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H.F. Hauff Pruner Housing & Ergonomics

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SENIOR PROJECT

H.F. HAUFF PRUNER

HOUSING & ERGONOMICS

Erich Heilman
TEAM: DANIEL GIBSON & THOMAS WILSON

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Introduction

Motivation

The H.F. Hauff Company Inc. is an engineering firm that moved to Yakima, Washington in 1965. They have dedicated themselves to designing and manufacturing the highest quality agricultural equipment for farmers and fruit orchardists around the world. The company's president - Neil Hauff - is always looking for new, innovative ideas to improve the agricultural industry.

Neil was approached by an orchardist named Emmanuel Maniadakis who wanted an orchard pruner that was similar but better than his current vineyard pruner, the Pellenc Treelion D45-900. The motivation of this project was to optimize the vineyard pruner so it can be used for orchard pruning.

After operation for a long time, the linear actuator which provides cutting force becomes too hot for the operator to hold, even when wearing gloves. The current reach of the pruner is also not sufficient. The single-finger trigger is difficult to operate when wearing gloves and causes discomfort on the operator's finger over time. Emmanuel would prefer a 4 finger/hand trigger similar to the triggers found on pneumatic tools. With the current pruner, a cut is made by holding down the trigger until a cut is made and then letting go of the trigger returns the blades to their initial position. Emmanuel would like the pruner to go through the whole cut cycle with just one press of the trigger.

The new design will eliminate the heat issue with the current pruner actuator. It will also have a longer reach. The single-finger trigger will be replaced with a new trigger system that is more comfortable for the operator and easier to operate with gloves. The cuts will be made by depressing the new trigger system once, and the blades will make one complete cycle starting at the open position and ending in the open position. Emmanuel is satisfied with the 44V DC battery pack.

Function Statement

There will be two function statements. The first function statement is for the pruner as a completed device while the second functions statements applies only to the housing and ergonomic design of the pruner.

Pruner: A device is needed that will receive electric power and use it to cut branches.

Housing & Ergonomics: The functions of the pruner housing are to safely house the inner mechanisms and be ergonomic.

Requirements

There are two lists of requirements. The first list is dedicated to the entire pruner device and the second list is specific to the housing and ergonomic design of the pruner. (See figure 1 on the following pages for terminology)

Pruner:

- The distance from the trigger to the end of the pruner blade must be no shorter than 3 feet
- After operating at a pruning rate of 250, 1 to 1.5 inch diameter branches/ hour for 6 hours, all the pruner components must remain under 110° F.
- The pruner must be able to cut up to a 1.5 inch diameter branch.
- The trigger system must be a four-finger hand trigger. (as per customer)
- The power supply must be a 44V DC battery belt. (as per customer)
- The combined weight of the pruner must be no greater than 15 pounds.
- The pruner center of mass must be within the first quarter of total pruner length (starting from handle end)
- The total cost to manufacture the pruner can be no greater than $2,500.
- The cut cycle time of each pruner cut can be no longer than 2 seconds. (as per customer)
- At any point on the pruner, the width can be no greater than 6 inch.
- The cutting cycle must be initiated by a single, momentary pull of the trigger, performed by the operator. (as per customer)
- The pruner must be manufactured within a 9 week period.

Housing & Ergonomics:

- Housing components can’t weigh more than 5 pounds
- Housing components (blade housing, central housing, and grip housing) must assemble and disassemble within 5 minutes
- Housing must prevent cutting mechanisms from unnecessary movement up to 1mm when fully assembled
- Housing material must withstand the necessary actions to generate the 600lb force to cut branches
- Blade housing must prevent debris larger than 1mm in diameter from entering the housing
- Grip housing must contain a trigger guard and safety switch (as per customer)
- Corrosion from water, pesticides, fruit juices, plant material, dirt, and sweat must not tarnish any surface more than 1cm in diameter or reduce mass by more than 0.05%
- Housing components can’t cost more than $200
- Grip and central housing diameters must fall in the size range of 1.2 inches – 1.8 inches
- Central housing must withstand a maximum bending load of 196 pounds

Engineering Merit

It is most important that the new pruner design is ergonomic. This is going to be achieved through overall weight, balance (weight kept near the handle), and re-designed trigger system. However, the new design must also adhere to the design requirements regarding power capability, operating temperature, and reach of the pruner. A formula that will be used to find the thermal diffusivity of the grip housing material is α = heat conducted / heat stored = $k / \rho c_p$. The main problem Mr. Maniadakis had with his Treelion pruner was that it would get too hot to hold after extended use, even with gloves. This problem can be solved – in part- by selecting a material that can diffuse some of the heat produced by the actuator.

Scope of Effort

This report will be dedicated to the design of the ergonomic housing for the orchard pruner. It's paramount that the housing be effective and inexpensive so the life span of the product can be at a maximum while costing the manufacturer the minimum price. The proper material choice and geometry will ensure the best housing for this pruner. Since this report only deals with the housing, choices in driving mechanisms and blade geometry won't be discussed in much detail. Driving mechanisms and blade choices are described in further detail in their own reports by Thomas Wilson and Daniel Gibson, respectively.

Success Criteria

The success of this pruner housing is determined by how effective the pruner houses the inner components, and whether or not it's comfortable to use for extended periods of time. It's crucial that the housing has a long life span while maintaining the requirements stated above. It is also important that the housing can be taken apart and put back together easily so parts can be replaced or cleaned.

Design and Analysis

Approach

The pruner housing will be separated into 3 sections. Referring to Figure 1, sections 1, 2, and 3 will be called “blade housing”, “central housing”, and “grip housing” respectively. Each of the 3 sections will be discusses separately in each sub-section of the report in order to stay organized.

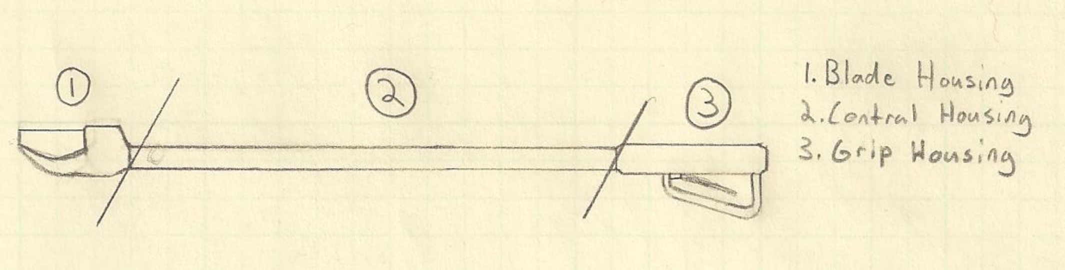


Figure 1: A simplification of the overall shape of the pruner being optimized. The purpose of this image is to illustrate the different sections of the pruner that will be discussed throughout this report. The sections will be referred to by their section name or number.

Section 1 / Blade Housing

The purpose of the blade housing is to protect the linkage connecting the driving rod to the blade. The blade housing prevents debris larger than 1mm from entering into the linkage compartment. This is necessary because the blade housing will be the closest to the trees when the pruner is in use, so there is a possibility that sap, water, wood debris, and other foreign substances can interfere with the linkage. These harmful substances can also damage the material that the blade housing is made from, so it is important that the chosen material can withstand prolonged exposure (6-8 hours of operation, 5 days a week) without having its mass reduced by more than 0.05% or have visible tarnishes larger than 1cm in diameter over a year of use.

Section 2 / Central Housing

The central housing is dedicated to protecting the driving rod which transmits force from the electric actuator to the blade linkage. This housing is relatively simple in geometry since it has to protect a cylindrical rod from the corrosive elements listed in the requirements. This means the central housing will be a carbon fiber tube 1.5 inches in diameter and will contain bushings to prevent the driving rod from having contact with the carbon fiber tube. The central housing material will have to be rigid enough to prevent deflections greater than 2mm across its length, and have the same corrosion resistance requirements stated in the requirements section above.

Section 3 / Grip Housing

The grip housing is the most diverse and complicated part of the pruner housing. The grip housing has to house the actuator, it’s wiring, and it’s linkage to the driving rod, support a comfortable trigger or handle to activate the actuator, prevent heat generated by the actuator from affecting the operator’s hands, and have safety mechanisms that prevent the pruner from making an unwanted cut. The most important parts of the grip housing is that it’s comfortable to operate. The trigger on the Pellenc Treelion D45-900 pruner requires that the operator apply constant pressure to it in order from the cuts to be made. Doing this for extended periods of time places unnecessary strain on the hand and fingers. This can be solved by having a larger trigger so more fingers can be used to activate the actuator. Another problem with the Treelion was the heat that the actuator would generate. Since it wasn't designed for apple orchards, the actuator inside the Treelion was forced to work harder than it was designed to do. This problem can be solved by choosing a more powerful actuator and selecting a material that has a better thermal diffusivity than the current material.

Description

Referring to Figure 1, the design descriptions will be separated into their respective sections.

Section 1 / Blade Housing

The blade housing needs to accomplish two things: it must meet the corrosion resistance requirements and prevent debris from entering the housing. There are multiple materials that are suitable for corrosion resistance such as stainless steel, composites, and aluminum. However, the weight of the material must be taken into consideration. While stainless steel could be the most resilient to the cutting environment, it is also the heaviest. The weight of the blade housing must be as light as possible. A composite housing would be the lightest of the choices and have the necessary properties to prevent corrosion, but fabricating the components is more expensive and requires more time. This would make aluminum the best choice for the blade housing because it won't rust or corrode, it's relatively light, and it can be easily machined into the geometry needed.

The geometry of the blade housing is largely dependent on the type of linkage used, and the design of the blades. The combination of blades, linkage, and housing needs to be as compact and light as possible in order to keep the weight distributed as per the requirements above.

Section 2 / Central Housing

The central housing needs to accomplish two things: it must meet the corrosion resistance requirements and protect the driving rod from impacts and harmful bending stress. The geometry of the central housing will be a straight, cylindrical tube to effectively house the driving rod, which will be a straight cylinder itself. Figure 2 illustrates the first design of the central housing. The major diameter is 1.5 inches and the minor diameter is 0.80 inches. The central housing is also responsible for getting the pruner to the desired length of 3ft. The blade and grip housing will have size limitations while this housing can range from 2.5 feet to 1 foot depending on the sizes of the blade and grip housing.

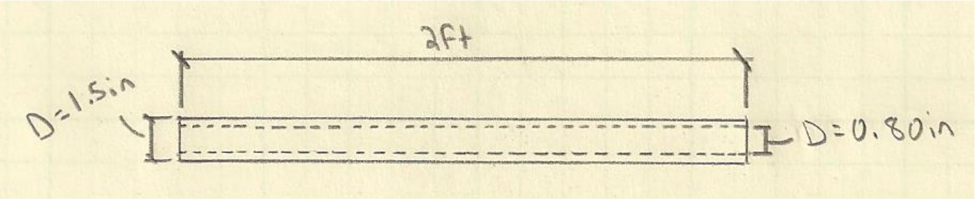


Figure 2: An initial design for the central housing

Section 3 / Grip Housing

The grip housing has to house the actuator, it’s wiring, and it’s linkage to the driving rod, support a comfortable trigger or handle to activate the actuator, prevent heat generated by the actuator from affecting the operator’s hands, and have safety mechanisms that prevent the pruner from making an unwanted cut. The shape of the grip housing is dependent actuator chosen to drive the pruner. The grip housing will have to be large enough so it’s comfortable for the operator to hold for the duration of 6-8 hours.

Figure 3 illustrates two options in mind for a trigger system. The circuitry of the trigger system will be designed so that the actuator will perform a full cut cycle with one depress/release of the trigger, much like firing a gun. The top option would utilize all fingers –except thumb- in initiating a cut. This design will guarantee little stress on each finger as a cut is made, and the loop towards the top of the trigger ensures constant contact with the grip housing. When the hand relaxes the hoop will still be engaged on the index finger, ensuring stability when the hand isn’t secured around the girth of the housing.

The second illustration utilizes a two-finger trigger to initiate a cut. The index and middle finger will be on the trigger at all times while the ring finger, pinky, and palm provide support. This design provides more support area for the hand initiating the cuts, but may require more force to activate the triggers. This increase in force will be negligible since the circuitry for the trigger system only requires one quick pull of the trigger for the pruner to make a cut.

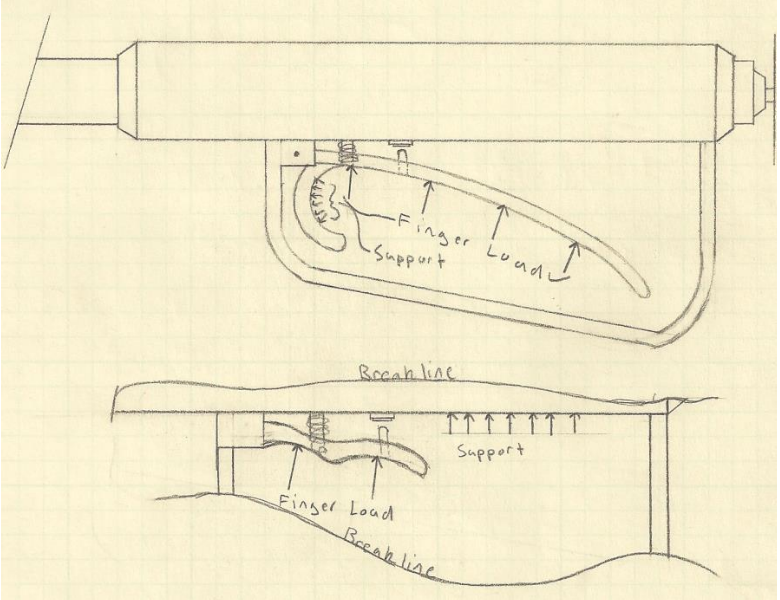


Figure 3: Two options for the trigger system

Benchmark

The benchmark is set at the current functions and design of the Pellenc Treelion D45-900. The overall goal is to produce a pruner that is similar in design to the D45-900 but has the ability to cut branches larger in diameter for longer periods of time. This report specifically discusses the housing of the pruner. When examining the Treelion pruner at H.F. Hauff Company Inc. it was determined that the housing on the Treelion wasn't designed for heavy duty orchard pruning. This was indicated by the epoxy patch job applied to the inside of the grip housing to prevent the fractures on the handle from getting worse. This is an example of a benchmark that must be reached.

Figure 4: Pellenc Treelion D45-900

Performance Predictions

The housing of the pruner is expected to perform at the expectations set for it. The main concerns with the housing were that the actuator would get to hot and the heat could harm the operator. By using a more appropriate actuator and using a material with better thermal diffusivity the external temperature of the grip housing will drop to a comfortable level, with or without gloves. The pruner will also withstand the forces of everyday use. When cutting a limb it is common to press the blades into the branch as it makes a cut so the blades have more bite. The new carbon fiber material chosen will be able to withstand these combined loadings.

Description of Analyses

In this section, the description of analysis for each portion of the housing will be discussed. Equations and methods will be outlined and design parameters will be determined.

Section 1 / Blade Housing

The blade housing geometry will be based on the geometry of the blades and linkage. The sole purpose of the blade housing is to ensure that the linkage is protected and prevents damage to the linkage. The parameters to be determined will stem from the choice in material for the blade housing, since this portion of the housing is in contact with corrosive elements more than bending, shearing, or impact forces. Materials that are light and are resistive to the corrosive environment described in the requirements section will be considered, and a decision matrix will be constructed. The parameters for the decision matrix will include: material name, stock price, machinability, availability, corrosion resistance, and weight. Finite element analysis will also be used to test the geometry of the blade housings unique geometry.

Section 2 / Central Housing

The central housings purpose it to protect the driving rod and bushings that transmit motion from the actuator to the blade linkage. This portion of the housing will be a long cylindrical tube made out of a light-weight and study material in order to maintain rigidity. Deflection equations will be used in order to meet the requirements of withstanding a 195 pound load applied to the end of the pruner. The central housing also must be comfortable to hold on to, since this product will most likely be used with two hands. The measure for "comfortable" is subjective to each person, however, there are basic guidelines that loosely define what is a "comfortable" range of diameters. That range of diameters is 1.2 inches at minimum to 1.8 inches maximum. The central housing will be a minimum of 1.2 inches in order to meet ergonomic requirements, and the smaller size will mean a cheaper central housing component. Appendix A has the green sheet dedicated to this portion of the housing. The green sheet is entitled “Central Housing”

Section 3 / Grip Housing

The grip housing is a complex part of the pruner. Its geometry, much like the blade housing, is largely dependent on the geometry of the actuator and required circuitry. After an actuator is chosen, the basic outline of the grip housing will be drafted. It is assumed that at some point on the actuator, there will be a straight component of 6 inches where the hand can easily be wrapped around the housing where the actuator will go. This will conserve space and comfortably distribute the weight. After the basic structure of the housing is created, paths for the circuity will be mapped out on the inner faces of the housing to connect the power output from the battery pack to the power input of the actuator. Once the geometry of the grip housing shell is completed, the trigger will be integrated into the housing. The completed grip housing will then be analyzed using finite element analysis software in order to double check calculations because of its unique geometry.

Scope of Testing and Evaluation

This pruner and it’s components (cutting system, power and transmission, and housing and ergonomics) will be evaluated as one completed product. Basic testing such as stress testing, housing component evaluation, and cutting a branch can be completed at Central Washington University using the equipment provided. However, the more long term testing such as how many branches can be cut before the battery dies, or how does the actuator over heat over time must be completed outside of the University in an environment that the pruner will most likely end up in. For these portions of testing, the pruner must be examined in the environment in which it was designed for. The pruner will be given to orchardists and they will be asked to use the product for the whole day or for as long as it can function. These tests will take place in the orchards of Yakima, Washington through associates of Neil Hauff. The pruner team will accompany the orchardist to observe the performance of the pruner and their respected components.

Analysis

This portion of the report will discuss the analysis and methods used to shape the housing components to meet the requirements listed in the requirements section above.

Approach: Proposed Sequence

The sequence of design is partially dependent on the design work of the other members of the design team. With this being the case, the proposed sequence of design goes: section 2 / central housing, and then section 1 / blade housing or section 3 / grip housing depending on which analysis is completed first. The central housing can be designed independently of the other sections since it isn’t dependent on choices made by those designers.

Designs

The following list of bullet points discusses the factors that changed the design of the housing components:

- Initially the actuator was assumed to be an inline actuator. It then changed to an actuator with a side mounted motor.
- Central housing was initially 2ft, but then changed to 3ft to meet the reach requirement.
- Blade linkage was initially bar linkage, then rack and pinion, then back to bar linkage
- Actuator changed sizes multiple times as the cutting force was being determined
- Grip housing initially had room for heat sinks, but those heat sinks were removed when it was determined that the actuator wouldn't reach critical temperatures because it's not being pushed passed its design limits.
- Blade housing and grip housing both supported cam latch locking mechanisms to join to the central housing. These cam latches were replaced with the current clamp mounts that are integrated in the housing components.
- Central housing will support a grip on its surface where the operator will place their second hand.

Calculated Parameters

The calculated parameters for each housing section will be discussed.

Section 1 / Blade Housing

Finite element analysis will be used to analyze the blade housing because of its unique geometry.

Section 2 / Central Housing

The central housing will be a 3ft carbon fiber tube of dimension 1.25 inches outside diameter and 1 inch inside diameter. It will be an intermediate modulus tube from Rock West Composites because it will only deflect 1 inch when a 195lb load is applied. This tube is also $29.99/foot which makes it one of the more affordable options. Appendix B drawing No. 35049 is the central housing of the pruner.

Section 3 / Grip Housing

The grip housing will be analyzed using finite element analysis software because of its unique design.

Device Shape

The entire pruner will retain the shape described in figure 1. The geometry of the housing components have changed, but overall shape and layout of parts remains static.

Device Assembly, Attachments

The device will be assembled fallowing drawing number A-1 in Appendix B. This drawing is an exploded view of all the pruner components and their names. Drawing number A-2 is another exploded view of the pruner with a list of steps to assemble and disassemble the pruner.

Ergonomics

One of the most important requirements of this pruner is that it must be comfortable to operate for extended periods of time. The two most important ergonomic areas are the location of the center of mass and the area in which the operator pulls the trigger. The center of mass of the pruner needs to be in a location in which the moment on the wrist is minimized. This means that the wrists will be counteracting the weight of the pruner, and if the center of mass is in front of the hands, then the stress on the wrists increases. Since the pruner is designed to be two handed, the center of mass should be located between the operator's hands. The trigger must also require minimal effort to pull since the trigger will be pulled many times during its use. The largest diameter for comfort on hand tools is 1.8 inches. The grip housing must be 1.8 inches or smaller in order to remain comfortable and the trigger must require a pull of less than 0.25 lbs to activate so the hand doesn't get tired.

Technical Risk Analysis, Failure Mode Analyses, Safety Factors, Operation Limits

This section discusses various forms of failure, technical risks and operational limits of the pruner.

Technical Risks

The main safety risk for the pruner is accidental injury from unwanted cuts. This can be prevented by implementing a safety button on the central housing grip that must remain depressed when in use. A draw back to this approach is the stress on the hand from pressing the button for extended periods of time.

Operational Limits

This pruner is designed to be used 5 days a week for 9 hours a day. Extended use can cause the battery to wear out faster, the blades to dull faster and require sharpening sooner, and the actuator can overheat and become damaged from high temperature exposure. The pruner is also only deigned to cut branches at 1.5 inches in diameter. Branches larger than this can over work the actuator.

Methods and Construction

Construction

This section is dedicated to describing how the device will be made. After the design process for all 3 pruner sections has been completed, the finalized drawings will be passed on to the machinists at H.F. Hauff Co. Inc. for fabrication. Here is when we address manufacturing problems that may have been missed, or mistakes will be corrected. In order to remain organized, sections may be broken up into their individual housing components. (e.g. blade housing, central housing, and motor housing).

Description

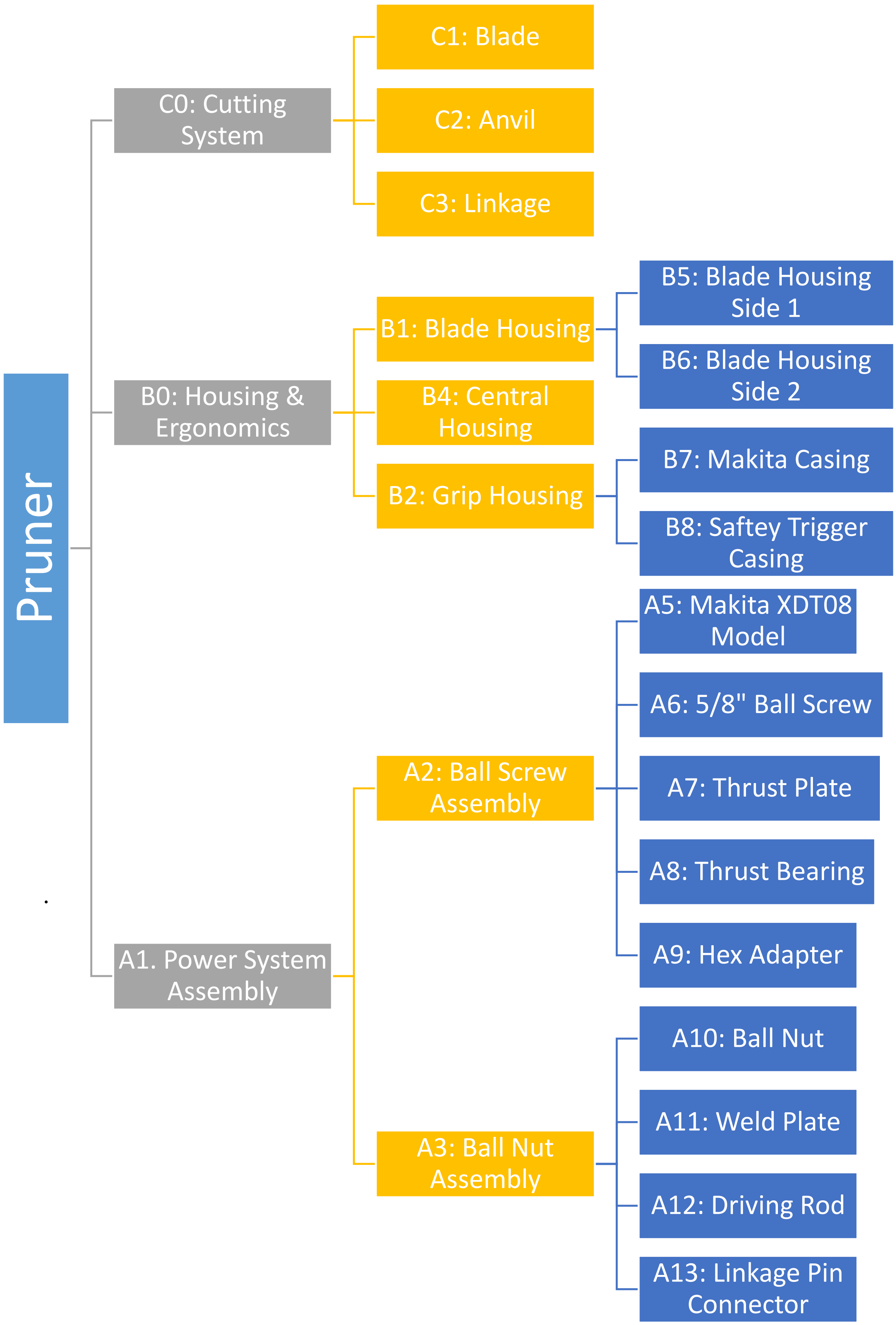
The blade system must be assembled first. This means the blade, anvil, and linkage are all connected. The blade assembly is then bolted to the blade housing through the handle. This ensures that the anvil will not move when cuts are made. Once the blade assembly is mounted to the blade housing, the two halves of the blade housing will be bolted together. The final product is a semi-encased cutting system ready to be attached to the driving rod. The linkage connecting the driving rod to the blade will be exposed to the elements in order to reduce weight at the front end of the pruner.

The driving rod will then be pinned to the appropriate linkage bar to properly transmit the linear motion to the blades. This driving rod/blade linkage connection will be made with steel pins. The central housing tube will then be placed over the driving rod, enclosing it in carbon fiber. The carbon fiber tube will then meet with the base of the blade housing, it’s set ring will meet with the corresponding grove in the blade housing, connecting the blade housing/blade assembly to the driving rod/central housing assembly. This resultant assembly is now ready to be attached to the motor housing.

The motor will be placed into the mounting section of the housing using the 4 screws on the nose of the Makita. The actuator/grip housing assembly will then slide onto the carbon fiber/driving rod assembly where the “male” end of the carbon fiber tube will mate with the “female” top of the grip housing using the same set ring configuration as the blade housing to central housing connection. A similar clamp will then be tightened on the grip housing, connecting the grip housing/actuator assembly to the driving rod/central housing assembly.

Drawing Tree, Drawing ID’s

The drawing tree will be located on the next page. The figure illustrates an organization of pruner components by section. The tree begins at the left with the box labeled “pruner”, and then branches into the three sections of the pruner. Then each of those sections is then broken down it their respective components that make up that section. This report focuses on the 3 housing components that make up the housing and ergonomics section of the pruner.


Pruner
C0: Cutting System
C1: Blade
C2: Anvil
C3: Linkage
B0: Housing & Ergonomics
B1: Blade Housing
B5: Blade Housing Side 1
B6: Blade Housing Side 2
B4: Central Housing
B2: Grip Housing
B7: Makita Casing
B8: Saftey Trigger Casing
A1. Power System Assembly
A2: Ball Screw Assembly
A5: Makita XDT08 Model
A6: 5/8" Ball Screw
A7: Thrust Plate
A8: Thrust Bearing
A9: Hex Adapter
A3: Ball Nut Assembly
A10: Ball Nut
A11: Weld Plate
A12: Driving Rod
A13: Linkage Pin Connector

Parts List

This section lists the parts required to build the pruner, their price, and the supplier that will be used to build the prototype

	Part	Dimensions	Supplier	Price	Quantity	Subtotal
Cutting System	Nickel Titanium	.0160" x 2.50"	NDC	$448.00/foot	1	$448.00
	SAE 1018 Cold Rolled	.125" x 1"	Online Metals	$1.67/foot	1	$1.67
	Grooved Clevis Pin with Retaining Ring	D 1/4" x L 1/2"	McMaster-Carr	$6.99/5 units	1	$6.99
	Cutting System Total					$456.66
Housing & Erg.	Cabon Fiber Filament Wound Tube	OD 1.675" x ID 1.5"	Rock West Composites	$29.99/foot	3	$90.00
	Light Duty Dry-Running Sleeve Bearings	OD 3/4" x ID 5/8" x L 3/4"	McMaster-Carr	$0.89/unit	2	$1.78
	Aluminum	3" square bar	Online Metals	$122.72/foot	1	$122.72
	Rubber Coating	11oz/5ftsq. coverage	Home Depot	$5.98/can	1	$5.98
	Screws	3/8" 2-56 #1 Drive	McMaster-Carr	$5.70/50 screws	1	$5.70
	Housing & Erg. Total					$226.18
Power & Trans.	Makita XDT08 Impact Driver	N/A	Home Depot	$119.00	1	$119
	Makita 5 Ah 18V Battery	N/A	Home Depot	$219.00	1	$219.00
	Makita Dual-Port Charger	N/A	Home Depot	$109.00	1	$109.00
	Ball Screw	5/8" OD 13/64" Lead	McMaster-Carr	$19.47/ foot	1	$19.47
	Ball Nut	13/64" Lead WxL = 1" x 1"	McMaster-Carr	$31.85	1	$31.85
	Thrust Bearing	1/2" ID .940" OD	McMaster-Carr	$3.11	1	$3.11
	Aluminum Plate	.125" Thick 12 x12	Online Metals	$12.64		$12.62
	Aluminum Tube	L12" x OD .875" x ID .777"	Online Metals	$5.82/foot	3	$17.46
	Aluminum Stock	L12" x OD .875"	Online Metals	$6.41	1	$6.41
	Power & Trans Total					$538.00
	Total Pruner Cost					$1,220.84

Manufacturing issues

The team originally planned to have all manufacturing take place at H.F. Hauff Co. Inc. in order to ensure that parts were designed and manufactured to the highest standards. H.F. Hauff Co. Inc. was able to manufacture 4 components of the entire pruner: the anvil, blade and two linkages. All of these parts are described in better detail in Daniel Gibsons report. The rest of the pruner components were purchases and fabricated by the pruner team.

This section of the report is dedicated to the manufacturing issues pertaining to the housing of the pruner. Each housing piece will be listed below and a summary of its manufacturing issues will be discussed.

Set Rings

The set rights are what hold the blade housing and Makita housing to the central housing tube. The manufacturing process for these two rings is fairly straight forward. A piece of bar stock first turned to desired outside diameter, then the inner diameter of the rings were bored out and finally the rings were parted off from the stock to the desired length.

The rings were cut larger than the drawings permitted, but that was easily remedied with some sanding.

Central Housing Tube

The central housing tube is primarily an unaltered carbon fiber tube purchased from Rockwest Composites. The dimensions are given in Appendix B of this report. The tube was 4ft long when purchased and had to be cut to a desired length determined by Thomas Wilson (more on this in the Power and Transmission report). The desired length for the central housing tube was determined to be 30.5 inches to accommodate the driving rod and its transmission components. When the tube was cut, there were some concerns of cracking in the tube but those assumptions were deemed inaccurate.

Blade Housing

The blade housing pieces proved to be the most challenging parts of the pruner to manufacture. Each half took about a week and a half to produce. Originally these were some of the components that were to be manufactured at H.F. Hauff Co. Inc. but circumstances changed and the pruner team manufactured them in the machine shop at Central Washington University. The largest obstacle the pruner team faced when manufacturing the blade housing pieces was brushing up on the CNC milling machine and its controls. The CADCAM code for machining the pieces was generated easily enough by Daniel Gibson, but setting up the work and its offsets was a bit more challenging. The team in total broke 5 end mills and 3 drill bits as a result of incorrect speeds and feeds. However, after the speeds and feeds were adjusted the machining process was relatively smooth after that. The other issue the team had with the blade housing pieces was a bend fixture plate. This didn’t harm the housing at all, the process just took longer because the mill would occasionally contact the fixture plate more than desired. The last obstacle the team had was CNC space. The seniors had to work alongside students in the advanced machining class so everyone could have space in the machine. This led to longer manufacturing times because the work had to be removed from the vices, since the advanced machining students have priority over the machines.

Makita Housing

The Makita housing was going to be the piece of the pruner that would have taken the longest time to manufacture at approx. 2 weeks per half assuming the speeds and feeds were correct in the CADCAM code. These housing pieces were going to be made from 3in x 1.5in 6061 T6 aluminum (same material as blade housing) but the team was running out of time, so 3D printing the components was the chosen manufacturing process. Calculations were adjusted to compensate for the change in material and it was determined that he housing pieces did not need to be changed so all that was left to do was hit “Print” each component took approximately 6 hours to complete.

Discussion of assembly, sub-assemblies, parts, drawings (examples)

The order in which the parts will be created is as follows:

1. Blade and anvil
2. Linkage
3. Driving rod

4. Central housing
5. Blade housing
6. Makita purchase
7. Makita housing
8. Circuitry purchase

Housing Assembly

After all of the housing components were fabricated (set rings, blade housing, Makita housing and central housing) they were assembled in order to ensure a secure fit between all housing parts.

The inner diameter of the set rings were coated in DP 420 Scotch Weld Epoxy and pressed onto the tube and left in the finishing room to cure. After the rings were set on the tube, the blade housing pieces were attached to the tube and bolted on and the fit was acceptable. The Makita housing pieces were then fit around the central housing tube to ensure their fit and those fits were acceptable as well. When considering the assembly of the housing pieces only, there were no complications.

Testing Method

Introduction

The housing components of the pruner must withstand the external forces of everyday use and the internal forces generated by the driving components. Requirements for the housing components include: 5 pound weight limit, 5 minute assembly time, bending strength, safety switches, price limit of $200 dollars, and various ergonomic requirements. The parameters of interest for the housing components are their weight, ergonomics, and strength. These parameters were chosen because the ideal housing is light, comfortable and strong since the housing components will be the pieces of the pruner that see a majority of the service and they hold the entire pruner together. Ideally, the pruner housing will not fail in any way when in use. The central housing tube of the electric pruner protects the driving rod and ball screw used to turn rotational force into linear force. It is important that the central housing tube prevents the driving rod and/or ball screw from bending under assumed high loads. The central housing tube will be strength tested to see if the tube meets the requirements set for it in the introduction of this engineering report. The Makita housing has two tasks: to attach the driving rod to the Makita, and to prevent the Makita from moving when the pruner is in use. Since a Makita is being used and it already has housing, there isn't a need to develop a second housing to protect the Makita. Lastly, the blade housing is meant to hold the blades so the driving rod can attach to the blade and transfer the linear motion into a cutting force to cut branches. With the hours contributed by each member of the team and input from Neil Hauff the housing pieces are expected to withstand all assumed loads and forces. The tube shouldn't snap or buckle with the given loads, the blade housing shouldn't break when making cuts and the Makita housing should keep the Makita held firmly in place while maintaining the driving rod to Makita connection. Data will be recorded using Microsoft Excel spreadsheets, traditional note taking, and digital assistance from equipment found around Central Washington University. The testing on the housing components will take approximately 4 weeks as per Gantt chart located in Appendix E.

Pruner Housing Component Testing

The intention of testing the housing components is to ensure that the components can protect all of the inner mechanisms for the pruner. Without a sturdy housing, the pruner wouldn't stand a chance in the field. The housing components will be tested by measuring their combined weight, damage resistance, and ease of assembly and disassembly.

Assembled Pruner Device Testing

The intention of testing the entire pruner is to ensure that it can accomplish the tasks it was designed for.

Method/Approach

Resources: In this section the resources for each test will be discussed. Below is a table laying out the materials required to perform each of the 4 tests for the housing portion of the pruner project. These 4 tests were chosen because they represent the parameters of interest for the housing as a whole. Those parameters are strength, weight, price, and ease of assembly. Now, it is important to note that the table below only mentions material resources. It should also be noted that every material resource in figure T1 can be found at Central Washington University.

Central Housing Bending Test	Total Weight Test	Assembly Test	Total Cost Test
Strain Gauges	Scale	Housing Components	Reciepts for pieces and parts
Scotch Tape	Note Taking Matls.	Stop Watch	Calculator
Techtronics Data Unit	Housing Components	Note Taking Matls.	Note Taking Matls.
Laptrop			
Safety Glasses			
CNC Mill work holding pieces			
Weight Sling			
Weights (increments of 10lb)			
Super Glue			

Figure: Testing component list for each housing test

In addition to the material resources listed above, these tests required the assistance of lab technicians and instructors located at Central Washington University. These tests need to be performed with the help of Matt Burvee, Greg Lyman, Andrew Kastning, Jose Bajar, Trevor Reher, Nancy Alvarez and Sydnee Johnson. These individuals assist in setting up tests, opening shops, providing feedback and most importantly they contributed to the validity of the tests and improved them to provide better and more accurate results.

Data Capture/Storage/Presentation: Two methods of data acquisition and processing will be used with the tests listed in figure T1. The first method for data recording will be writing test values on paper to later be transferred into a computer program such as Microsoft Excel. Excel will then be used to process data to calculate testing results, and Excel will be used to generate the final tables that are viewable in the appendix.

Test Procedure Overview: All tests will be performed using the same general format: acquire necessary testing materials, set up test, perform test, record results, repeat for consistency. A more detailed test procedure can be found in the later section titled “Test Procedure”. The goal of these tests is to be reputable as to get a range of values for each test and compare them to calculated values. Success or failure will be determined from these results.

Operational Limitations: These tests were performed in such a way that there were little to no limitations in the testing methods themselves. The weight tests required only a scale (which was provided by the Construction Management department), the cost test only required receipts and a calculator, and the assembly tests requires only basic tools (such as screwdrivers and small wrenches) and a stop watch. With that being said, the bending stress test had operation limitations because the tube couldn’t be fully tested to max estimated strength. While, it is believed that the tube could withstand the 196 pound force at its max moment arm, there was a chance that the tube could fracture or crack and that can’t happen because the pruner needs to be fully reassembled and working after testing is completed.

Precision vs. Accuracy: For the weight, cost, and assembly time tests precision and accuracy can easily be determined since the tests and testing environments are very controllable. The precision of the weight and cost tests will be high because there is little input from the tester. These two tests require basic observational skills. The assembly test is based entirely on the abilities of the tester being able to put the pieces of the housing together. The bending strength test has a few more variables to take into consideration. The integrity of the strain gauge equipment is important as to produce accurate results, the temperature of the room is important because the temperature of the room can alter the effectiveness of the strain gauge, and the testing rig needs to be set up the exact same each time. The precision of the bending strength test will be lower than the previous 3 tests mentioned. The accuracy of each test will be determined by comparing the experimental results with the calculated results.

Test Procedure

This section provides an example of a test procedure used in the testing of the central housing tube. This procedure provided accurate testing results and the 3 other tests followed procedures similar in detail to this one.

The test will take place in the machine shop at Central Washington University on April 11, 2016 and should take approximately 4 hours to complete.

Preparing the Carbon Fiber Tube

Wear safety glasses during the duration of this test.

1. Acquire carbon fiber central housing tube, 220 sand paper, rubbing alcohol, masking tape, 5 strain gauges, paper towels, latex safety gloves, super glue, pencil/marking utensil, ruler/tape mesure
2. Starting at one end of the tube, measure 6 inches from the end and sand a smooth surface to place a strain gauge (a 2” x 2” square will do) repeat this step for the entire length of the tube and be sure to mark the 6 inch increments with a horizontal line perpendicular to the tubes long axis.
3. Put on the latex safety gloves and apply enough rubbing alcohol to a section of paper towels to wipe away the carbon fiber residue from the sanding. The sanded surfaces are now cleaned for strain gauges. (Note: make sure the surfaces remain free of dust/debris)
4. Retrieve the strain gauges, super glue and masking tape (Note: safety glasses and gloves should still be on) coat the first 6 inch increment mark with a thin layer of super glue and place the strain gauge so that the lines on the strain gauge match the previously marked line in step 2.
5. Take a piece of masking tape approx. 3 inches long and place over the strain gauge. Press firmly on the strain gauge so that the glue between the gauge and the tube is squeezed out. Repeat steps 4 and 5 for the remaining 4 strain gauges. Allow super glue to cure.

Placing the Tube in the Testing Rig

Safety glasses should still be on, gloves can be removed

6. Acquire computer, Techtronics data unit, testing rig, pencil and paper (or other data recording equipment)
7. Using the ruler/tape measure mark 4 inches on the tube from the same starting end used in step 2. Place tube with strain gauges into the circular vice grip so that the 4 inch mark is aligned with the front of the vice face and the strain gauges are facing directly up. Tighten the vice so that the tube is secure in the vice.
8. Attach the strain gauge leads to the data unit and open the program. Start the program and firmly push down on the free end of the tube. There should be a response in the program. (Make sure the wires from the tube to the data unit have slack in them)

Applying Loads to the Tube

Safety glasses should still be on

9. Acquire 10 lb, 20 lb, 30 lb, 40 lb, 2-50 lb weights, weight sling, foam mat, note taking materials
10. Place the weight sling and 10 lb weight on the free end of the carbon fiber tube and record the readings reported by each strain gauge. Repeat this step and increase the weight by 10 lbs every time until 200 lbs is reached. Ex. 10 lb, record then 20 lb load, record, etc.. (See safety section now)

Risk/Safety

Safety glasses should be worn at all times in the event of tube failure, and protective cloves should be worn when noted in the procedure.

If at any point you observe cracking/tube failure (visual or audible) remove the weight and stop testing immediately. Note the weight at the end of the tube and values recorded by the strain gauges in the Techtronics software program. The purpose of this is to preserve the tube so the pruner can still be assembled.

Data Evaluation

The Techtronics program will receive input from the strain gauge and run those numbers through calculations to output microstrain at the location of the gauge. The equations and tube dimensions have already been recorded and implemented in the program. These numbers will then be compared to the numbers calculated by the Central Housing Tube Combined Calculations spread sheet on page 28 of the engineering report.

Discussion

This test will provide excellent data if the procedure is followed correctly. The test is set up almost exactly like problems from engineering textbooks, so validating experimental calculations should be simple. The accuracy of those numbers depends largely on the individual taking measurements and marking the tube. The assumed load of 200 pounds is close to what the average weight of a male according to the CDC. The assumed max load scenario is one which the entire pruner product is rendered immovable while in duty (ex. the blade is stuck in a branch and can't be shaken loose) and the operator hangs off the end of it.

Deliverables

The parameters of the bending stress test were stress values +/- 10% of calculated values. Figure T2 shows the spreadsheet used to calculate the values used in figure T3 which is the results from the bending stress test. As seen in figure T3 the data indicated a failure after more than 10 pounds was placed on the tube. Also, during the test there was an audible cracking sound as the weight was placed on the tube. The testing immediately stopped in order to preserve the tube. This test would be considered a failure when compared to its success criteria of supporting 200 pounds at its max moment.

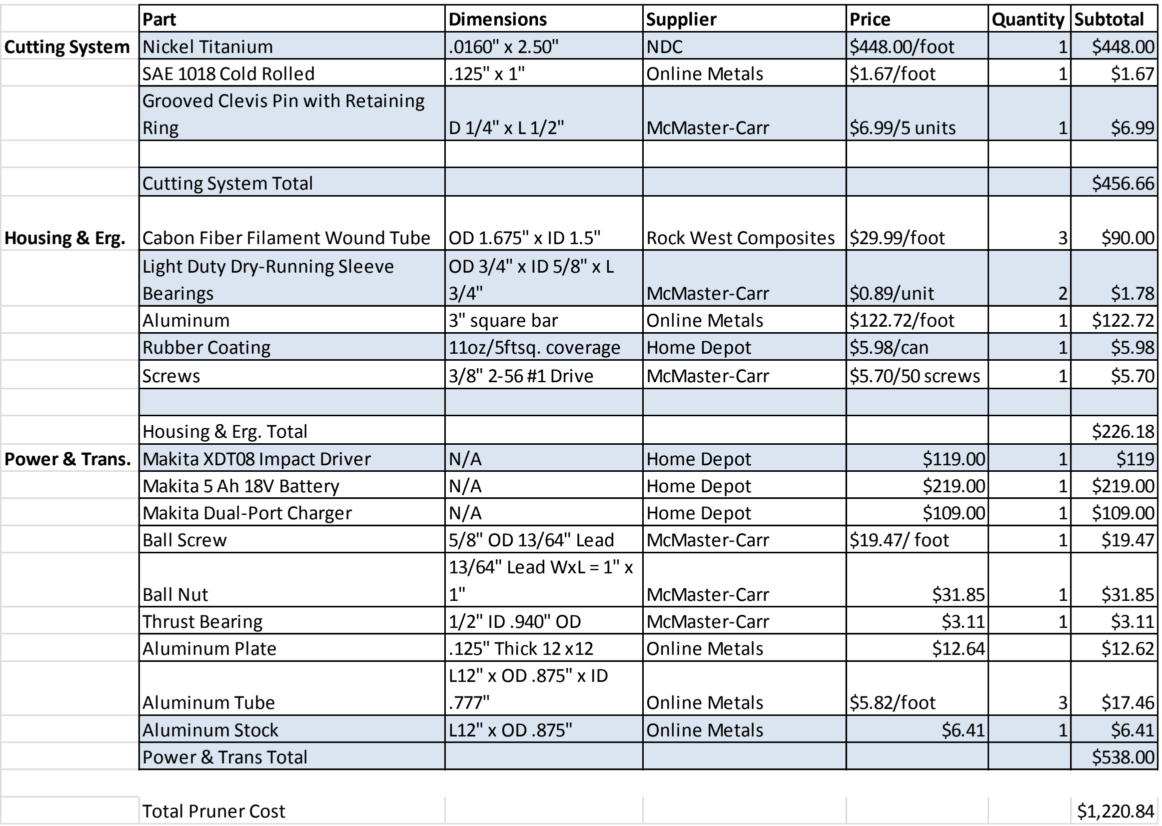
The parameters for the other 3 tests (weight, assembly time and cost) were defined in the requirements for the housing. The weight of the housing pieces could not exceed 5 pounds, the price of housing components couldn't exceed $200.00 and the assembly time for the housing pieces could be longer than 5 minutes. As seen in figure T6 the total weight of the pruner pieces was 1.553 pounds which is under the requirement of 5 pounds, so that's a success. Figure T4 shows multiple assembly times which averaged to be 5 minutes and 11 seconds. Even though the average time is above the expected, there was one run in which a tool couldn't be located and that is an outlier for the runs. If that run wasn't there than the average time would be less than 5 minutes. Figure T5 lists the prices of each component used in the assembly of the housing. The price was supposed to be less than $200.00 but the total price came out to be $348.54. This is considered a failure, but it can be fixed by using less aluminum.

Conclusion

The testing of the pruner housing pieces saw 2 failures and 2 successes. The failures for these tests don't necessarily mean that the entire pruner is a failure. When the pruner is fully assembled it will have its own set of requirements. The housing components of the pruner have been tailored to the most extreme orchard environment. Its filament wound carbon fiber tube can stand up to any bend, twist or compression you can throw at it while in the field. The grip housing securely holds the Makita in place and attached to the driving rod. The blade housing keeps large debris from entering the housing and interfering with the blade linkage, minimizing maintenance times.

Proposed Budget

This section will cover the proposed budget for the entire pruner and the specific budget for the pruner housing components.



	Part	Dimensions	Supplier	Price	Quantity	Subtotal
Cutting System	Nickel Titanium	.0160" x 2.50"	NDC	$448.00/foot	1	$448.00
	SAE 1018 Cold Rolled	.125" x 1"	Online Metals	$1.67/foot	1	$1.67
	Grooved Clevis Pin with Retaining Ring	D 1/4" x L 1/2"	McMaster-Carr	$6.99/5 units	1	$6.99
	Cutting System Total					$456.66
Housing & Erg.	Cabon Fiber Filament Wound Tube	OD 1.675" x ID 1.5"	Rock West Composites	$29.99/foot	3	$90.00
	Light Duty Dry-Running Sleeve Bearings	OD 3/4" x ID 5/8" x L 3/4"	McMaster-Carr	$0.89/unit	2	$1.78
	Aluminum	3" square bar	Online Metals	$122.72/foot	1	$122.72
	Rubber Coating	11oz/5ftsq. coverage	Home Depot	$5.98/can	1	$5.98
	Screws	3/8" 2-56 #1 Drive	McMaster-Carr	$5.70/50 screws	1	$5.70
	Housing & Erg. Total					$226.18
Power & Trans.	Makita XDT08 Impact Driver	N/A	Home Depot	$119.00	1	$119
	Makita 5 Ah 18V Battery	N/A	Home Depot	$219.00	1	$219.00
	Makita Dual-Port Charger	N/A	Home Depot	$109.00	1	$109.00
	Ball Screw	5/8" OD 13/64" Lead	McMaster-Carr	$19.47/ foot	1	$19.47
	Ball Nut	13/64" Lead WxL = 1" x 1"	McMaster-Carr	$31.85	1	$31.85
	Thrust Bearing	1/2" ID .940" OD	McMaster-Carr	$3.11	1	$3.11
	Aluminum Plate	.125" Thick 12 x12	Online Metals	$12.64		$12.62
	Aluminum Tube	L12" x OD .875" x ID .777"	Online Metals	$5.82/foot	3	$17.46
	Aluminum Stock	L12" x OD .875"	Online Metals	$6.41	1	$6.41
	Power & Trans Total					$538.00
	Total Pruner Cost					$1,220.84

Above is a parts list that includes a subtotal for the housing components of the pruner, as well as subtotals for the other two sections of the pruner, and an overall total for the entire pruner itself. The table lays out the name of the part, the required dimensions for the part, the supplier that has that part, the price that the supplier sells the part for, the number of parts needed, and the price. Suppliers have a high chance of changing, since the number one factor in choosing the parts for the pruner is the price. If an equal part can be found for less money, the supplier will change.

Currently, the most expensive parts for the pruner housing are the filament wound carbon fiber tube and the stock 6061 aluminum. The price of the aluminum is guaranteed to decrease since aluminum can be purchased through the school for a significantly cheaper price. The prince of the carbon fiber tubing will also decrease because the wall thickness of the tube is going to decrease as the driving rod from the power and transmission section increases in OD.

Proposed Schedule

The schedule for the entire pruner project is outlined in a Gantt chart found in Appendix E. The Gantt chart includes dates and tasks for the all 3 sections of the project. Below is a summary of the 2015-2016 MET 495 course.

Fall Quarter – Proposal Drafting and Initial Design

The goal of fall quarter is to write a majority of the project proposal and to fully design the product, in this particular case, the product is the pruner. Looking at the Gantt chart, tasks include “housing/ergonomic research”, “housing/ergonomic design”, and “housing/ergonomic analysis”. These tasks illustrate the design process for fall quarter.

Winter Quarter – Assembly and Troubleshooting

At the beginning of winter quarter the proposal is “frozen” and any changes to design or construction must be marked by dated revisions. This quarter is dedicated to manufacturing the product designed in fall quarter, and addressing any design flaws that may have been overlooked. At the end of this quarter, as indicated on the Gantt chart by a milestone marker, the full pruner must be fully assembled and working.

Spring Quarter – Testing and Proposal Completion

Now that the product is completed, it must be tested in order to assess our design based on the requirements set for it during fall quarter. Whether the product meets the requirements of the product or not, the results of the testing must be noted in the proposal. This will also be the quarter where the proposal is complete, as indicated on the Gantt chart by a milestone.

Project Management

This section will list the many resources used while creating this product.

Human Resources

- H.F. Hauff Co. Inc. employees
    - Neil Hauff
    - Casey MacFalrlen
    - Machinists
- Central Washington University Staff

  - Dr. Craig Johson
  - Charles Pringle
  - Roger Beardsley
  - Matt Burvee
  - Greg Lyman

Physical Resources

- Central Washington University machining equipment
- H.F. Hauff Co. Inc. machining equipment

Soft Resources: Software, Web support, etc.

- SolidWorks
- FEA Software
- Efatigue

Financial Resources

- Pruner team will purchase cheaper components less than $100
- H.F. Hauff Co. Inc. will provide funds for more expensive components

Discussion

Project Risk Analysis

The main safety risk for the pruner is accidental injury from unwanted cuts. This can be prevented by implementing a safety button on the central housing grip that must remain depressed when in use. A draw back to this approach is the stress on the hand from pressing the button for extended periods of time.

This project is also a financial risk for the pruner assembly team if certain components aren’t purchased by H.F. Hauff Co. Inc. For example, the actuator itself costs $1500.00 and the pruner team doesn’t have that money.

Successful

The success of this pruner housing is determined by how effective the pruner houses the inner components, and whether or not it’s comfortable to use for extended periods of time. It’s crucial that the housing has a long life span while maintaining the requirements stated above. It is also important that the housing can be taken apart and put back together easily so parts can be replaced or cleaned.

Next Phase

This section is dedicated to the next phase of the pruner. After testing is completed, the proper alterations to each component will be made in order to deliver a fully functioning product to the customer. Failures in the testing portion will be addressed and reworked so the product meets all necessary requirements set for the product. For example, the new geometry of the grip housing may not distribute heat as well as intended, so the grip housing will be redesigned so it fits the requirements set for it. Another example is that the cycle time for cuts is too long, so the stroke length can be shortened or the linkage can be reshaped.

Conclusion

The entire pruner exceeded expectations. With its nickel-titanium blades it can cut 1.5 inch diameter braches for 4 weeks before being sharpened. The expertly designed blade linkage amplifies the force generated from the linear actuator to provide strong, smooth cuts when pruning trees. With the pruners light weight of only 20 pounds, pruning those high to reach branches has never been easier. Speaking of easy, the ergonomic grip and trigger requires only a quarter of a pound of force to easily make a cut, but not accidently cut when you don't want to.

The housing components of the pruner have been tailored to the most extreme orchard environment. Its filament wound carbon fiber tube can stand up to any bend, twist or compression you can throw at it while in the field. The grip housing securely holds the linear actuator motor while keeping motor heat from reaching the operators hand. The blade housing keeps large debris from entering the housing and interfering with the blade linkage, minimizing maintenance times.

This pruner wouldn't have been possible without the support and guidance from Neil Hauff of H.F. Hauff Co. Inc. and its employees. Their expert machinists created each part within tolerances of thousands of an inch. Their engineering experts ensured that the pruner team designed every piece to the requirements set for them. Without Neil Hauffs generosity and determination, this product wouldn't exist.

The success of this pruner is dependent on the successes of its 3 individual sections: the blade system, power and transmission, and housing and ergonomics. This pruner housing will be considered a full success if every single requirement is met in the requirements section of this report. However, since some requirements specify a pruner life of times up to a year the scope for success will be narrowed.

This pruner will be considered successful if the pruner can cut a 1.5 inch branch after assembly. If that goal is met then more specific and significant testing will take place.

The entire pruner housing (blade, central, and grip) will be considered successful if all housing components can withstand stress testing, assemble together around the cutting system and power systems, and not weigh more than 20 lbs.

Acknowledgements

This project couldn’t have been completed without the help of industry, Central Washington University staff, my partners, or my friends and family. In no particular order, I’d like to specifically call out the individuals that made this happen.

Thank you to:

Neil Hauff of H.F. Hauff Co. His interest in providing students of Central Washington University with engineering experience is the reason our team had this project. Mr. Hauff was gracious enough to offer two projects to the senior mechanical engineering technology students, and the pruner was one of them. His input was vital in the final design, funded the project, and most importantly he taught our team so many lessons that we will use often in our careers.

Central Washington University alum, Casey MacFarlen. Casey was very helpful in providing insight into creating this proposal and his design input helped us stay on a realistic path for designing this pruner.

My partners in designing this pruner, Daniel Gibson and Thomas Wilson. Their long hours of work and dedication made this pruner a reality. We had a lot of long nights designing this pruner, and I couldn’t have asked for better partners.

Dr. Craig Johnson, Roger Beardsley, Charles Pringle, Matt Burvee, Greg Lyman, Ted Bramble of Central Washington University staff. Dr. Jonson, Mr. Beardsley, and Mr. Pringle all had specific input in the drafting in this proposal that made it what it is today. The time it took to read the same 30 plus proposals every week is greatly appreciated. Mr. Burvee, Mr. Lyman, and Mr. Bramble all aided in the construction, testing, data gathering, and dirty work that made the physical pruner possible.

My parents Vince and Shauna Heilman. There were a lot of weekends where I didn’t come home to play board games, but they always understood how much work senior year required. The support of your parents is always something to be grateful for.

My friends. Their understanding in my prolonged absences was a blessing. When you vanish from video games like I did, it’s easy to be replaced. I was lucky enough to be able to come back to my usual spot in our gaming sessions like I was never gone.

Last, but most important, my girlfriend of 3.5 years Nancy Alvarez. I could write books about this woman, but I’ll keep it short. I relied on her support the most and I couldn’t have gotten through these long, dark days without her. She was there for me through thick and thin, and I’m lucky to have held onto her for this long.

Again, a thank you to everyone who aided in this project. No matter how small a part they played, they made this happ

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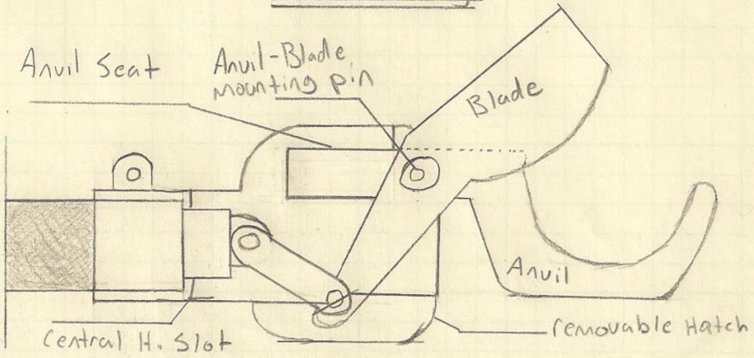
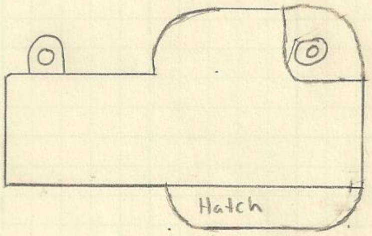
Appendix A - Analyses

Blade Housing

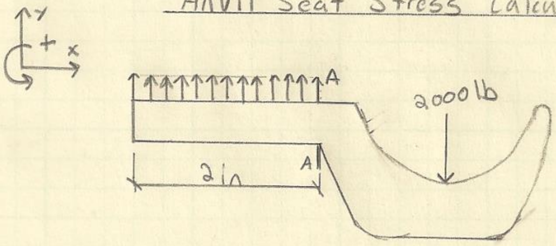


The blade housing profile is shown above.



Initial Blade Housing

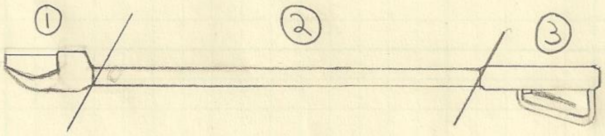
Anvil Seat Stress Calculation



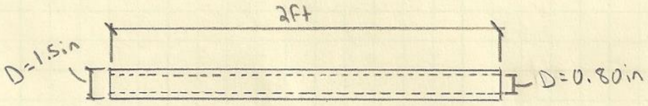
The Anvil is Fixed at plane A

$\circlearrowleft \Sigma M_A = 0$:

Housing Components

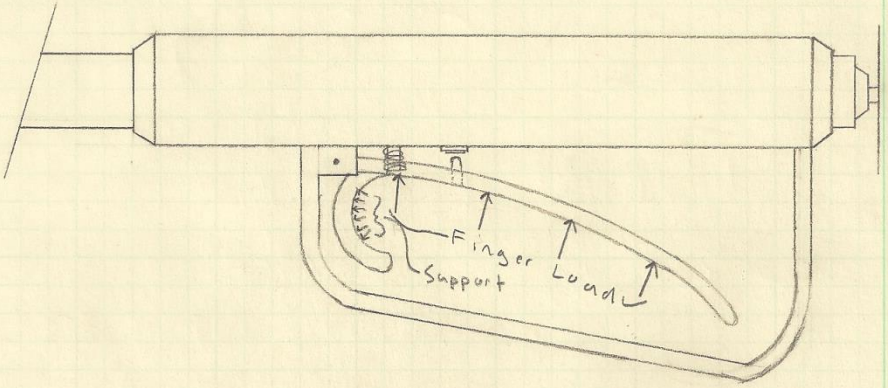


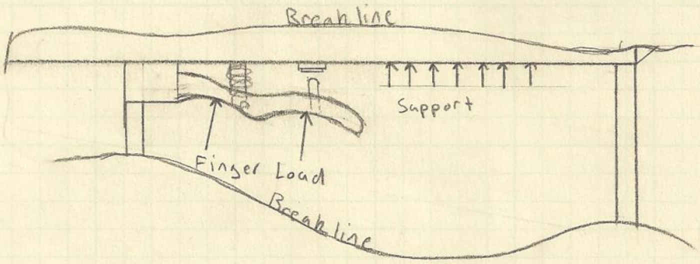
1. Blade Housing
2. Central Housing
3. Grip Housing



Erich Heilman Senior Project

Grip Housing Trigger Options



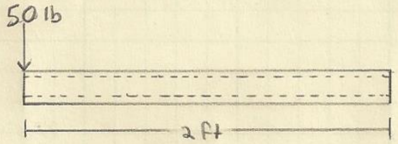


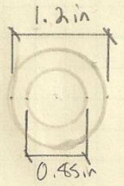
Erich Heilman | MET 495a | 11-14-15 | 1/1

RADD Assessment

1.2 OD
0.75 ID

Requirement: • Central housing can't deflect more than 1/8" when a 50 pound load is applied as shown below





Modulus = 34msi
42msi

• Customer wants material to be carbon Fiber tube, filament wound
• Similar geometry to existing pruner central housing

Analysis: • Equations to use are $I = \frac{\pi(D^4 - d^4)}{64}$, $y = \frac{-PL^3}{3EI}$

$$y = \frac{-PL^3}{3EI} = \frac{-(50lb)(24in)^3}{3(34\times10^6 psi)\left(\frac{\pi(1.2in^4 - 0.85^4)}{64}\right)} \Rightarrow \boxed{y = 0.0890in}$$

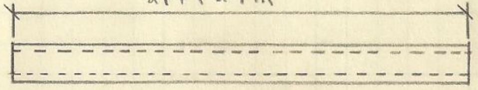
Design: The resultant y value is lower than the required deflection so the wall thickness and length are good.

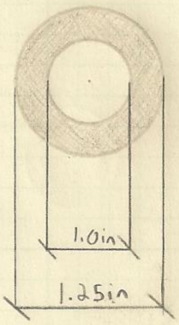
$0.0890in < 0.125$

*The ID is dependent on the size of the driving rod. The 0.85 in is the absolute biggest the ID will be.

1/1

Central Housing

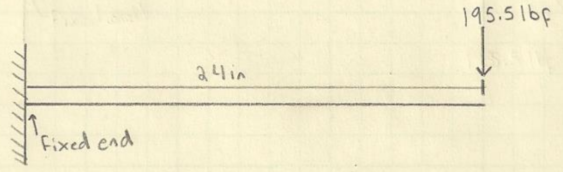




Rockwest Comp

Std.	34msi	700
Int.	42msi	825
High.	57msi	670
Higher	66msi	670
Ult H	94msi	380

- Average weight of an adult male = 195.5 lbf
- Assuming the max force this pruner housing will support is an adult male hanging from a pruner that is fixed at one end.
- Rochwell Composites carbon fiber tubing will be used in this analysis

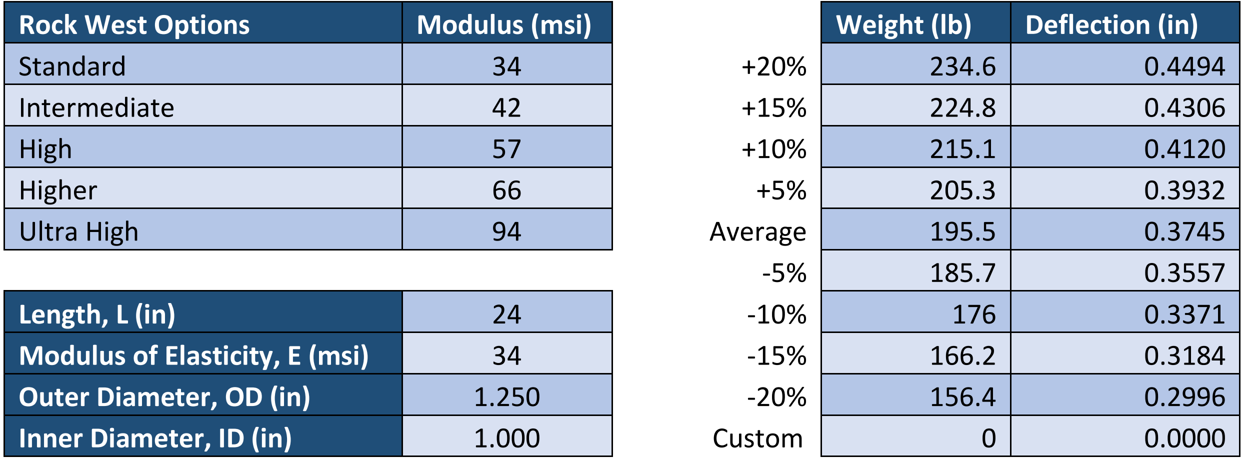


$$\delta = \frac{PL^3}{3EI} = \frac{(195.5\,\text{lbf})(24\,\text{in})^3}{3(34\times10^6\,\text{lbf/in}^2)[(\pi/64)((1.25\,\text{in})^4-(1.00\,\text{in})^4))} \Rightarrow \boxed{\delta = 0.374\,\text{in}}$$

$$I = \frac{\pi(OD^4 - ID^4)}{64}$$

Sources: www.rochwestcomposites.com
www.cdc.gov
www.ehstoday.com
www.humantech.com
Machine Elements in Mechanical Design

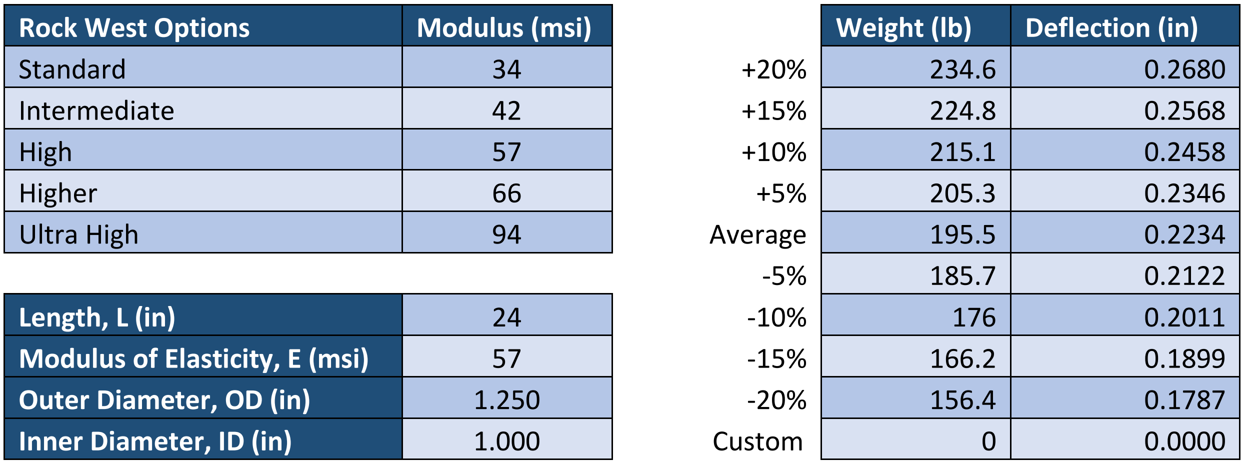
Extended Bending Analysis Via Excel Spreadsheet



Rock West Options	Modulus (msi)
Standard	34
Intermediate	42
High	57
Higher	66
Ultra High	94

Length, L (in)	24
Modulus of Elasticity, E (msi)	34
Outer Diameter, OD (in)	1.250
Inner Diameter, ID (in)	1.000

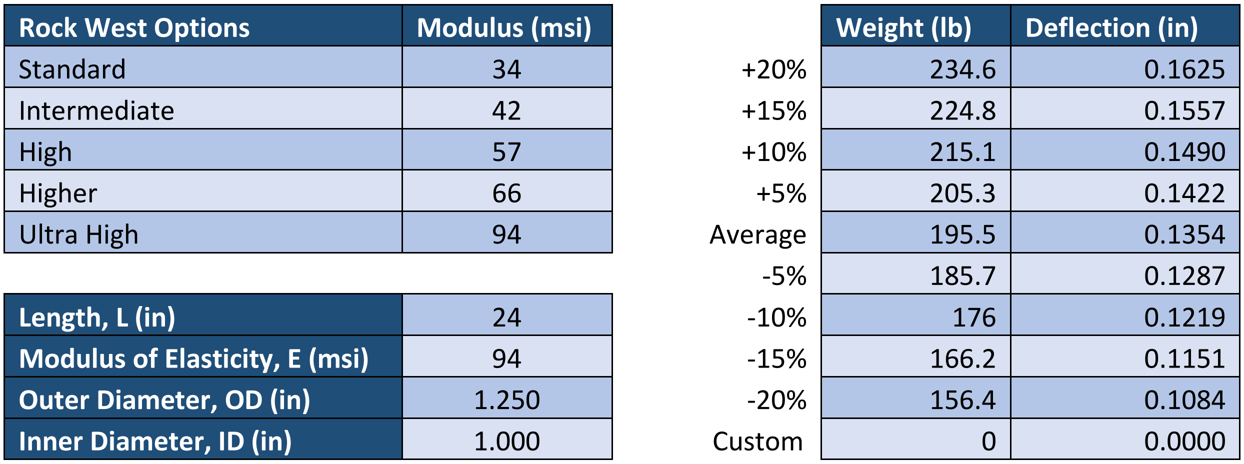
	Weight (lb)	Deflection (in)
+20%	234.6	0.4494
+15%	224.8	0.4306
+10%	215.1	0.4120
+5%	205.3	0.3932
Average	195.5	0.3745
-5%	185.7	0.3557
-10%	176	0.3371
-15%	166.2	0.3184
-20%	156.4	0.2996
Custom	0	0.0000



Rock West Options	Modulus (msi)
Standard	34
Intermediate	42
High	57
Higher	66
Ultra High	94

Length, L (in)	24
Modulus of Elasticity, E (msi)	57
Outer Diameter, OD (in)	1.250
Inner Diameter, ID (in)	1.000

	Weight (lb)	Deflection (in)
+20%	234.6	0.2680
+15%	224.8	0.2568
+10%	215.1	0.2458
+5%	205.3	0.2346
Average	195.5	0.2234
-5%	185.7	0.2122
-10%	176	0.2011
-15%	166.2	0.1899
-20%	156.4	0.1787
Custom	0	0.0000



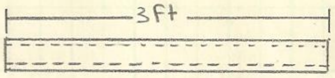
Rock West Options	Modulus (msi)
Standard	34
Intermediate	42
High	57
Higher	66
Ultra High	94

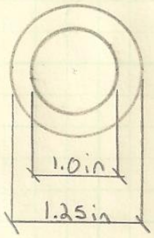
Length, L (in)	24
Modulus of Elasticity, E (msi)	94
Outer Diameter, OD (in)	1.250
Inner Diameter, ID (in)	1.000

	Weight (lb)	Deflection (in)
+20%	234.6	0.1625
+15%	224.8	0.1557
+10%	215.1	0.1490
+5%	205.3	0.1422
Average	195.5	0.1354
-5%	185.7	0.1287
-10%	176	0.1219
-15%	166.2	0.1151
-20%	156.4	0.1084
Custom	0	0.0000

Central Housing

Buckling





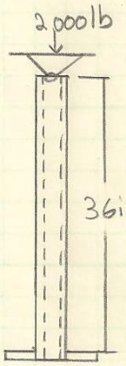
$E = 42\text{msi}$
$A = 0.441\text{in}^2$

Using Rockwest Composites Filamat
Wound tube, intermediate modulus
$E = 42\text{msi}$

Purpose: Determine if the central housing tube can withstand the max force (2000lb) generated by the cutting blades.

The force generated by the blades is transfered from the blades, to the connections to the blade housing, to the central housing tube.

Assume Axial Loading
Assume Fixed-pin column setup



- Assuming Long Column

$K = 0.8$

- Effective Length, $L_e = KL = (0.8)(36\text{in}) \Rightarrow L_e = 28.8\text{in}$

- Checking for critical load, given the material and dimensions

$$P_{cr} = \frac{\pi^2 EA}{\left(\frac{L_e}{r}\right)^2} = \frac{\pi^2 (42\times10^6\,\text{psi})(0.441\text{in}^2)}{\left(\frac{28.8\text{in}}{0.400195\text{in}}\right)^2}$$

$$r = \frac{\sqrt{D^2+d^2}}{4} = \frac{\sqrt{1.25\text{in}^2 + 1\text{in}^2}}{4} \Rightarrow r = 0.400195\text{in}$$

$$\left[P_{cr} = 35298\,\text{lb}\right]$$

↑

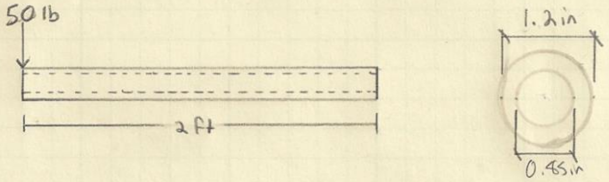
This is the critical load in which the cylindrical tube will buckle. The max compressile force on the tube will be 2000lb so this tube resists that compressile force with a saftey factor of $N = 17.6$

Erich Heilman | MET 495a | 11-14-15 | 1/1

RADD Assessment

1.2 OD
0.75 ID

Requirement: • Central housing can't deflect more than 1/8" when a 50 pound load is applied as shown below



Modulus = 34 msi
42 msi

- Customer wants material to be carbon fiber tube, filament wound
- Similar geometry to existing pruner central housing

Analysis: • Equations to use are $I = \frac{\pi(D^4 - d^4)}{64}$, $y = \frac{-PL^3}{3EI}$

$$y = \frac{-PL^3}{3EI} = \frac{-(50lb)(24in)^3}{3(34\times10^6 psi)\left(\frac{\pi(1.2in^4 - 0.85^4)}{64}\right)} \Rightarrow \boxed{y = 0.0890in}$$

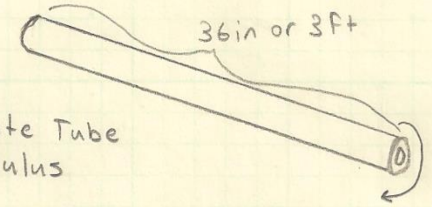
Design: The resultant y value is lower than the required deflection so the wall thickness and length are good.

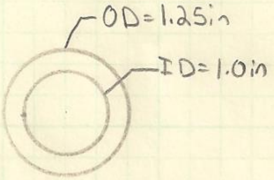
0.0890in < 0.125

*The ID is dependent on the size of the driving rod. The 0.85 in is the absolute biggest the ID will be.

Central Housing

Torsion Stress

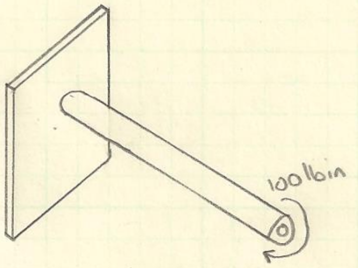


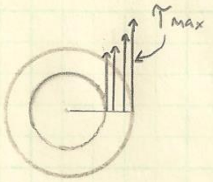


$E = 42msi$

Rock West Composite Tube
Intermediate Modulus

Assume fixed at one end and free floating at the other.
Assuming a max torque of 100 lbin





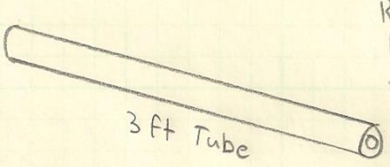
Finding max shear at outer surface

$$\tau_{max} = \frac{Tc}{J} = \frac{(100lbin)(1.25in)}{\pi/32\,(1.25in^4 - 1.0in^4)} \Rightarrow \boxed{\tau_{max} = 883.3psi}$$

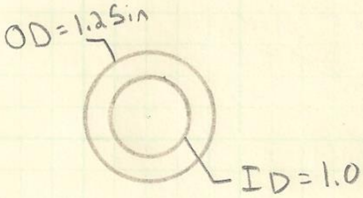
Significantly
lower than S_y of
material

Central Housing

Torsion Deflection



Rock West Composites
Filament wound tube
Intermediate Modulus



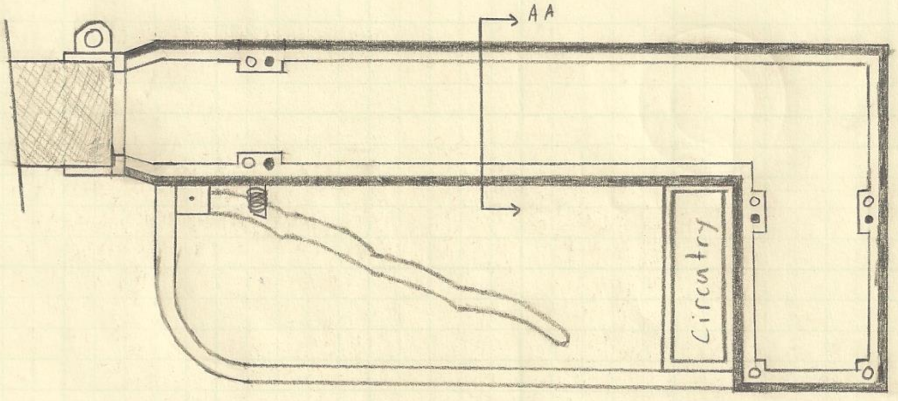
Assume the max torque on the rod is 100 lbin

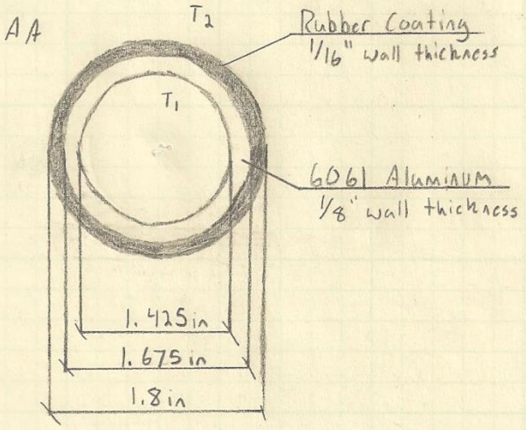
Minimizing angle of deflection is important in this situation because the driving rod inside the housing shouldn't rotate so the actuator isn't damaged

$K = 0.141 a^4$

$$\theta = \frac{TL}{GK} = \frac{(100 lbin)(36 in)}{(G)(K)}$$

Grip Housing



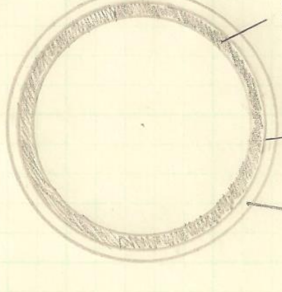


T_1 = Max Op. Temp of Actuator

T_2 = Ambient air temp

$K_{6061} = 167 \frac{W}{M\text{-}K} = 1160 \frac{BTU\text{-}in}{hr\text{-}ft^2\text{-}F}$

Set Ring Calcs



Filament wound carbon fiber tube
OD = 1.625in
ID = 1.500in

DP420 Scotch Weld
Shear Strength = 4500lb

Aluminum set ring for joining housing components

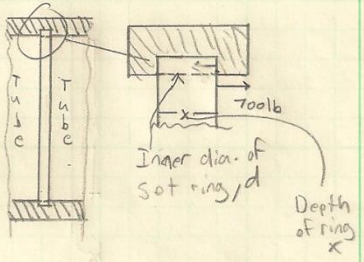
6061-T6 Aluminum → $E = 10\times10^6$ psi
$S_t = 45$ ksi $= 45\times10^3$ psi
$S_y = 40$ ksi $= 40\times10^3$ psi
Shear Strength $= 30$ ksi $= 30\times10^3$ psi
Endurance Strength $= 14$ ksi $= 14\times10^3$ psi
} Mott MEMD Pg 734

Max force experienced by set rings = linear force generated by Makita

Makita max force:

$$T_u = \frac{FL}{2\pi e}$$

$$F = \frac{T_u 2\pi e}{L} = \frac{(\overset{\text{given}}{1420\,\text{lb in}})\,2\pi(0.9)}{0.203\ \text{in/rev}} \Rightarrow \boxed{F = 39556\text{lb}}$$



Major dia = D
Minor dia = d

Set ring depth:

$$\tau = \frac{V}{A} = \frac{V}{\pi d x} \Rightarrow x = \frac{V}{\pi d \tau}$$

$$= \frac{39556\text{lb}}{\pi(1.625\text{in})(30000\ \text{lb/in}^2)} = \boxed{x = 0.2583\text{in} \downarrow \text{use } 5/16}$$

Measured from actual tube

Assumptions; Shear pin does not fail
epoxy holds
Makita limit switch doesn't activate

Dimensions of the rings are as follows:

OD = 1.7500 in
ID = 1.640 in
Length = 5/16 = 0.3125 in

Erich Heilman | Set Rings | 1-25-16 | 2/2

Clearance Fits for Set rings

OD = 1.7500 in
ID = 1.6400 in ← Clearance
Length = 5/16 in = 0.3125 in

Actual Tube Dimensions
OD = ~~1.617~~ 1.625 + 12 in
~~1.614~~ 1.625 + 12 in
~~1.611~~ 1.625 + 16 in
~~1.616~~ 1.625 × 16 in

ID = 1.5001 in
1.5002 in
1.501 in
1.502 in

Measured Tube Dimensions:

OD = 1.640 in
ID = 1.500 in

RC2 For ring ID => Hole tolerance is -.04 thous.
-0.8

ID = 1.6406

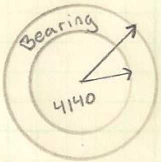
FN1 for ring depth => OD tol = +1.0
+1.4

Blade Housing toler: +0.6

Final Dims on ring

OD: 1.750 − 0.005 in
ID: 1.640 $-^{0.0004}_{0.0008}$
Length: 0.3125 + 0.001
+ 0.0014

Part Fits



Fitting the thrust bearing to the machined lead screw

FN1.

$\alpha_{4140} = 6.2 \times 10^{-6}$ in/in·F

Mott pg. 496

-100°F

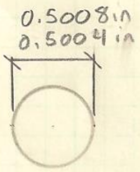
Measured ID of bearing = [0.5000 + 0.0040 in] ← hole already meets FN1 Fit limits

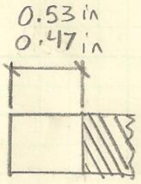
Nominal Diameter of 4140 HT rod = 0.5000 in

FN1 Force Fit [OD = 0.5000in + 0.0008]

[OD of 4140 Screw = 0.5000 in + 0.0008in]

[Depth of turning op = 0.50 ± 0.0300in]





Erich Heilman | MET 495 | 2-23-16 | 1/1

Shrink Fits

Aluminum 6061 α: 13.0×10^{-6} in/in°F T 13-5 pg 496
Steel 4140 α: 6.2×10^{-6} in/in°F
↓
Mott

Ring #1 Dims:
OD = 1.748 in – 1.746
ID = 1.642 in

Ring #2 Dims:
OD = 1.748 in
ID = 1.641 in

Ring #3 Dims:
OD = 1.750 in
ID = 1.644 in

$$\delta = \alpha L(\Delta t) \Rightarrow \Delta t = \frac{\delta}{\alpha L} = \frac{0.005\text{in}}{(13.0\times10^{-6}\ \text{in/in°F})(1.643\ \text{in})} \Rightarrow \Delta t = 234\text{°F}$$

$$T_{Final} = T_{amb} + \Delta t = 68\text{°F} + 234\text{°F} \Rightarrow \boxed{T = 302\text{°F}}$$

Length, L (in)	36
Modulus of Elasticity, E (msi)	34
Outer Diameter, OD (in)	1.630
Inner Diameter, ID (in)	1.500
End Fixity Constant, K	0.8

Rock West Options	Modulus (msi)
Standard	34
Intermediate	42
High	57
Higher	66
Ultra High	94

-------Key-------

Input
Notes
Output

Bending Stress = Mc/I

Variation	Weight (lb)	Stress (PSI)
+20%	234.6	70230
+15%	224.8	67304
+10%	215.1	64378
+5%	205.3	61451
Average	195.5	58525
-5%	185.7	55599
-10%	176.0	52673
-15%	166.2	49746
-20%	156.4	46820
Custom	0	0

Torsional Stress = Tc/J

Variation	Torque (lb*in)	Stress (PSI)
+20%	864	3592
+15%	828	3443
+10%	792	3293
+5%	756	3143
Average	720	2994
-5%	684	2844
-10%	648	2694
-15%	612	2545
-20%	576	2395
Custom	0	0

Bending Deflection = PL^3/3EI

Variation	Weight (lb)	Deflection (in)
+20%	234.6	1.0949
+15%	224.8	1.0493
+10%	215.1	1.0036
+5%	205.3	0.9580
Average	195.5	0.9124
-5%	185.7	0.8668
-10%	176.0	0.8212
-15%	166.2	0.7755
-20%	156.4	0.7299
Custom	0	0.0000

Torsional Deflection = TL/GK

Variation	Torque (lb*in)	Deflection (in)
+20%	1.2	4
+15%	1.15	3
+10%	1.1	3
+5%	1.05	3
Average	1	3
-5%	0.95	3
-10%	0.9	3
-15%	0.85	3
-20%	0.8	2
Custom	0	0

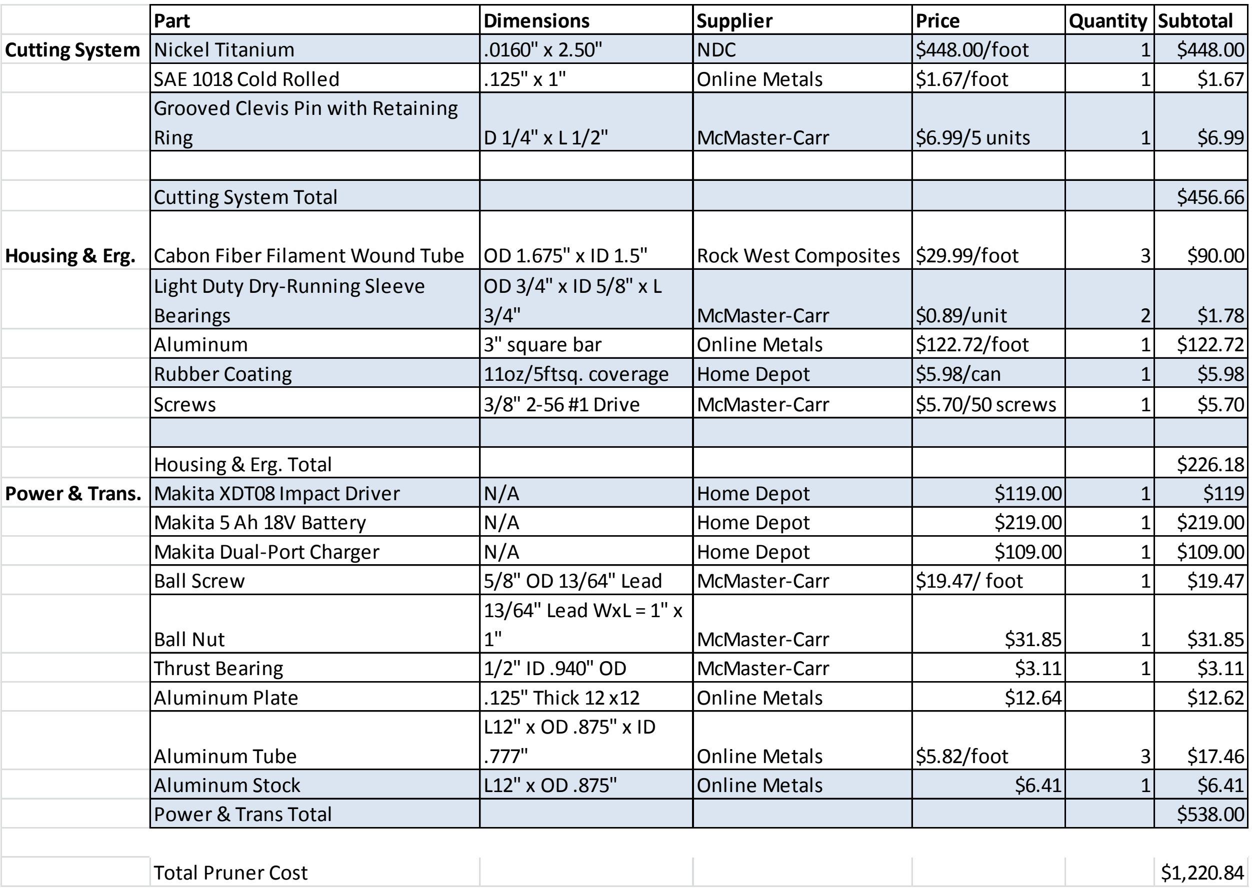
Critical Buckling Load = PI^2EA/(Le/r)^2

Critical Load, Pcr	39651
Assumed Long Column	

Appendix B – Drawings

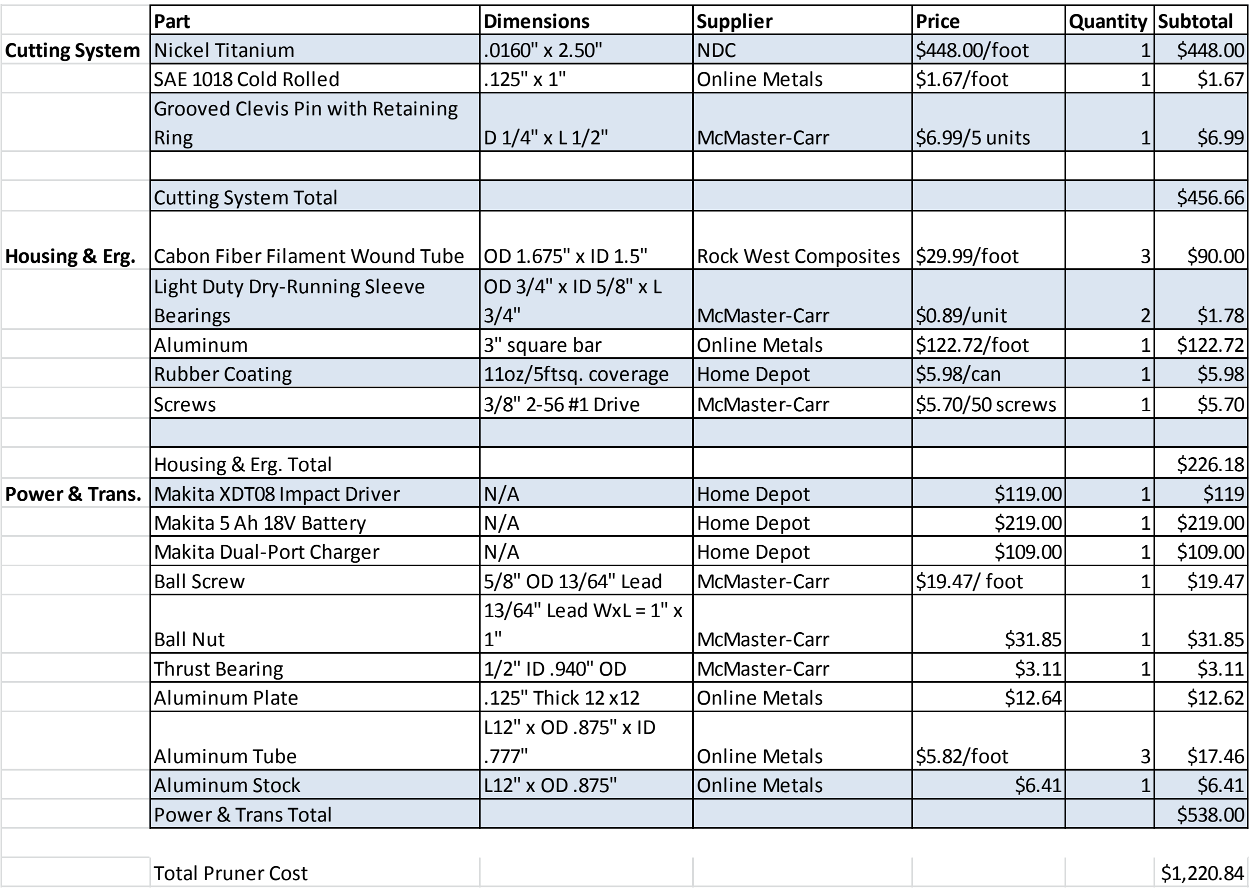
REMOVED

Appendix C – Parts List



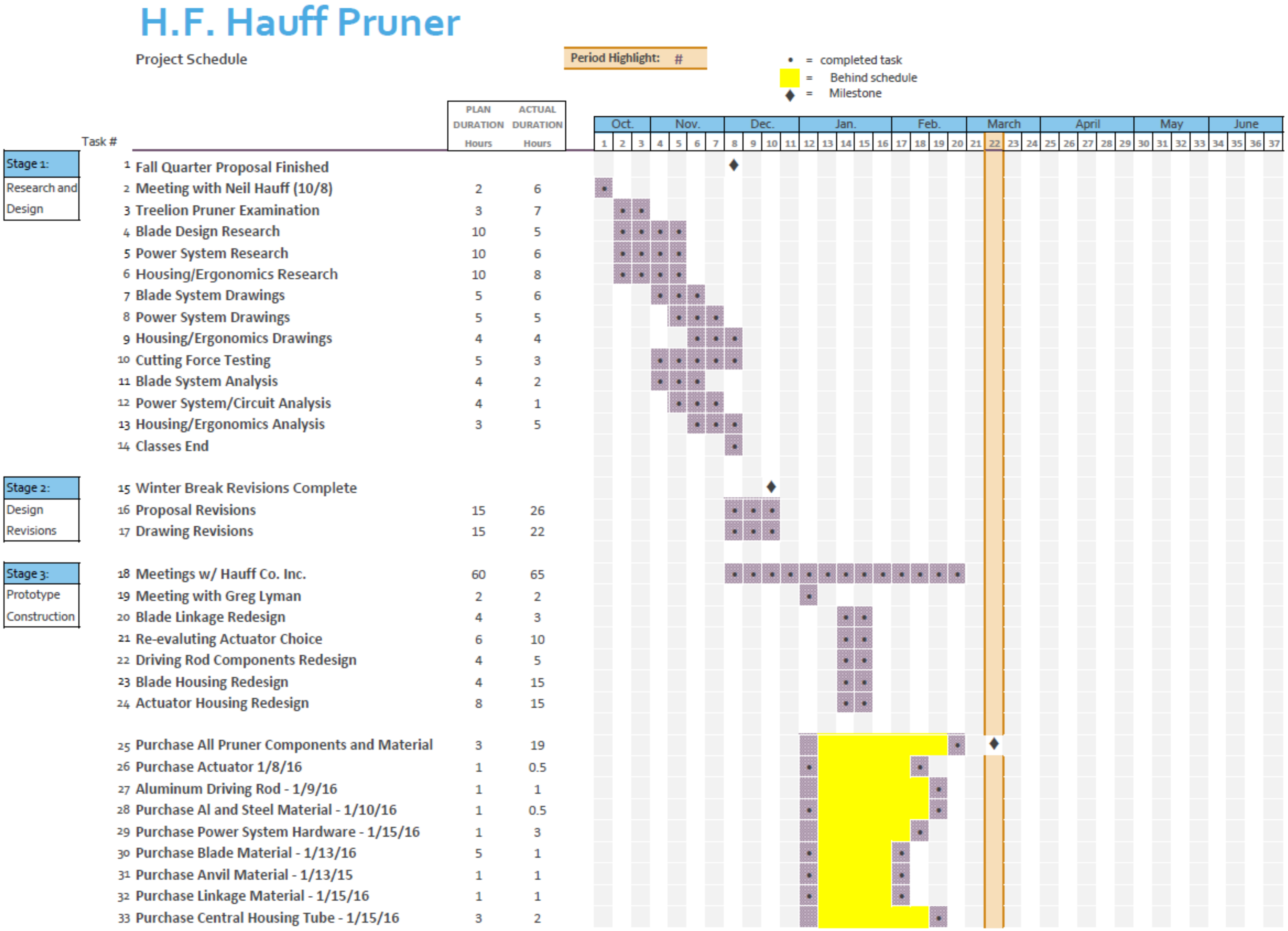
	Part	Dimensions	Supplier	Price	Quantity	Subtotal
Cutting System	Nickel Titanium	.0160" x 2.50"	NDC	$448.00/foot	1	$448.00
	SAE 1018 Cold Rolled	.125" x 1"	Online Metals	$1.67/foot	1	$1.67
	Grooved Clevis Pin with Retaining Ring	D 1/4" x L 1/2"	McMaster-Carr	$6.99/5 units	1	$6.99
	Cutting System Total					$456.66
Housing & Erg.	Cabon Fiber Filament Wound Tube	OD 1.675" x ID 1.5"	Rock West Composites	$29.99/foot	3	$90.00
	Light Duty Dry-Running Sleeve Bearings	OD 3/4" x ID 5/8" x L 3/4"	McMaster-Carr	$0.89/unit	2	$1.78
	Aluminum	3" square bar	Online Metals	$122.72/foot	1	$122.72
	Rubber Coating	11oz/5ftsq. coverage	Home Depot	$5.98/can	1	$5.98
	Screws	3/8" 2-56 #1 Drive	McMaster-Carr	$5.70/50 screws	1	$5.70
	Housing & Erg. Total					$226.18
Power & Trans.	Makita XDT08 Impact Driver	N/A	Home Depot	$119.00	1	$119
	Makita 5 Ah 18V Battery	N/A	Home Depot	$219.00	1	$219.00
	Makita Dual-Port Charger	N/A	Home Depot	$109.00	1	$109.00
	Ball Screw	5/8" OD 13/64" Lead	McMaster-Carr	$19.47/ foot	1	$19.47
	Ball Nut	13/64" Lead WxL = 1" x 1"	McMaster-Carr	$31.85	1	$31.85
	Thrust Bearing	1/2" ID .940" OD	McMaster-Carr	$3.11	1	$3.11
	Aluminum Plate	.125" Thick 12 x12	Online Metals	$12.64		$12.62
	Aluminum Tube	L12" x OD .875" x ID .777"	Online Metals	$5.82/foot	3	$17.46
	Aluminum Stock	L12" x OD .875"	Online Metals	$6.41	1	$6.41
	Power & Trans Total					$538.00
	Total Pruner Cost					$1,220.84

Appendix D – Budget



	Part	Dimensions	Supplier	Price	Quantity	Subtotal
Cutting System	Nickel Titanium	.0160" x 2.50"	NDC	$448.00/foot	1	$448.00
	SAE 1018 Cold Rolled	.125" x 1"	Online Metals	$1.67/foot	1	$1.67
	Grooved Clevis Pin with Retaining Ring	D 1/4" x L 1/2"	McMaster-Carr	$6.99/5 units	1	$6.99
	Cutting System Total					$456.66
Housing & Erg.	Cabon Fiber Filament Wound Tube	OD 1.675" x ID 1.5"	Rock West Composites	$29.99/foot	3	$90.00
	Light Duty Dry-Running Sleeve Bearings	OD 3/4" x ID 5/8" x L 3/4"	McMaster-Carr	$0.89/unit	2	$1.78
	Aluminum	3" square bar	Online Metals	$122.72/foot	1	$122.72
	Rubber Coating	11oz/5ftsq. coverage	Home Depot	$5.98/can	1	$5.98
	Screws	3/8" 2-56 #1 Drive	McMaster-Carr	$5.70/50 screws	1	$5.70
	Housing & Erg. Total					$226.18
Power & Trans.	Makita XDT08 Impact Driver	N/A	Home Depot	$119.00	1	$119
	Makita 5 Ah 18V Battery	N/A	Home Depot	$219.00	1	$219.00
	Makita Dual-Port Charger	N/A	Home Depot	$109.00	1	$109.00
	Ball Screw	5/8" OD 13/64" Lead	McMaster-Carr	$19.47/ foot	1	$19.47
	Ball Nut	13/64" Lead WxL = 1" x 1"	McMaster-Carr	$31.85	1	$31.85
	Thrust Bearing	1/2" ID .940" OD	McMaster-Carr	$3.11	1	$3.11
	Aluminum Plate	.125" Thick 12 x12	Online Metals	$12.64		$12.62
	Aluminum Tube	L12" x OD .875" x ID .777"	Online Metals	$5.82/foot	3	$17.46
	Aluminum Stock	L12" x OD .875"	Online Metals	$6.41	1	$6.41
	Power & Trans Total					$538.00
	Total Pruner Cost					$1,220.84

Appendix E – Schedule



H.F. Hauff Pruner

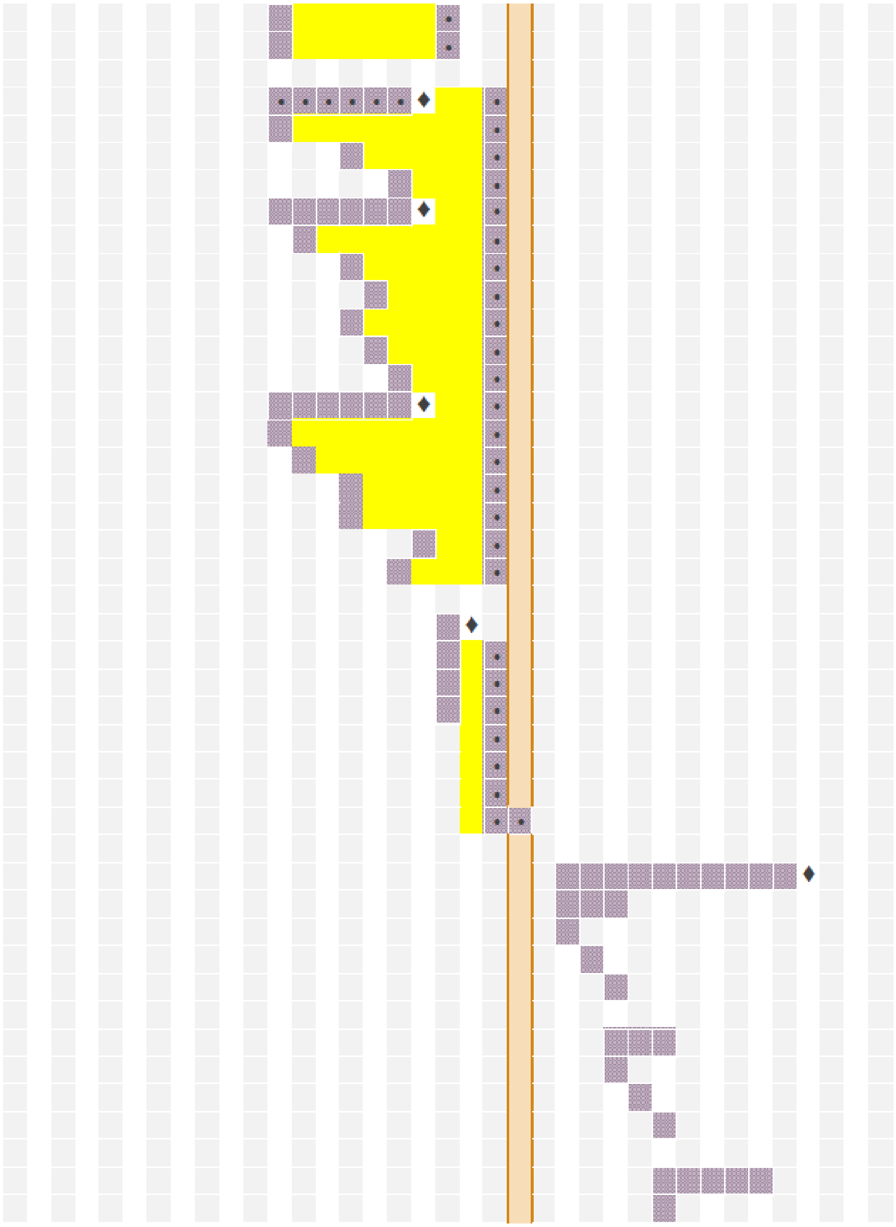
Project Schedule

Period Highlight: #

● = completed task
🟨 = Behind schedule
◆ = Milestone

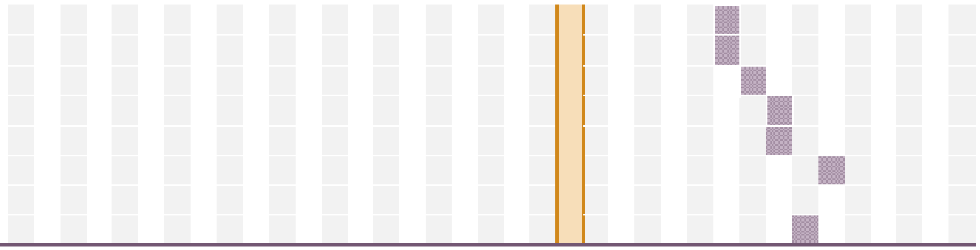
	Task #		PLAN DURATION Hours	ACTUAL DURATION Hours
Stage 1: Research and Design	1	Fall Quarter Proposal Finished		
	2	Meeting with Neil Hauff (10/8)	2	6
	3	Treelion Pruner Examination	3	7
	4	Blade Design Research	10	5
	5	Power System Research	10	6
	6	Housing/Ergonomics Research	10	8
	7	Blade System Drawings	5	6
	8	Power System Drawings	5	5
	9	Housing/Ergonomics Drawings	4	4
	10	Cutting Force Testing	5	3
	11	Blade System Analysis	4	2
	12	Power System/Circuit Analysis	4	1
	13	Housing/Ergonomics Analysis	3	5
	14	Classes End		
Stage 2: Design Revisions	15	Winter Break Revisions Complete		
	16	Proposal Revisions	15	26
	17	Drawing Revisions	15	22
Stage 3: Prototype Construction	18	Meetings w/ Hauff Co. Inc.	60	65
	19	Meeting with Greg Lyman	2	2
	20	Blade Linkage Redesign	4	3
	21	Re-evaluting Actuator Choice	6	10
	22	Driving Rod Components Redesign	4	5
	23	Blade Housing Redesign	4	15
	24	Actuator Housing Redesign	8	15
	25	Purchase All Pruner Components and Material	3	19
	26	Purchase Actuator 1/8/16	1	0.5
	27	Aluminum Driving Rod - 1/9/16	1	1
	28	Purchase Al and Steel Material - 1/10/16	1	0.5
	29	Purchase Power System Hardware - 1/15/16	1	3
	30	Purchase Blade Material - 1/13/16	5	1
	31	Purchase Anvil Material - 1/13/15	1	1
	32	Purchase Linkage Material - 1/15/16	1	1
	33	Purchase Central Housing Tube - 1/15/16	3	2

	34	Purchase Aluminum Housing Material - 1/15/16	1	2
	35	Purchase Hardware for Pruner Assembly - 1/15/:	1	4
	36	Blade System Fabrication - Completed 2/12/16	15	
	37	Blade Laser Cutting - 1/11/16	3	4
	38	Anvil Laser Cutting - 1/22/16	3	4
	39	Linkage Laser Cutting - 2/3/16	3	4
	40	Housing Fabrication - Completed 2/12/16	1	
	41	Makita Housing - Left CNC - 1/18/16	15	6
	42	Makita Housing - Right CNC - 1/22/16	15	6
	43	Central Housing - Cut to OAL - 2/4/16	0.5	1
	44	Blade Housing - Anvil Holding CNC - 1/23/16	3	10
	45	Blade Housing - Enclosure CNC - 1/28/16	3	15
	46	Ball Screw modifications - 2/4/16	0.5	6
	47	Power Transmission Fabrication - 2/12/16	10	
	48	Driving Rod - Cut OAL - 1/7/16	0.5	1
	49	Driving Rod - Drill Pin Holes - 1/14/16	2	1
	50	Blade End Collar - CNC - 1/28/16	2	3
	51	Actuator End Collar - CNC - 1/28/16	2	1
	52	Driving Rod Linkages - Drill Pin Holes - 2/11/16	3	2
	53	Driving Rod Linkages - Bend Faces - 2/5/16	3	2
	53	Prototype Assembly - Completed 2/26/16		
	54	Attach Grip Housing to Actuator	4	1
	55	Assemble Grip Housings to Central Housings	4	2
	56	Clamp Main Blade Housing to Central Housing	3	1
	57	Assemble Cutting System Blade/Anvil/Linkage	2	1
	58	Attach Removable Hatch to Main Blade Housing	3	1
	59	Assemble Grip Housings to Central Housings	1	1
	60	Troubleshooting	20	
Stage 4: Testing & Evaluation	61	Pruner Testing/ Evaluation Complete		
	62	Power System Testing	15	
	63	Maximum Branch Testing		
	64	Actuator Endurance Testing		
	65	Shear Pin Testing		
	66	Blade System Testing		
	67	Blade + Anvil Branch Cutting Test	15	
	68	Stress Testing Linkage	15	
	69	Shear Pin Testing	30	
	70	Housing Testing		
	71	Central Housing Deflection Testing		



72 Central Housing Buckling Testing
73 Central Housing Torsion Testing
74 Grip Housing Mounting Pin Shear Testing
75 Blade Housing Material Corrosion Testing
76 Grip Housing Heat Transfer Testing
77 Trigger Pull Force Testing

88 Source Presentation - 5/18/16



Appendix F – Expertise and Resources

This project wouldn’t have been possible without the help of Central Washington University staff including but not limited to: Matt Burvee, Tedman Bramble, Grey Lyman, Roger Beardsley, Charles Pringle, Jose Bajar, Andrew Kastning, Trevor Reher, Dr. Craig Johnson and Kevin “The Bushing Guy”

The help of Neil Hauff and Casey MacFarlane was integral in making this pruner the success that it was.

A special thank you goes out to all of the teams friends and families for their support through this seemingly endless endeavor.

Appendix G – Testing Data

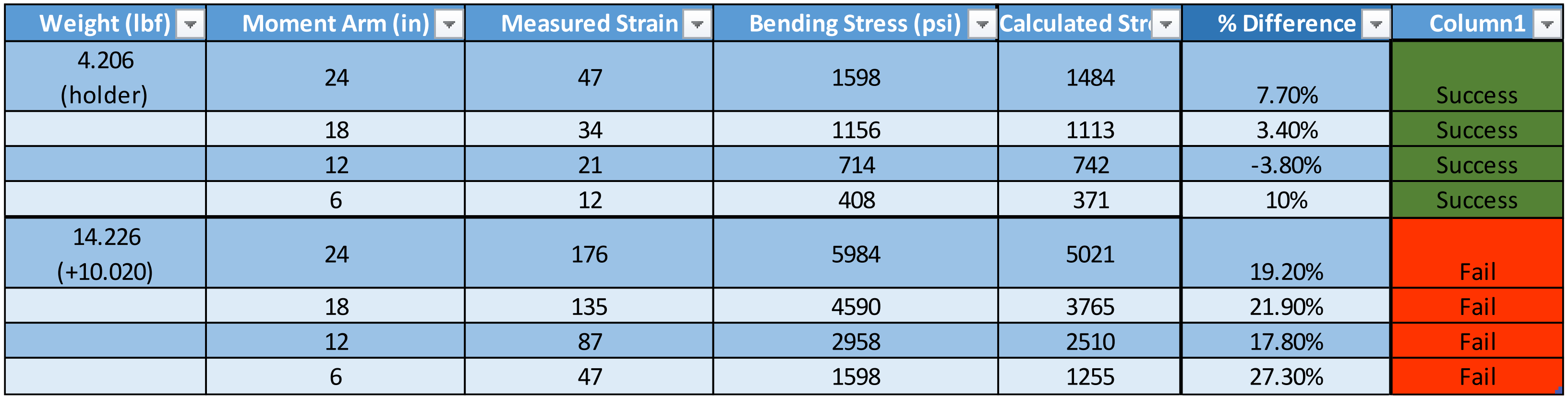
Trial Number	Assembly Time
1	4min 56sec
2	8min 12sec
3	4min 3sec
4	3min 59sec
5	4min 44sec
Avg. Time	5min 11sec

Part	Price
Carbon Fiber Tube	$120.00
6061T6 Aluminum	$122.72
3D Printing Matls.	$87.94
Nuts/Bolts/Washers	$17.88
Total	$348.54

Part	Weight
Blade Housing	0.987lb
Central Housing	0.312lb
Makita Housing	0.254lb
Total	1.553lb

Central Housing Bending Test	Total Weight Test	Assembly Test	Total Cost Test
Strain Gauges	Scale	Housing Components	Reciepts for pieces and parts
Scotch Tape	Note Taking Matls.	Stop Watch	Calculator
Techtronics Data Unit	Housing Components	Note Taking Matls.	Note Taking Matls.
Laptrop			
Safety Glasses			
CNC Mill work holding pieces			
Weight Sling			
Weights (increments of 10lb)			
Super Glue			

Appendix H – Evaluation Sheet



Weight (lbf)	Moment Arm (in)	Measured Strain	Bending Stress (psi)	Calculated Str	% Difference	Column1
4.206 (holder)	24	47	1598	1484	7.70%	Success
	18	34	1156	1113	3.40%	Success
	12	21	714	742	-3.80%	Success
	6	12	408	371	10%	Success
14.226 (+10.020)	24	176	5984	5021	19.20%	Fail
	18	135	4590	3765	21.90%	Fail
	12	87	2958	2510	17.80%	Fail
	6	47	1598	1255	27.30%	Fail

Appendix I – Testing Report

This section provides an example of a test procedure used in the testing of the central housing tube. This procedure provided accurate testing results and the 3 other tests followed procedures similar in detail to this one.

The test will take place in the machine shop at Central Washington University on April 11, 2016 and should take approximately 4 hours to complete.

Preparing the Carbon Fiber Tube

Wear safety glasses during the duration of this test.

1. Acquire carbon fiber central housing tube, 220 sand paper, rubbing alcohol, masking tape, 5 strain gauges, paper towels, latex safety gloves, super glue, pencil/marking utensil, ruler/tape mesure
2. Starting at one end of the tube, measure 6 inches from the end and sand a smooth surface to place a strain gauge (a 2” x 2” square will do) repeat this step for the entire length of the tube and be sure to mark the 6 inch increments with a horizontal line perpendicular to the tubes long axis.
3. Put on the latex safety gloves and apply enough rubbing alcohol to a section of paper towels to wipe away the carbon fiber residue from the sanding. The sanded surfaces are now cleaned for strain gauges. (Note: make sure the surfaces remain free of dust/debris)
4. Retrieve the strain gauges, super glue and masking tape (Note: safety glasses and gloves should still be on) coat the first 6 inch increment mark with a thin layer of super glue and place the strain gauge so that the lines on the strain gauge match the previously marked line in step 2.
5. Take a piece of masking tape approx. 3 inches long and place over the strain gauge. Press firmly on the strain gauge so that the glue between the gauge and the tube is squeezed out. Repeat steps 4 and 5 for the remaining 4 strain gauges. Allow super glue to cure.

Placing the Tube in the Testing Rig

Safety glasses should still be on, gloves can be removed

6. Acquire computer, Techtronics data unit, testing rig, pencil and paper (or other data recording equipment)
7. Using the ruler/tape measure mark 4 inches on the tube from the same starting end used in step 2. Place tube with strain gauges into the circular vice grip so that the 4 inch mark is aligned with the front of the vice face and the strain gauges are facing directly up. Tighten the vice so that the tube is secure in the vice.
8. Attach the strain gauge leads to the data unit and open the program. Start the program and firmly push down on the free end of the tube. There should be a response in the program. (Make sure the wires from the tube to the data unit have slack in them)

Applying Loads to the Tube

Safety glasses should still be on

9. Acquire 10 lb, 20 lb, 30 lb, 40 lb, 2-50 lb weights, weight sling, foam mat, note taking materials

10. Place the weight sling and 10 lb weight on the free end of the carbon fiber tube and record the readings reported by each strain gauge. Repeat this step and increase the weight by 10 lbs every time until 200 lbs is reached. Ex. 10 lb, record then 20 lb load, record, etc.. (See safety section now)

Risk/Safety

Safety glasses should be worn at all times in the event of tube failure, and protective cloves should be worn when noted in the procedure.

If at any point you observe cracking/tube failure (visual or audible) remove the weight and stop testing immediately. Note the weight at the end of the tube and values recorded by the strain gauges in the Techtronics software program. The purpose of this is to preserve the tube so the pruner can still be assembled.

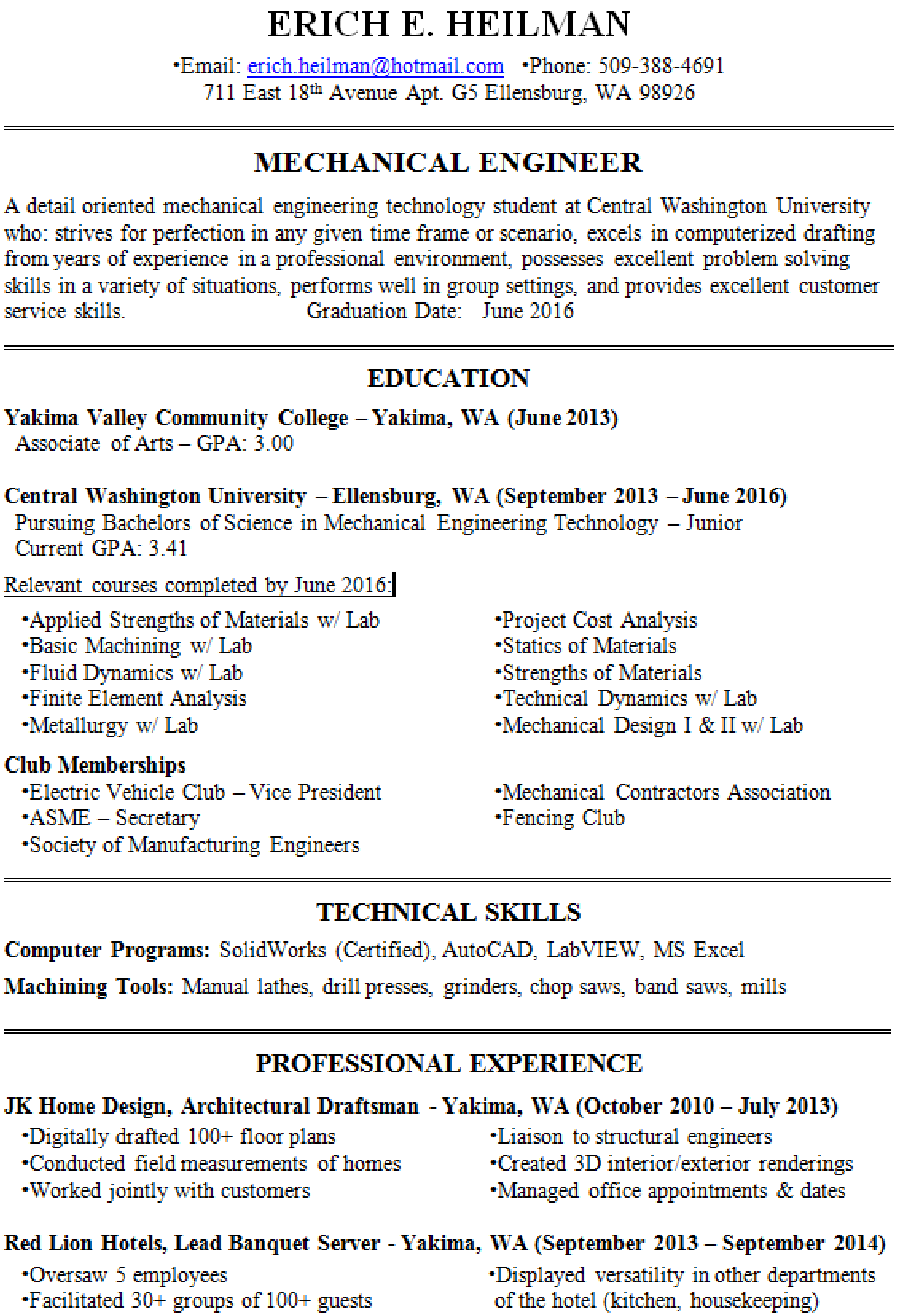
Data Evaluation

The Techtronics program will receive input from the strain gauge and run those numbers through calculations to output microstrain at the location of the gauge. The equations and tube dimensions have already been recorded and implemented in the program. These numbers will then be compared to the numbers calculated by the Central Housing Tube Combined Calculations spread sheet on page 28 of the engineering report.

Discussion

This test will provide excellent data if the procedure is followed correctly. The test is set up almost exactly like problems from engineering textbooks, so validating experimental calculations should be simple. The accuracy of those numbers depends largely on the individual taking measurements and marking the tube. The assumed load of 200 pounds is close to what the average weight of a male according to the CDC. The assumed max load scenario is one which the entire pruner product is rendered immovable while in duty (ex. the blade is stuck in a branch and can’t be shaken loose) and the operator hangs off the end of it.

Appendix J - Resume



ERICH E. HEILMAN

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711 East 18th Avenue Apt. G5 Ellensburg, WA 98926

MECHANICAL ENGINEER

A detail oriented mechanical engineering technology student at Central Washington University who: strives for perfection in any given time frame or scenario, excels in computerized drafting from years of experience in a professional environment, possesses excellent problem solving skills in a variety of situations, performs well in group settings, and provides excellent customer service skills. Graduation Date: June 2016

EDUCATION

Yakima Valley Community College – Yakima, WA (June 2013)
Associate of Arts – GPA: 3.00

Central Washington University – Ellensburg, WA (September 2013 – June 2016)
Pursuing Bachelors of Science in Mechanical Engineering Technology – Junior
Current GPA: 3.41

Relevant courses completed by June 2016:

- Applied Strengths of Materials w/ Lab
- Basic Machining w/ Lab
- Fluid Dynamics w/ Lab
- Finite Element Analysis
- Metallurgy w/ Lab
- Project Cost Analysis
- Statics of Materials
- Strengths of Materials
- Technical Dynamics w/ Lab
- Mechanical Design I & II w/ Lab

Club Memberships

- Electric Vehicle Club – Vice President
- ASME – Secretary
- Society of Manufacturing Engineers
- Mechanical Contractors Association
- Fencing Club

TECHNICAL SKILLS

Computer Programs: SolidWorks (Certified), AutoCAD, LabVIEW, MS Excel

Machining Tools: Manual lathes, drill presses, grinders, chop saws, band saws, mills

PROFESSIONAL EXPERIENCE

JK Home Design, Architectural Draftsman - Yakima, WA (October 2010 – July 2013)

- Digitally drafted 100+ floor plans
- Conducted field measurements of homes
- Worked jointly with customers
- Liaison to structural engineers
- Created 3D interior/exterior renderings
- Managed office appointments & dates

Red Lion Hotels, Lead Banquet Server - Yakima, WA (September 2013 – September 2014)

- Oversaw 5 employees
- Facilitated 30+ groups of 100+ guests
- Displayed versatility in other departments of the hotel (kitchen, housekeeping)