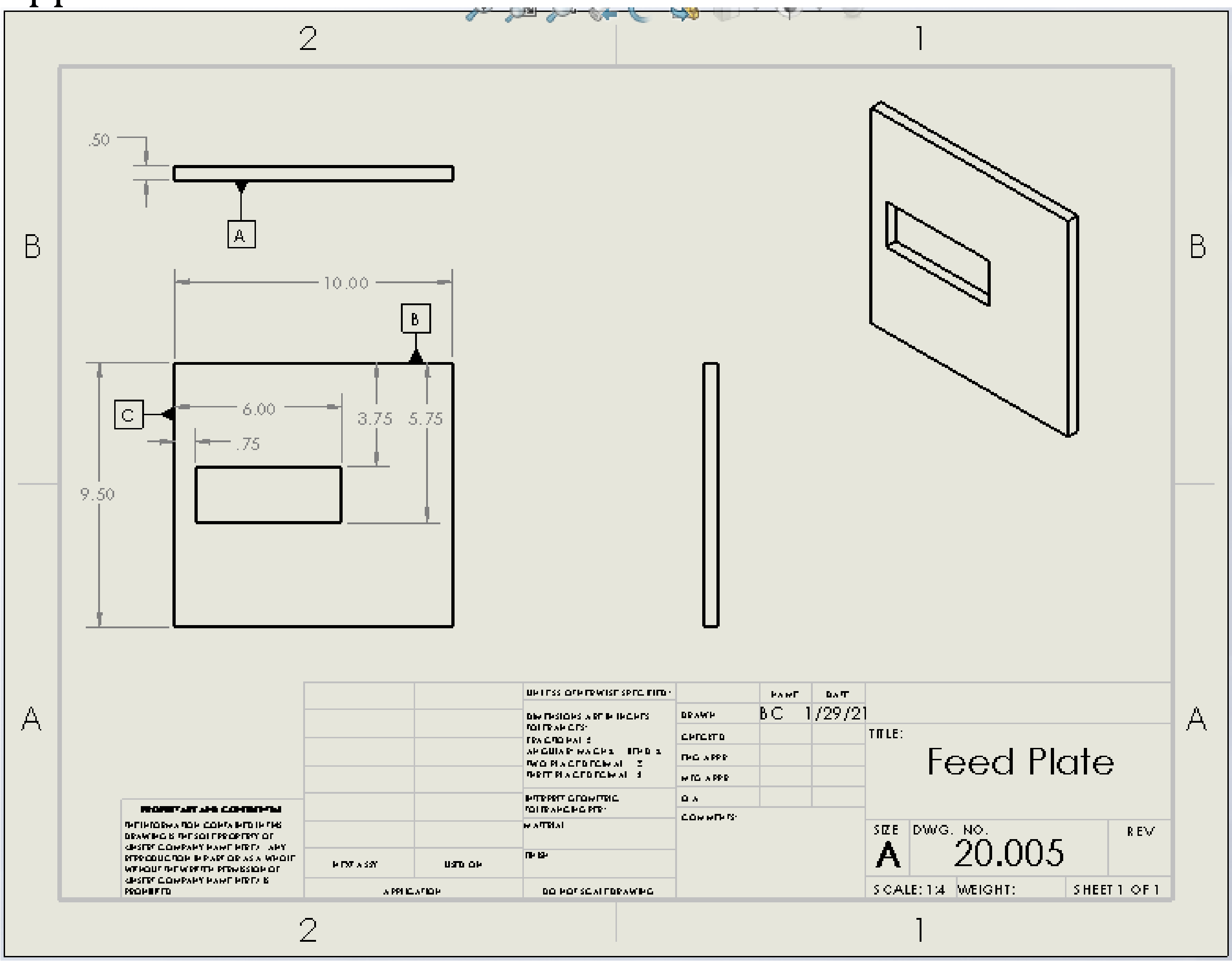
Appendix B – Housing Baseplate



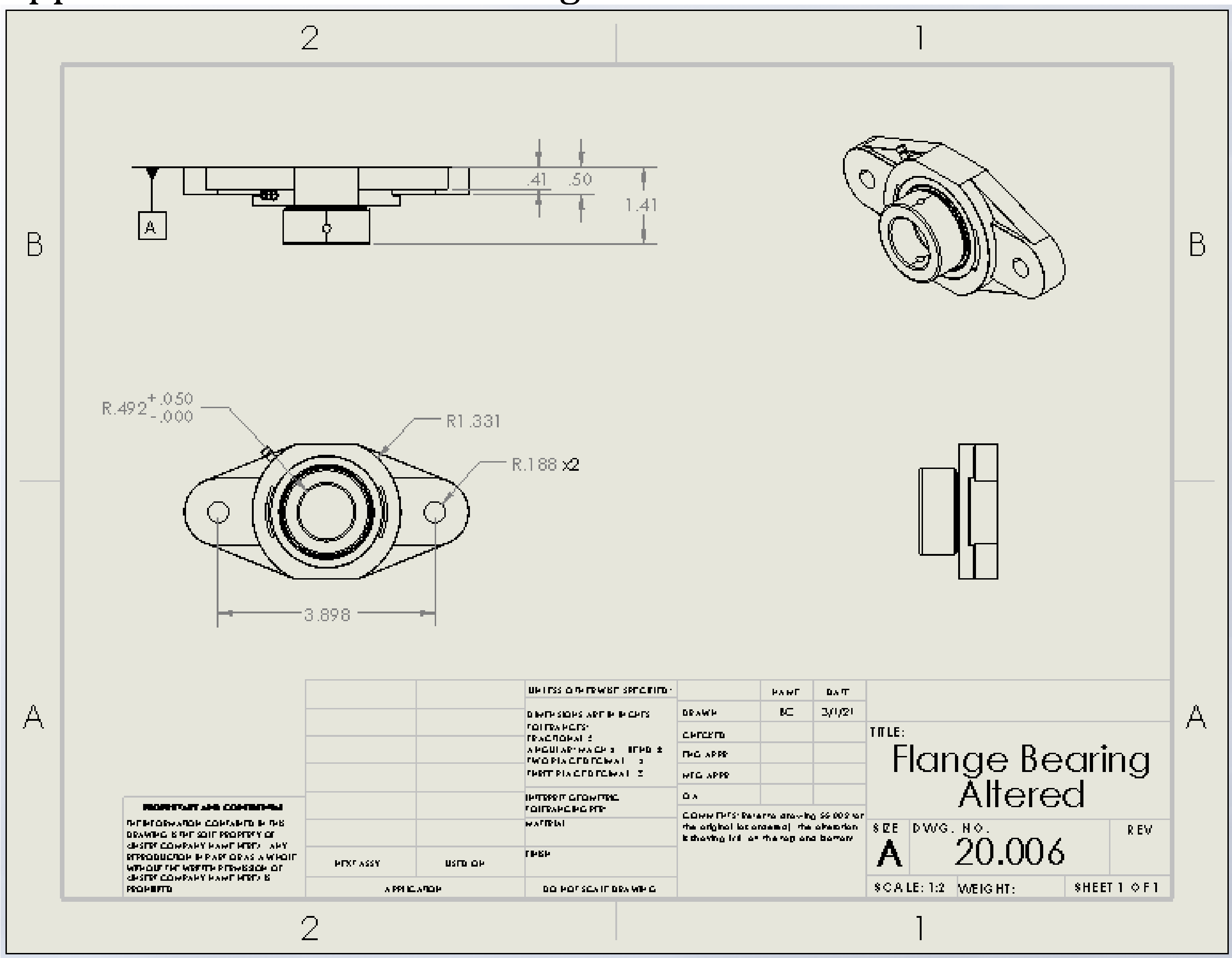
Appendix B – Sideplate



Appendix B – Feed Plate

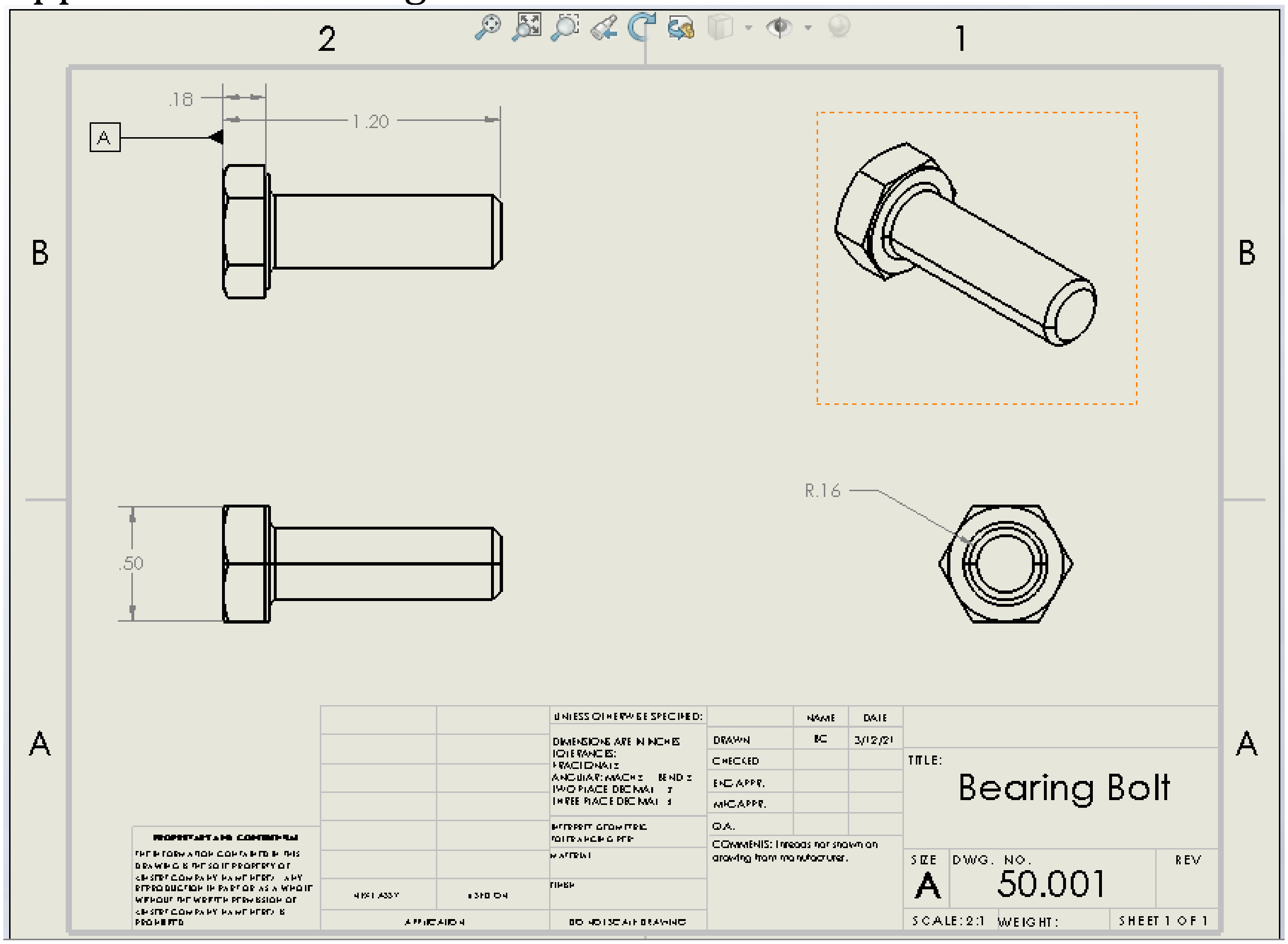


Appendix B – Modified Bearing

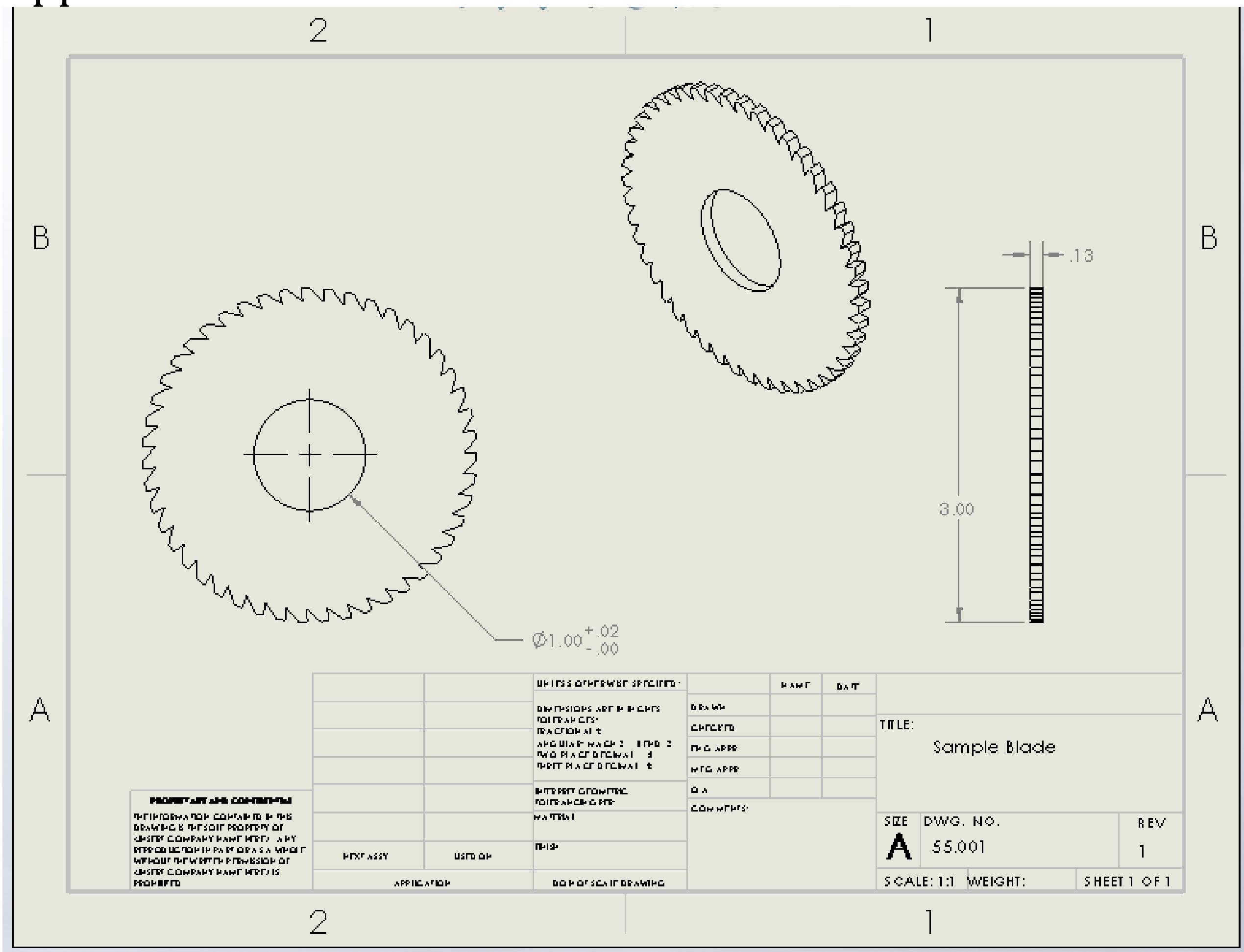


Reference original: 55.002

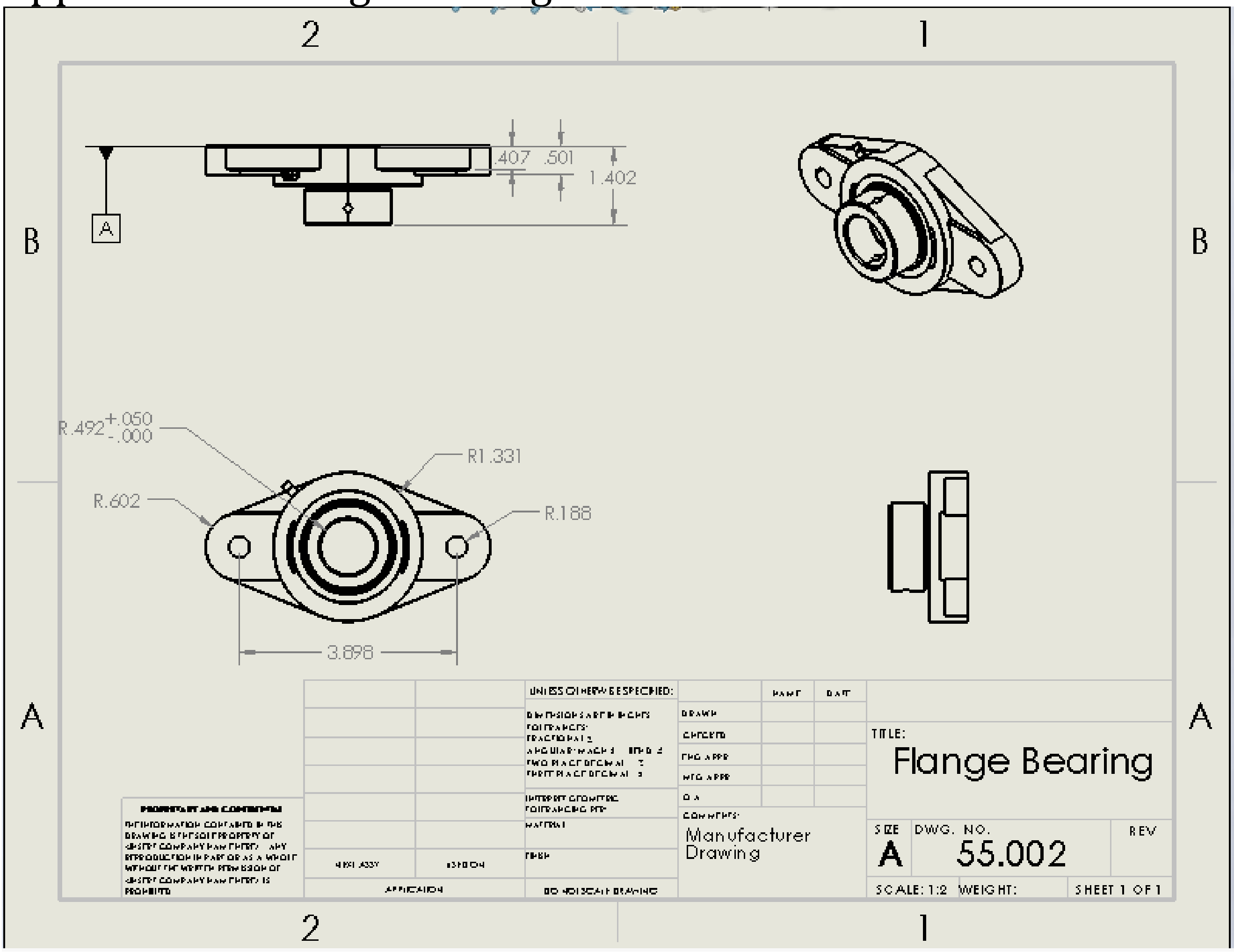
Appendix B – Bearing Bolt



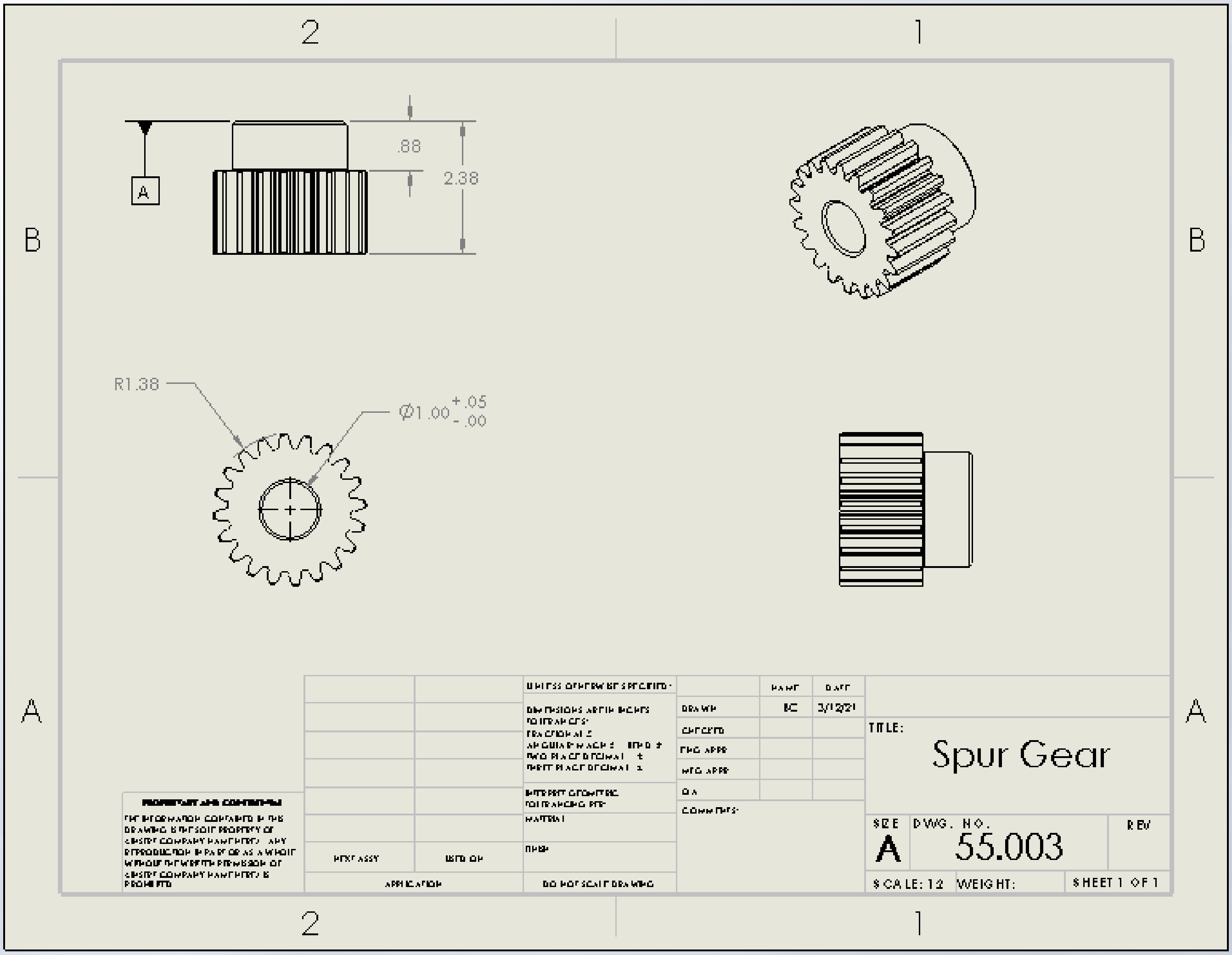
Appendix B – Blade



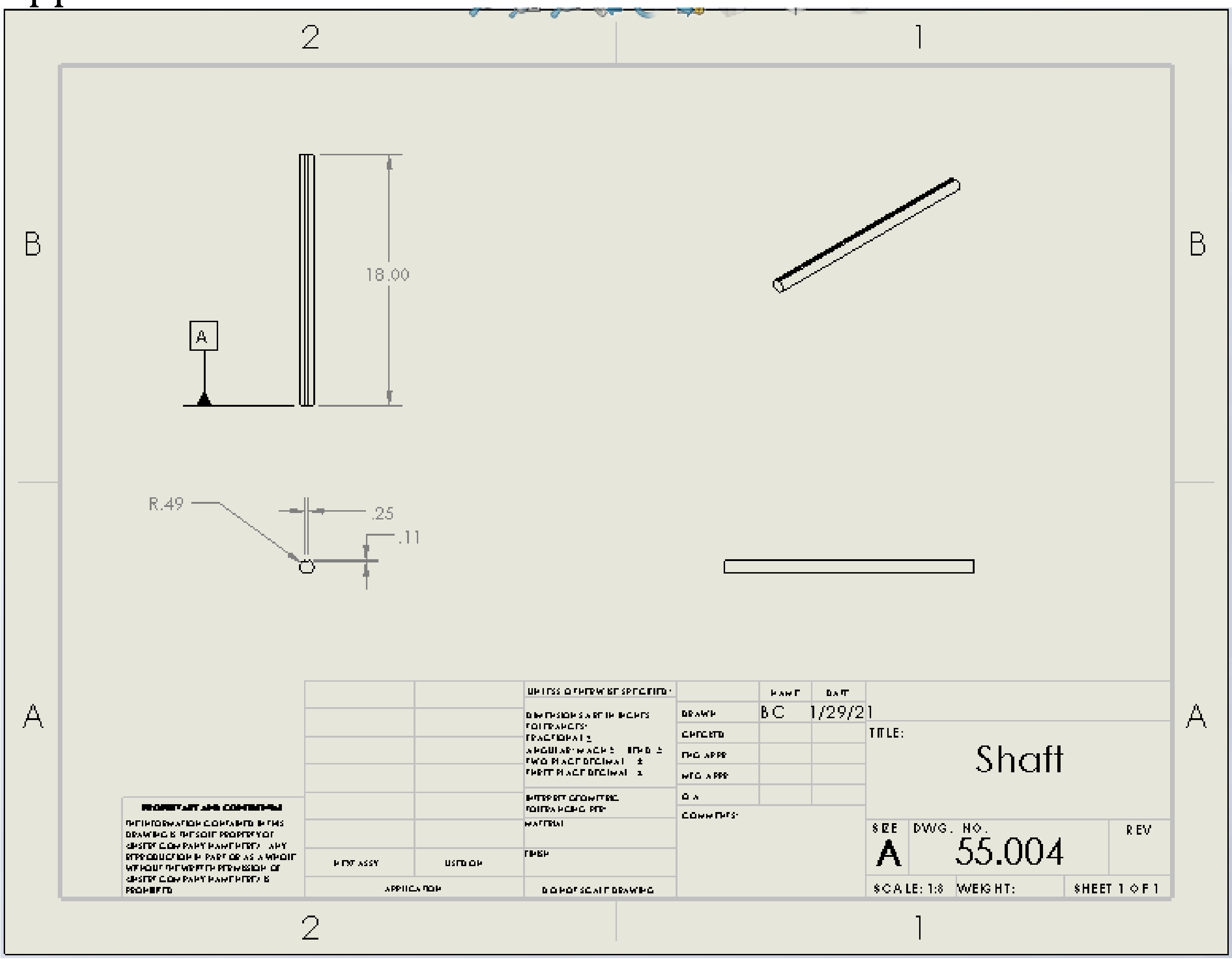
Appendix B – Flange Bearing



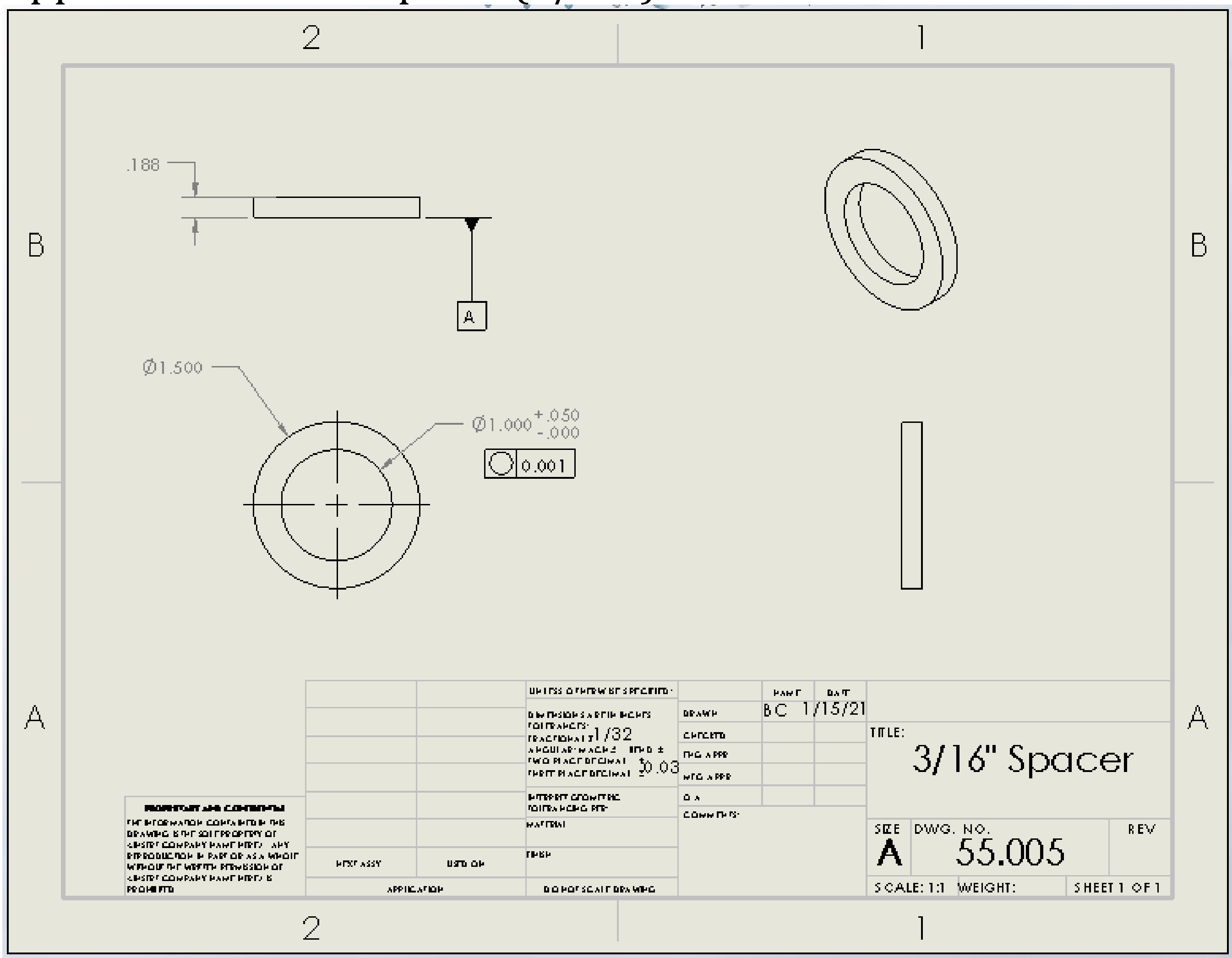
Appendix B – Spur Gear



Appendix B – Shaft



Appendix B – Blade Spacer (3/16”)



APPENDIX C – Parts List and Costs

Part Number	Qty	Part Description	Source	Cost (each)	Disposition
20.001	2	Brass spacers	Grainger.com	7.42	Custom
20.002	1	Blade alignment spacer	Machined in house	TBD	Custom
20.003	2	Baseplate	N/A	0	Pre-purchased
20.004	1	Sideplate	N/A	0	Pre-purchased
20.005	1	Feed plate	N/A	0	Pre-purchased
55.001	22	Blades	mscdirect.com	48.43	12 pre-purchased
55.002	4	2 bolt flange bearings	Grainger.com	15.08	New
55.003	2	Spur gears	N/A	0	Pre-purchased
55.004	2	Shaft	McMaster-Carr	38.39	New
55.005	21	Blade spacer	Grade Industrial Supply	6.72	New
50.001	8	Bearing Bolts	Fastenal	0.1702	Taken from stock

APPENDIX D – Budget

Item	Description	Cost
Parts	Blades, housing, drive components, hardware	800
Labor	None	0
Total cost	Estimated:	800
Total cost	Final:	843.53
Funds available		2500

APPENDIX E – Schedule

3	PROJECT TITLE:JCATI Cutting Gears														
4	Principal Investigator.: Ben Cooley														
5			Duration												
6	TASK:	Description	Est.	Actua	%Cor	Septemb	October	November	Dec	January	February	March	April	May	June
7	ID		(hrs)	(hrs)											
8															
9	1	Proposal*													
10	1a	Outline	0	0											
11	1b	Intro	1	1		X									
12	1c	Methods	0	0			X				X				
13	1d	Analysis	0	0		X X X	X X X X	X		X X					
14	1e	Discussion	0	0				X		X		X	X	X	
15	1f	Parts and Budget	0	0		X					X X	X X		X	
16	1g	Drawings	1	2		X X X	X X X X	X X		X X X X		X			
17	1h	Schedule	0	0			X				X			X	
18	1i	Summary & Appx	0	0											
19		subtotal:	2	3											
20															
21	2	Analyses													
22	2a	Heat Trans=>Geo	0	0											
23	2b	Stress Anal=>Geo	2	1.75		X X	X X X X								
24	2c	Power Anal=>Geo	0	0											
25	2d	Kinematic => Geo	0	0											
26	2e	Tolerance => Geo	0	0											
27		subtotal:	2	1.75											
51	7	Part Construction									◇				
52	7a	Disassembly	0	0						X X	X				
53	7b	Part Manufacturing	0	0							X X X X	X		X	
54	7c	Assembly/Construction	0	0								X X	X X		
55	7d		0	0											
56	7e		0	0											
57	7f		0	0											
58	7g		0	0											
59	7h		0	0											
60	7i		0	0											
61		subtotal:	0	0											
72	10	Device Evaluation											◇		
73	10a	List Parameters	0	0											
74	10b	Design Test&Scope	0	0											
75	10c	Obtain resources	0	0											
76	10d	Make test sheets	0	0											
77	10e	Plan analyses	0	0											
78	10f	Instrument Robot	0	0											
79	10g	Test Plan*	0	0								X	X X X	X	
80	10h	Perform Evaluation	0	0									X X	X X	
81	10i	Take Testing Pics	0	0									X X	X	
82	10h	Update Website	0	0											
83		subtotal:	0	0											
84															
85	11	489 Deliverables												◇	
86	11a	Get Report Guide	0	0		X									
87	11b	Make Rep Outline	0	0		X									
88	11c	Write Report	0	0		X X X X	X X X X	X X X X	X X	X X X X	X X X X	X X X	X X X X	X	
89	11d	Create Website	1	1		X									
90	11e	Make Slide Outline	0	0		X									
91	11f	Create Presentation	0	0										X X	X
92	11g	Make CD Deliv. List	0	0											
93	11h	Write 495 CD parts	0	0											
94	11i	Update Website	0	0		X X X X	X X X X			X	X X X X	X X	X X	X X	X
95	11j	Project CD*	0	0											
96		subtotal:	1	1											
97															
98		Total Est. Hours=	5	5.75				=Total Actual Hrs							
99	Labor		100												
100															

APPENDIX F – Expertise and Resources

Machine shop and equipment provided by Central Washington University
Solidworks student license provided by Dassault Systèmes
Mechanical engineering expertise provided by Dr. Charles Pringle
Mechanical engineering expertise provided by Dr. John Choi

APPENDIX G – Testing Report

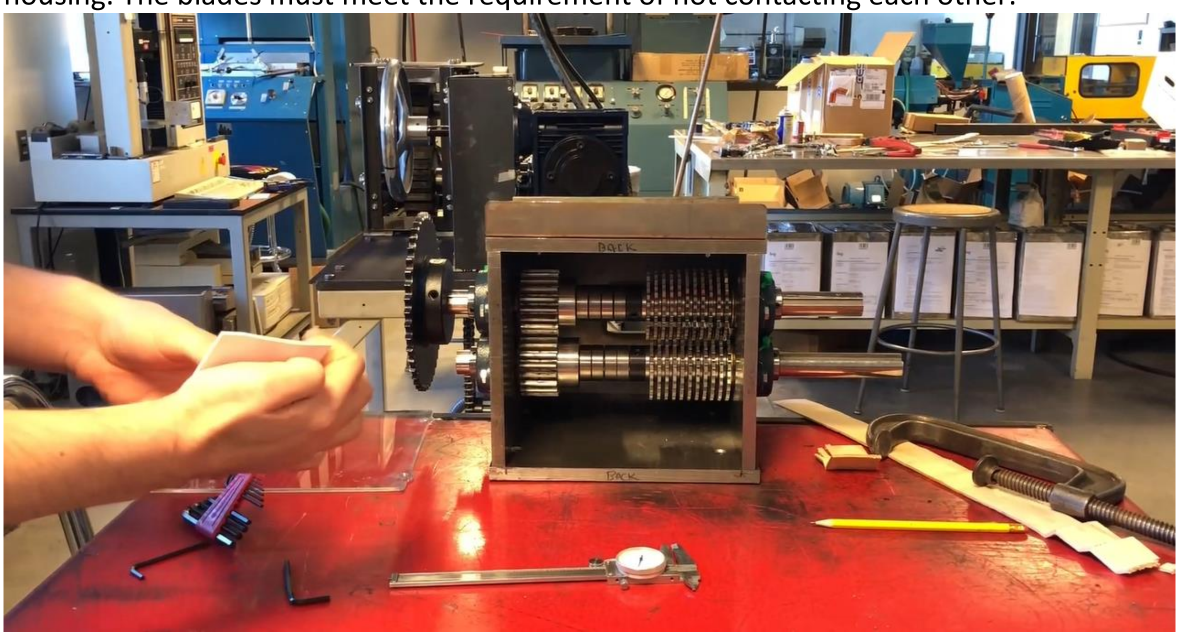
Test 1

The requirement for this test is that the blades do not contact each other. The parameter that will be measured is the length of the gap between each blade. The predicted value for the gap between blades is 31 thousandths of an inch, and was attained by subtracting the width of a blade from the width of a spacer and dividing by 2. The data was collected using calipers and feeler gauges. The test was completed on schedule during the second week of April.

Required resources for this test included calipers, paper, and feeler gauges, as well as Allen wrenches to tighten the blades and spacers in place. After the feeler gauges were measured by calipers, the measurements were recorded in a table on an Excel document. The test was conducted by inserting progressively larger feeler gauges into the spaces between blades until the gauge could not fit any more, and the size of the largest gauge that fit between was recorded. The limits of the testing operation arose from the ability to find feeler gauges large enough to measure the gaps, as the calipers could not be directly inserted into the recessed blade housing. The precision and accuracy of the measurement was limited by the accuracy of the feeler gauges, and the increment at which the gauge size increased. The data was recorded on an Excel document, and calculations were made for the predictions on the same sheet. The data will be presented in a table format.

Test 1 Procedure: (formal procedure)

Summary: This procedure details the measuring of the space between blades in the shredder housing. The blades must meet the requirement of not contacting each other.



Time: The test was conducted on Monday, 4/4/21 from 9:15 to 10:00. Half an hour was used to collect tools, secure the blades, and devise the measurement plan, and 15 minutes were required to insert the gauges and collect the measurements.

Place: Room 127, Hogue Hall, Central Washington University campus in Ellensburg, WA.

Required equipment included:

- Feeler gauge set
- A stack of paper
- Calipers
- The completed shredder assembly

Risk: The risk associated with this test is avoiding the sharp blades which have the potential to cut fingers.
Safety glasses were required at all times while conducting the test. Additional personnel were not required but could be on hand as observers and in case of emergency.
The test procedure is as follows:

1) Collect equipment:
    a. Feeler gauge set
    b. Calipers
    c. Stack of paper

2) Go to Hogue 127 and carbon fiber recycling device (North end of the room). Locate the cutter housing of the device and open it up.

3) Start with the blade on the far left of the shafts. Insert the smallest feeler gauge into the gap between that blade and the next blade to the right.

4) If the gauge fits, remove it and insert the next largest gauge into the same space. Do not force the feeler, it must slide in easily.

5) Repeat step 3 until the current feeler gauge does not fit into the gap. Once this occurs, record the thickness of the largest gauge that fit as the gap between the two blades.

6) Repeat steps 3-5 for the gap between each pair of blades, moving to the right each time.

The test was originally going to be conducted using calipers to measure the gap between each blade pair, but the calipers could not fit inside the blade housing to measure the gap directly. The next step was to use feeler gauges as noted in the procedure above. But when feeler gauges could not be located in time for the first testing, a stack of paper was used to determine the gaps, and after enough paper had been removed that the gaps could fit the stack inside, the stack was removed and measured with calipers.

	Predicted Gap (both sides)	**Gap to the Left**	**Gap to the Right**
	0.031 in	0.034 in	0.023 in
Test Success		Yes	Yes

Test 2

The requirement for this test is that the blade shafts turn at 9.6 rpm. As such, the parameter of interest is rpm. The predicted performance was calculated by dividing the motor rpm under no load by the gear ratio, which resulted in 613 rpm. The data will be gathered using a digital contact tachometer, and recorded on a table. The test will be conducted on Monday morning, April 26.

The resources needed for this test are a contact tachometer, access to the ETSC lab, and Dr. Charles Pringle for oversight of running the device under power. The data will be captured in a table and processed on a chart. The procedure will consist of turning on the motor to run the device, attaching the tachometer to the end of one of the blade shafts, and reading and recording the data. Operational limitations include the ability to reach the blade shafts for measurement and the range of measurement of the tachometer. Precision and accuracy both depend on that of the tachometer and how fast the digital display updates, and relies on the (safe) assumption that the blades rotate with the blade shafts. Data will be stored on the table as it is recorded, and analyzed by plotting on a line chart. The data will be presented in both the table and chart.

Test 2 Procedure: (formal procedure)
Summary: This procedure details the process of powering on the machine and measuring the rpm of the blade shafts using a tachometer. The blade shafts must rotate at an rpm of 9.6 for the test to be considered a success.

Time: The test was conducted on 4/26/21 from 9:00 am to 10:00 am in Hogue 127. There was approximately 15 minutes of gathering equipment and setting up the device, and 15 minutes of getting a stable reading from the tachometer. The remainder of the time was spent debating the accuracy of the results and recording them.
Place: Room 127, Hogue Hall, Central Washington University campus in Ellensburg, WA.
Required equipment included:
• Assembled cutter housing
• Digital contact tachometer

Risk: This test cannot be conducted without high voltage electrical power. The device under electrical power involves components rotating at high speed. There is a risk of injury to hands or fingers when hands are near the blades and shafts. Safety glasses were required at all times while conducting the test.

The test procedure is as follows:

1) Collect equipment:

   a. Digital contact tachometer (example pictured right)

   b. Hand crank and composite strip from cart of device parts next to Hogue 127 work bench.

2) Go to Hogue 127 and carbon fiber recycling device (North end of the room).

3) Place the tachometer on a table or bench nearby.

4) Ensure that power to the device is off and the machine will not run with lock out/tag out.

5) Ensure that all collars and retainers are tightened on the cutter housing and shaft.

6) Put all safeguards and covers in place over the chain and blades.

7) Go to the power switch and turn on the power to the device.

8) Turn on the switch that runs the electric motor and powers the device.

9) Observe the shafts for any runout or interference. If none is present, continue to the next step.

10) Place the tip of the tachometer against the exposed end of a blade shaft, holding it steady in the center to obtain the clearest reading.

11) When the reading on the digital display settles around a number, record the number as the rpm for the shaft.

12) Turn off the device and ensure lock out/tag out.

The test proceeded as anticipated. The only difficulty was getting the tachometer tip at the very center of the shaft and holding it with the correct amount of pressure to keep it on. This difficulty in holding the tachometer on lead to a difficulty in obtaining a steady measurement, but the reading leveled out at around 620 rpm. This value was very close to the calculated value of 613 rpm. However, the test was considered a fail because the required rpm for the test to be successful was much lower, at 9.6 rpm.

Motor RPM (No Load)	Predicted Output RPM	Required RPM	Measured RPM	Pass
1798	613	9.6	620	No

<u>Test 3</u>

The requirements for this test are that the fibers are between 0.25" and 0.5". Hence, the length of the fibers is the parameter of interest, measured in inches. The predicted value for fiber length is 0.25", due to the blade teeth being close together. The data will be collected by measuring the fibers with calipers after they have been chopped with the blades. This test will be completed the week of May 3 of Spring quarter.

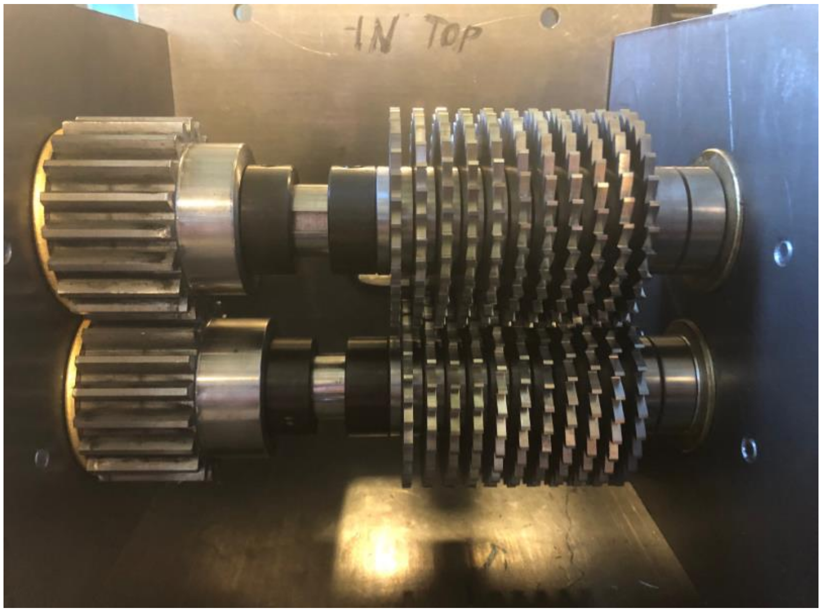
The resources for this test are Dr. Charles Pringle to aid in operating the device, carbon fiber composite strips provided by Boeing, the ETSC 127 lab at CWU, and calipers and other tools from the CWU shop. The data will be captured by measuring with calipers, and recorded with pictures and on a text document. The test will be conducted by running the device under power, feeding composite strips through it, collecting the chips that come out, and measuring the length of the fibers in the chips. Operational limitations of the test include the rpm of the driving electric motor, the space between the blades to accommodate composite material, and the accuracy of the calipers used to measure. The calipers measure to thousandths of an inch, but the calipers used appeared to be slightly misaligned and the fibers were difficult to measure precisely, so the measurements were recorded to the nearest ten thousandth. A sample of the chopped fiber chips was taken, and the longest fiber in the sample was measured, along with the shortest, and many other samples in between. The longest, shortest, and an average fiber size was recorded. The most consideration was given to the average size because outliers will always be a factor. The data will be presented in a table showing the long, short, and average fiber size.

Test 3 Procedure: (formal procedure)
Summary: This procedure documents the process of powering, running, and operating the cutting blades of the JCATI carbon fiber recycling device. This cutter blade assembly was designed and manufactured by Mechanical Engineering Technology students for senior projects. The blades are designed to be powered by the electric motor on the device and run continuously without supervision, while severing the composite feed into chips containing 0.25"-0.5" long fibers.

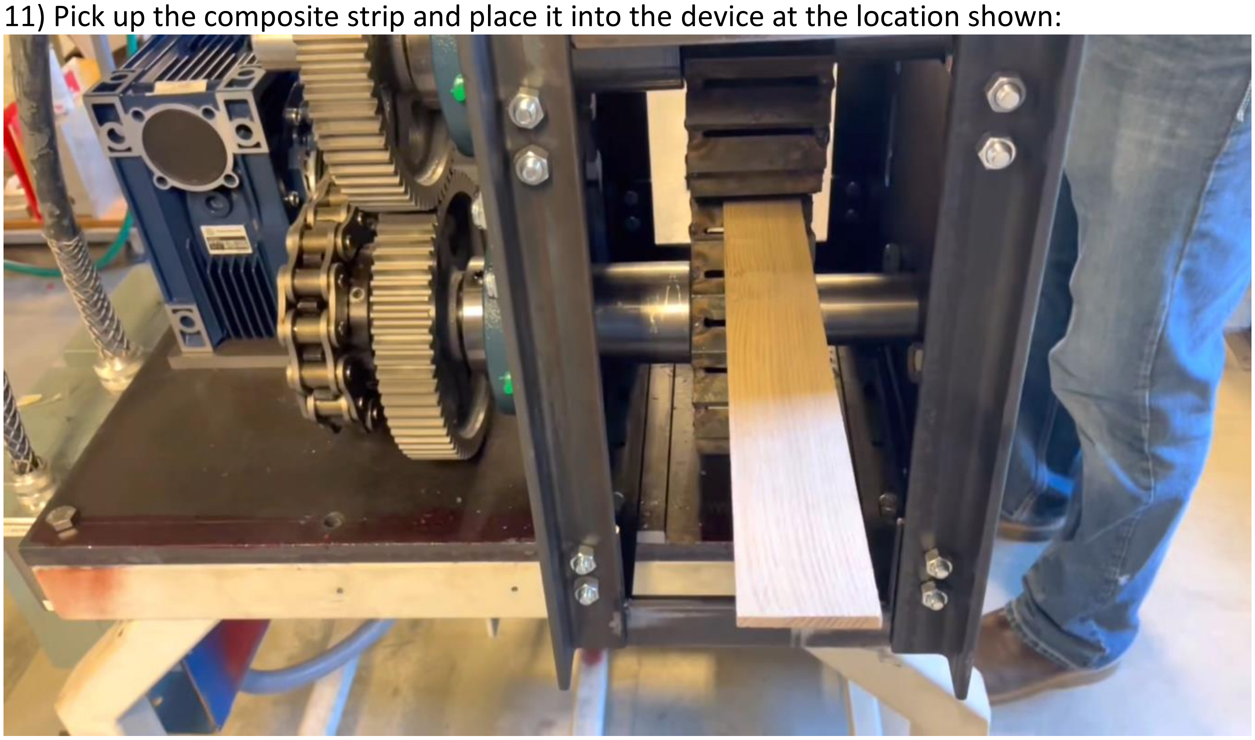
Time: The test was conducted on 5/4/21 from 10:00 am to 11:00 am in Hogue 127. There was a half an hour of collecting equipment

and setting up prior to the test. After the test, 15 minutes was required to remove the leftover fibers and resin from the cutter housing and return the device to a safe powered-off state.
Place: Room 127, Hogue Hall, Central Washington University campus in Ellensburg, WA.
Required equipment included:
• Camera (cell phone)
• Carbon fiber composite strip (approximately 4” wide, 0.5” thick)
• Hand crank
• Allen wrench set
• Ruler
• Carbon fiber crusher
• Latex gloves

Risk: This test cannot be conducted without high voltage electrical power. The device under electrical power involves components rotating at high speed. There is a risk of injury to hands or fingers when hands are near the blades.
Risk to successful completion of the test would be a loose or interfering fit between the blades that causes binding or fracturing.
Safety glasses were required at all times while conducting the test. Additional personnel were not required but could be on hand as observers and in case of emergency.
The test procedure is as follows:
1) Collect equipment:
a. Source a cell phone or other video camera-equipped device.
b. Hand crank and composite strip from cart of device parts next to Hogue 127 work bench.
c. Allen wrench set from Hogue 127 work bench.
d. Ruler from Hogue 127 or Hogue machine shop.
e. Latex gloves from the machine shop.
2) Go to Hogue 127 and carbon fiber recycling device (North end of the room).
3) Place all the equipment on a table or bench nearby.
4) Ensure that power to the device is off and the machine will not run with lock out/tag out.
5) Observe the cutting gears and check that there is space between the blades. Jiggle the blades in the axial direction of the shaft to ensure there is no play. If the blade sets on each shaft are touching each other, or if there is motion in the axial direction, loosen the locking collars and move each blade set until they are no longer contacting each other and are tight against the housing wall. Tighten the collars after adjusting.



6) Slowly rotate the crank and observe the rotation of the blades. If rotation becomes difficult or there is visible contact between the blades, stop and remove the crank immediately, and repeat from step 5.
7) Once the blades have been rotated without binding or contacting, remove the hand crank and place it back on the table.
8) Go to the power switch and turn on the power to the device.
9) Turn on the switch that runs the electric motor and powers the device.
10) Observe the blades for contacting or runout of the shafts. If none is present, continue to the next step.
11) Pick up the composite strip and place it into the device at the location shown:



Insert the strip as follows: hold it by one end and feed the opposite end into the crushing gears pictured.
12) Observe the strip as it goes through the crushing gears and into the cutting gears.
13) After a pile of composite chips has accumulated on the other side of the cutting gears, stop the device and completely shut the power off with lock out/tag out. Use a brush to remove the chips from the housing.
14) Using latex gloves, measure the fibers visible in the chips to determine whether they are in the acceptable 0.25”-0.5” range.

The test proceeded as planned, with the exception of the entire device being operational. The crushing wheels on the device were not functioning properly at the time of testing, so the strips were fed manually into the cutters using pliers and clamps to deliver and secure them. The resulting fibers came out in smaller chunks than expected, they were thoroughly shredded instead of cut into chips as predicted. This did not effect the testing result directly, as the fibers could still be measured in this form.

	Short Fiber	**Long Fiber**	**Average Length**
Sample 1	0.2 in	3 in	0.4 in
Test Success			Yes

Appendix G1

After testing:

- Shut off power
- Lock out/tag out
- Put tools away

Appendix G2

	Predicted Gap (both sides)	Gap to the Left	Gap to the Right
	0.031 in		
Test Success			

Motor RPM (No Load)	Predicted Output RPM	Required RPM	Measured RPM	Pass
1798	613	9.6		

	Short Fiber	Long Fiber	Average Length
Sample 1			
Test Success			

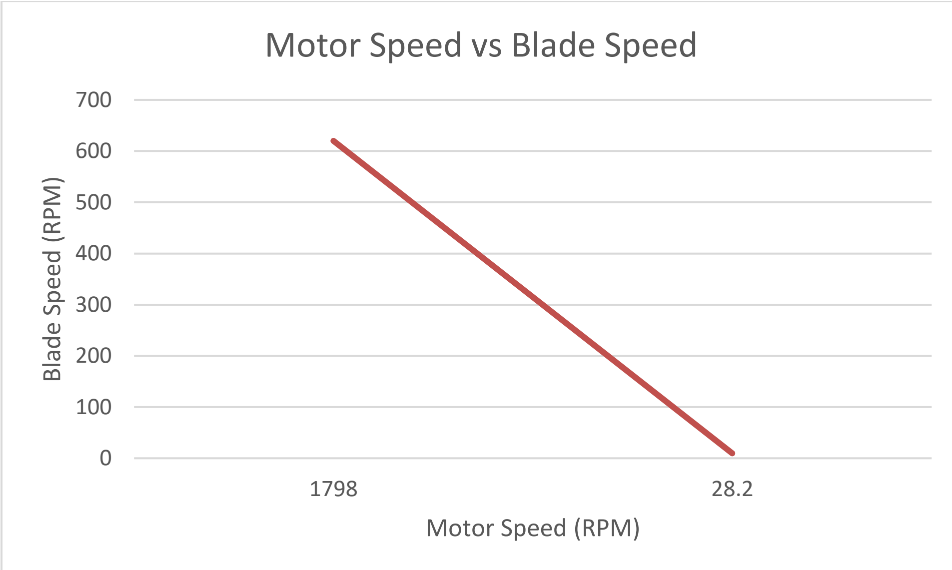
Appendix G3

	Predicted Gap (both sides)	Gap to the Left	Gap to the Right
	0.031 in	0.034 in	0.023 in
Test Success		Yes	Yes

Motor RPM (No Load)	Predicted Output RPM	Required RPM	Measured RPM	Pass
1798	613	9.6	620	No

	Short Fiber	Long Fiber	Average Length
Sample 1	0.2 in	3 in	0.4 in
Test Success			Yes

Appendix G4



Appendix G5

3	PROJECT TITLE:JCATI Cutting Gears														
4	Principal Investigator.: Ben Cooley														
5			Duration												
6	TASK:	Description	Est.	Actua	%Cor	Septemb	October	November	Dec	January	February	March	April	May	June
63	9	Device Construct									◇				
64	9a	Assemble Sub LL	0	0											
65	9b	Assemble Sub RR	0	0											
66	9c	Assemble Sub FF	0	0											
67	9d	Assemble Robot	0	0											
68	9e	Take Dev Pictures	0	0											
69	9f	Update Website	0	0											
70		subtotal:	0	0											
71															
72	10	Device Evaluation											◇		
73	10a	List Parameters	0	0											
74	10b	Design Test&Scope	0	0											
75	10c	Obtain resources	0	0											
76	10d	Make test sheets	0	0											
77	10e	Plan analyses	0	0											
78	10f	Instrument Robot	0	0											
79	10g	Test Plan*	0	0								X	X X X	X	
80	10h	Perform Evaluation	0	0									X X	X	
81	10i	Take Testing Pics	0	0									X X	X	
82	10h	Update Website	0	0											
83		subtotal:	0	0											

APPENDIX H – Resume

(360) 525-7248
benlcooley2@gmail.com

EDUCATION:

BS Mechanical Engineering Technology, Central Washington University; graduation June 2021

Associates of Applied Science Degree **General Engineering**, Whatcom Community College; June 2019

Lynden High School, Lynden, WA 98264; June 2018

SKILLS AND ABILITIES:

Mechanical knowledge

- Familiar with drawings and operating fabrication tools through classwork and internships
    - Welding, milling machine and lathe operation, sheet metal fabrication
- CAD experience with AutoCAD, Solidworks, Rhino and OnShape
- Familiar with general shop practices
- Experience with automobiles and other mechanical systems

Proficient in Microsoft Office and other programs
Programming experience with Java and C++ for Arduino PLCs
Professional communications in memo and report form, written and verbal
Staying organized, working hard, following directions

WORK EXPERIENCE:

Shop Intern, Bryans Racing Enterprises, **Santee, CA** Summer 2018
Gained experience in professional automotive shop and engineering practices, familiarity with operating metal fabrication tools, and hands-on experience with engineering vehicle systems.
Painter, Top Quality Painting, Bellingham, WA Summer 2020
Practiced attention to detail in producing results to a high standard. Adapted to work long physical hours at a variety of locations.
Shop Helper, 1st Class Auto Body, Bellingham, WA February – September 2019
Learned shop etiquette and professionalism; Diligently completed a variety of tasks for the business.
Kitchen Assistant, Good to Go Meat Pies, Everson, WA June 2017 – October 2018
Showed versatility by helping customers, making products, and doing minor maintenance.
Processing Plant Seasonal Worker, Curt Maberry Farms, Lynden, WA Summer 2014, 2015, 2016
Worked long hours on a variety of physically demanding tasks, around processing equipment.