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H.F. Hauff Pruner Cutting System

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H.F. Hauff Pruner: Cutting System

Daniel Gibson

Partners:
Erich Heilman - Housing and Ergonomics
Thomas Wilson - Power and Transmission
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INTRODUCTION

Motivation
Founded in 1947, H.F. Hauff Company Inc. of Yakima, Washington has been a nation-wide manufacturer and distributor of specialized agricultural equipment. The company is constantly striving to provide quality, dependable products using innovative technological advancements and the highest engineering standards. The company’s president, Neil Hauff, is the driver behind this innovation. Neil’s efforts towards perfection and customer satisfaction are the motivation behind this project.

Neil Hauff was approached by a Greek organic orchardist, Emmanuel Maniadakis. Emmanuel approached Neil with his Pellenc Treelion D45-900 battery-powered pruner and he explained the issues he has with the current design.

After operating for a long time, the linear actuator which provides cutting force becomes too hot for the operator to hold the housing surrounding the actuator, 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 after pruning for a long time. Emmanuel would prefer a four-finger trigger (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. Emmanuel needs a cut to be made by only pressing the trigger once, momentarily.

The new design will eliminate the heat issue with the current pruner actuator and housing. The new design will also have a longer reach. The single-finger trigger system will be replaced with a new trigger system that is more comfortable for the operator and easier to operate with gloves. For the new design, a cut will be made by pressing the trigger once, momentarily. However, Emmanuel is satisfied with the current power supply system, a 44 V DC battery belt.

Function Statement
Function statement #1 applies to the new pruner design in its entirety. Function statement #2 applies to the cutting system of the new pruner design.

1. **H.F. Hauff Pruner (Entire Pruner):**
   - A device is needed which can cut branches all day without overheating.

2. **H.F. Hauff Pruner: Cutting System:**
   - A device is needed cut through apple tree branches, such as those found in an apple orchard.
**Design Requirements**
The design requirements for the pruner, as a whole, are as follows:

- The power system must use a 44 V DC power supply (as per customer)
- The power system must be able to supply a force to the pruner blade which can cut at minimum a 1.60-in diameter branch.
- The weight of all power system components must be no greater than 7 lbs.
- The power system components must be able to fit inside a 1.60-in inner-diameter housing.
- At least 50% of the power system components’ weight must be positioned directly over the trigger system for ergonomic balance.
- When the power system is operating at a pruning rate of 250 1.60-in diameter branches/ hour, the components must not exceed a temperature of 110 degrees F.
- The pruner power system must provide at least 450 lbs of force to the pruner blade.
- The cutting power system must supply cutting force for 6 hours when pruning at a rate of 300 1.60-in diameter branches/ hour.
- After a cut is initiated by the operator, the cut cycle must be no longer than 2.0 seconds. (as per customer)
- The cut cycle must be initiated by a single, momentary pull of the trigger. (as per customer)
- The trigger must be designed so 4 fingers are used to operate it. (Hand trigger) (as per customer)
- The cost of all power system components must be no greater than $500.

The design requirements for the cutting system of the pruner are as follows:

- As requested by the customer, the cutting system must employ a blade and anvil assembly - as found on manual tree loppers.
- The blade must cut through a branch with a maximum diameter of 1.60 inches.
- As requested by the customer, the blade and anvil must be made of nickel titanium (nitinol).
- The blade and anvil must have a geometry capable of producing the maximum shear at the branch’s maximum width.
- The cutting system must be capable of disassembly in less than three minutes with a common size screw driver.
- The cutting system must weigh less than 3 pounds.
- The cutting system must not exceed, in any position of the cutting cycle, the boundaries of a 6-in x 6-in x 6-in cube.
- As requested by the customer, the blade and anvil geometry is to be based on the design found on the Fiskars PowerGear manual tree lopper.
**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 a 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. For the cutting system, it is most important that it produces enough shear to cut through the branch. This is to be achieved through linkages and geometry of the blade and anvil. To determine the amount of shear force the blade can produce, the equation \( F = \tau_{ult} A \) (\( \tau_{ult} \) is the ultimate shear strength of the branch and \( A \) is the cross-sectional area of the blade edge) is utilized.

**Scope of Effort**
The scope of this document is focused on the cutting system of the automated tree pruner for the H.F. Hauff Company. Effort is mostly directed towards the geometry of the blade and the mating anvil. This is for two reasons: 1) The geometry determines how well a branch can be cut - with a blade shaped to generate an asymmetric shear and an anvil shaped to prevent the branch from sliding out of the cut; and 2) With a specified material desired by the customer, it is possible to know exactly how much a certain volume of material will cost.

**Success Criteria**
The cutting system for the pruner will be successful if it cuts through branches with diameter of at least 1.750 inches, if the blades retain sharpness for at least 700 hours of continuous operation, and if it cuts through the entire thickness of the branch in one cutting cycle.

### DESIGN & ANALYSIS

**Approach**
While the main issue of this project is to have a device to cut through a branch in one cutting cycle, the first step is to have a branch be able to fit into that device.

**Design Description**
The design of the cutting system fuses the linkage-rod power transmission of the Treelion pruner with the blade and anvil geometry of the Fiskars PowerGear. The minimal use of linkages in the Treelion allows for a more compact shape. The “hooked” anvil shape of the Fiskars prevents the branch from slipping out of the cut, reducing the need to “push” the pruner into the branch to finish the cut.
The original intention was to design a blade and anvil from scratch. This decision was made so that the geometry could be customized to fulfill the objectives of this project. For the blade, a simple rectangular shape with a slight curve for a blade edge served as the foundation for the design. Through testing and calculations, the curve could be optimized through linearly offsetting. The anvil has a hook-like shape to prevent the branch from slipping out of the cut. The result of this process is shown in Figure 1, which shows the cutting system open and closed with a 1.60-in circle as reference for the branch.

![Figure 1](image1.png)

An idea to add to the design in Figure 1 was to create a four-bar linkage, in hopes to amplify the force of the actuator. This idea was abandoned due to the amount of space required to fit the four-bar linkage. After encountering complications with the custom blade geometry (not getting the right clearance to fit a tree branch or not cutting through the entire branch), it was decided to take the blade and anvil from a consumer tree lopper. This way, the electric pruner would utilize a proven blade and anvil geometry. The result of this effort is shown in Figure 2.

![Figure 2](image2.png)

**Benchmark**
The benchmark for this project is a French-made electric tree pruner (Pellenc Treelion D45-900) that is currently in production for similar applications. This tree pruner is powered by an electric, linear actuator which drives a rod which pulls the blade into the anvil. To cut a 1.60-in diameter branch, the Treelion requires multiple cutting cycles. Since the desired operation is to cut through a branch in one cycle, the blade and anvil geometry of the Treelion is discarded in favor of a new design.
**Performance Predictions**
The cutting system is designed to operate with an electric linear actuator which supplies 600 pounds of force. This will allow the blade to cut through the widest portion of the 1.50-inch diameter branch. Should failure occur, it will be at the pin holding the blade to the anvil. The situation that would cause this is if the blade is unable to cut through a particular branch, causing a high load from the actuator and a high reaction from the branch to shear the pin.

**Description of Analysis**
The analyses performed are stress calculations of the blade, anvil, linkages, and pins to be sure the dimensions to not allow for yield at the designated design factor.

**Scope of Testing and Evaluation**
Testing and evaluation of the cutting system consists of placing the blade and anvil in a jig and placed in a tensile tester. This allows for testing of the amount of force required to cut through a 1.50-inch diameter branch. The jig is also used to test the stress experienced in the linkages. For overall pruner testing, the cutting system is assembled to the full automated pruner and put through endurance tests to ensure the pruner operates for the required time amount.

**Analysis**
The green sheets mentioned are found in Appendix A.

Green Sheet A-1
This green sheet calculates the amount of force that is transferred from the driving rod to the branch. The 600 pound tensile load pulls on a pin, connected to a linkage pair, which pulls on another pin, connected to the blade, which rotates the blade to apply the load to the branch. This resulting force was found to be 635 pounds, which exceeds the 500 pound force required to cut through the branch.

Green Sheet A-2
This green sheet calculates the dimensions of the linkages and the two pins the linkages are held by. Using the various forces found from A-1 and the equation $\sigma = F / A$, it was found that AISI 1018 linkage would yield with a thickness of 0.014 inches. So a standard thickness of 1/8 inches was selected. The two pins (in double shear) used the equation $\tau = F / 2A$ to obtain yielding diameters of 0.10 inches. So the standard diameter of 1/4 inches was selected.

Green Sheet A-3
This green sheet calculates the diameter of the pin that holds the blade to the anvil. It is at this location in which the most stress is experienced if the pruner is unable to cut through an object.
Using the single shear equation of \( \tau = \frac{F}{A} \), the yielding diameter was determined to be 0.21 inches. So a standard diameter of 1/4 inches was selected. This is the location designed to fail should the pruner generate excessive loads when unable to cut through a branch.

**Device**
The device is a pruner blade and anvil which operate using a linear driving rod. This comes in direct association with the other two systems of the automated pruner: Housing/Ergonomics (driving rod) and Power/Transmission (cutting system housing and driving rod housing).

**Device Assembly**
The device consists of one blade, one anvil, two linkages, and three pins. The blade is pinned to the anvil to allow for blade rotation, while the anvil is held firmly in the cutting system housing. The linkages transmit the force from the driving rod to the blade, and they connect to each component with pins.

**Technical Risk Analysis, Failure Mode Analysis, Safety Factors, Operation Limits**
The cutting system is designed with a 1.5 safety factor. Should a branch require more than the 600 pounds of force delivered by the linear actuator, the blade will cease to cut through the branch. However, since the cutting system is the most easily accessible portion of the pruner and has inexpensive pins, the pin holding the blade to the anvil is designed to fail should excessive loads be experienced when unable to cut through a branch.

**METHODS & CONSTRUCTION**

**Construction**
The cutting system is to be manufactured in collaboration with the H.F. Hauff Company. Making use of their facilities, the three components of the cutting system will be made using a laser cutter. This operation will be used because the parts are very thin and the geometries would be difficult to produce using a CNC mill.

**Descriptions**
The main components of the cutting system are the blade and anvil. The design of these are based on the blade and anvil of a Fiskars PowerGear tree pruner. As such, the dimensions of the parts are fairly freeform and difficult to callout. The laser cutter has ease with producing these shapes based off of the cutting code programmed into it.
The minor component of the cutting system is the linkage pair. These would be simple to produce using even a manual mill, but the laser cutter expedites the manufacturing process and, if necessary, can produce a higher quantity at a quicker rate.

**Drawing Tree and Drawing ID’s**

The drawing tree, as seen in Appendix B, exhibits the three components of the cutting system as well as the parts required for the other two systems of the automated pruner. Labelling for the drawings of the cutting system are as such:

- C0: Exploded view of cutting system assembly with bill of materials
- C1: Blade Drawing
- C2: Anvil Drawing
- C3: Linkage Drawing
- B5: Blade Housing - Back
- B6: Blade Housing - Front

**Manufacturing Issues**

A variety of issues occurred when producing the required parts, starting when the partnered company dropped their manufacturing support. Over half of the way through the school term, the pruner team was left to machine the necessary parts.

Due to time constraints, the housing for the impact drill needed to be produced through additive manufacturing. Completing the two halves of the blade housing took two weeks. This was accomplished by generating the CNC programs with computer aided manufacturing (HSMWorks) and a CNC mill. There was a difficult period of trial-and-error to attain the correct tool feeds and spindle speeds because the type of aluminum was unknown. Since these housing parts were not designed by the correct team member (resulting in undesirable performance), they will need to be redone in the beginning weeks of the Spring term. Hopefully the CAD/CAM course will not require the CNC mills during this time so that the new parts can be machined. For the short term, small support members of aluminum have been welded to the blade housing.

The partnered company did produce a few parts: the blade, anvil, and linkage pair. This was done using their laser cutting table. Unfortunately, they were unable to acquire the nickel titanium material and used, instead, stainless steel. Testing will show if the material change is a detriment to the performance of the cutting action. The parts were produced to the correct dimensions, but the sharp edge on the blade was anything but. It was necessary to grind the edge down to improve results. The anvil was also given a ground edge to increase ease of cutting (the branch tries to wedge itself between the blade and anvil, bending the two components).
TESTING METHOD

Introduction
Testing is performed on the blade and anvil of the cutting system to ensure the 1.50-inch diameter branch is cut through at the desired force. This force occurs when the blade is cutting through the widest portion of the branch. The force at this moment is the highest force experienced by the cutting system and determines the type of linear actuator required. A test is performed on the linkages to ensure they do not yield under normal pruner operation. After this isolated testing, the cutting system will be assembled to the automated pruner for endurance testing.

Method / Approach
The idea for these tests is to seclude the cutting system from the rest of the automated pruner to isolate performance, and then to test the pruner in its fully assembled form. With the cutting system separated, it is possible to measure the force required to cut through a 1.50-inch branch using just the blade and anvil in a tensile tester. It is also possible to measure the force required to cause the pin, which holds the blade to the anvil, to fail. This is the intended failure location of the pruner should excessive loads be experienced when unable to cut through a branch. This location was selected because: 1) The pin already experiences the most stress in the pruner; and 2) The pin is easy and inexpensive to replace, should failure occur.

Test Procedure
To test the maximum cutting force required of a 1.50-inch diameter branch, the blade and anvil are attached to a jig and placed in a tensile tester. This allows for testing of the amount of force required to cut through a 1.50-inch diameter branch. The jig is also used to test the stress experienced in the linkages. For overall pruner testing, the cutting system is assembled to the full automated pruner and put through endurance tests to ensure the pruner operates for the required time amount.

BUDGET / SCHEDULE / PROJECT MANAGEMENT

Proposed Budget
The budget for the cutting system is roughly 500 U.S. dollars. This includes nickel titanium for the blade and anvil, AISI 1018 steel for the linkages, and grooved clevis pins to hold everything together. The nickel titanium is the most expensive of these items. As such, parts using this material receive extra attention in design to ensure that money is not wasted. The complete list of the automated pruner’s budget is located in Appendix D.
**Proposed Schedule**
The proposed schedule can be seen in the Gantt Chart of Appendix E.

**Project Management**
This project is managed by the Central Washington University Mechanical Engineering Technology students: Daniel Gibson, Erich Heilman, and Thomas Wilson. Supervision is provided by Neil Hauff and Casey McFarlen of the H.F. Hauff Company. Additional supervision is provided by Matt Burvee, Roger Beardsley, Greg Lyman, Charles Pringle, and Dr. Craig Johnson of Central Washington University.

**CONCLUSION**

The proposed design for the cutting system of the automated pruner - being produced under the supervision of the H.F. Hauff Company - will function as outlined in the requirements listed above. Given a load of 600 pounds by the actuator, the cutting system will be able to cut through apple orchard branches of at least 1.50 inches with minimal fatigue to the components of the system. The nickel titanium material of the blade increases durability - reducing the amount of grinding required to maintain sharpness. In the event an object placed into the cutting system exceeds the applicable cutting force, the pin holding the blade to the anvil will fail. This is the most reasonable outcome since this pin is less expensive than the other components of the cutting system and is easy to access and replace. The failure of this pin will reduce stress buildup or failure of the other components, allowing them continued use.

**ACKNOWLEDGEMENTS**

Neil Hauff, Casey McFarlen, Matt Burvee, Greg Lyman, Ted Bramble, Charles Pringle, Craig Johnson, Roger Beardsley, Darryl Fuhrman, Erich Heilman, Thomas Wilson, Martha Gibson, John Gibson, Gretchen Gibson, Jillian Gibson, Melanie Bell, Steven Linden, Carlos Bonilla, Antonia Simonis-Paul, Benoit Porte, Santiago Garcia, Roldan Guillen Jr., Frédéric Reaud, Valerie Harris, Paula Ferguson, William Fitzpatrick, Janice Park, Lazslo Lak, Derrick Acosta, Rocco Botte, Shawn Chatfield, Garrett Hunter, Eric Baudour, Kevin Buschong, Bryan Abou Chacra
Appendix A – Analyses

Given: A rod pulls with 600 lb on a linkage pair attached to a pivoting blade. The blade reacts on the branch at D. The angle configuration shown in the figure is where the normal force is required when cutting the branch. Pin F is fixed and the rod only moves on an x-axis.

Fixed: Force applied to branch
Dimensions of linkages
Dimensions of pins

Solve: Force applied to branch (F)

\[ F_{B} = F_{y} \]

1. \[ F_{x} = 600 \text{ lb} \]

2. \[ 2F_{x} = 0 \]
   \[ F_{x2} = 573,7829 \text{ lb} \rightarrow \]
   \[ F_{y2} = 175,7230 \text{ lb} \uparrow \]

3. \[ 2F_{x} = 0 \]
   \[ F_{x4} = 573,7829 \text{ lb} \sin(167) = 0 \]
   \[ F_{y4} = 551,3555 \text{ lb} \downarrow \]

4. \[ 2M_{C} = 0 \]
   \[ F_{y} (1.15 \text{ in}) + F_{y} (1.00 \text{ in}) = 0 \]
   \[ F_{y} = 634.7888 \text{ lb} \]

5. \[ F = 634 \text{ lb} \]
Linkage Dimensions

Choose AISI 1018 steel and design to yield strength ($f_y = 44,000$ psi)

Choose a height of $0.625$ in.

FBD - One Linkage

$s_y = \frac{44,000}{2} = 22,000$ psi

$A = \frac{E}{b}$

$A = \frac{F_b}{b}$

$E = \frac{1}{(1.5)(287.1)}$ $\times \frac{(0.625)^2}{22,000} = 0.01406$ in

Choose a standard thickness of $0.125$ in for the linkages. Consider using a cheaper material with a lower yield strength.

Pin Dimensions

Choose Clevis Pins

Choose AISI 1018 steel and design to yield strength ($f_y = 44,000$ psi)

Use a safety factor of 1.5

FBD

$\frac{F}{2}$

$\frac{F}{2}$

Pin A (Double Shear)

$T = \frac{F}{2}$

$S_y = \frac{22,000}{(1.5)(600)}$

$A = \frac{F}{3y}$

$D = \frac{2F}{(1.5)(600)}$

$d = \frac{D}{4(1.5)(600)}$

$d = 0.188$ in

Assume thicknesses of rod connection and blade are $0.15$ in.

$L = 2(0.125) + (0.15)$

$L = 0.40$ in

For both pin A and B, use a standard diameter of $0.25$ in and a usable length of $0.40$ in. Consider using a cheaper material.
Pin C (Single Shear)

\[ F_{\text{up}} = 0: \quad F_a \cos 12^\circ + F_b \cos 12^\circ - F_c = 0 \]
\[ F_c = \frac{(F_a + F_b) \cos 78^\circ}{(\cos 51.5^\circ) + (634.2898 \text{ in}) \cos 12^\circ} \]
\[ F_c = 1157.19 \text{ in} \]
\[ F_c = 1160 \text{ lb} \]

\[ \tau = \frac{F_c}{A} \]
\[ \tau = \frac{(1.5)(1160 \text{ lb})}{\frac{4\pi}{d^2}} \]
\[ d = \sqrt{\frac{4\pi}{\tau}} \]
\[ d = 0.27 \text{ in} \]

Assume thicknesses of blade and anvil are 0.15 in

\[ L = (0.15 + 0.15) \text{ in} \]
\[ L = 0.30 \text{ in} \]

For pin C, use a standard diameter of 0.25 in and a usable length of 0.30 in.
Rendering of Cutting System
## Appendix D – Budget

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<th>Part</th>
<th>Dimensions</th>
<th>Supplier</th>
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<th>Quantity</th>
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<td>Grooved Clevis Pin with Retaining Ring</td>
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<td>Light Duty Dry-Running Sleeve Bearings</td>
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<td>$1.99/ring</td>
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<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
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<td>$1,584.29</td>
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Appendix F – Testing Data
Appendix G - Résumé

DANIEL J. GIBSON
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PROFILE
I am currently pursuing a Post Baccalaureate degree in Mechanical Engineering Technology at Central Washington University in Ellensburg, Washington. I am seeking employment in Mechanical / Manufacturing Engineering or a related field.

EDUCATION
Central Washington University, Ellensburg, WA - BS in Mechanical Engineering Technology and Minor in Mathematics, Expected to Graduate June, 2016 (GPA 3.651)

Chapman University, Orange, CA - BM in Music Composition and Minor in German, Class of 2012 (GPA 3.300)

SKILLS & EXPERIENCE
- Internship with AMG - Aero Technologies (June - September 2015, Miami, FL): High Speed Pneumatic Flow Test Bench Design, Tool Design, Tooling Database Maintenance, and Drafting / Modeling

- Designed the cutting system of an electric-powered tree pruner as part of the CWU Engineering Senior Project for H.F. Hauff Co. Inc. (Yakima, WA) and received an Outstanding Presentation award for said project at CWU SOURCE 2016

- Proficient with SolidWorks (Associate Certification), AutoCAD, LabVIEW, Additive Manufacturing, and Computer Aided Manufacturing

- Proficient with Microsoft Office and Apple iWork

- Courses taken in Composites, Ceramics, Metallurgy, Lean Manufacturing, and Quality Control

- Experienced with manual machine tools, CNC machine tools, CNC programming, and welding

- Design and fabrication of a solar air-heating unit for UW's Environmental Innovation Challenge 2014

- Scheduled to take the Fundamentals of Engineering Exam in Summer 2016

- President of CWU Electric Vehicle Club (2014-15), Officer of CWU ASME and SME Clubs (2014-16), President of CWU Fencing Club (2015-16)

- Proficient in German

- Volunteer work with FIRST Lego League and VEX Robotics competitions and Assistance League of the Eastside (Redmond, WA)

- Proficient on various musical instruments; Performed violin in orchestras, operas, musicals, New Music ensembles, and Bluegrass groups

REFERRALS
Frédéric Reaud - Director of Engineering at AMG Aero Technologies (Miami, FL)

Charles Pringle, EIT - Assistant Professor of Mechanical Engineering Technology at Central Washington University

Contact information available upon request