Pin Router Duplicator

Daniel Phan
phand@cwu.edu

Follow this and additional works at: http://digitalcommons.cwu.edu/undergradproj

Part of the Applied Mechanics Commons, Computer-Aided Engineering and Design Commons, and the Manufacturing Commons

Recommended Citation
Aluminum Alloy; Metal; Nonferrous Metal” MatWeb, LLC. MatWeb. Web. 05 December 2016.
Pin Router Duplicator

(Router Head)

By

Daniel Phan

Partner:

Matt Tebo – Base Frame
Abstract:

The purpose of this project is to develop a pin router duplicator to accurately produce guitar bodies, necks, and fret boards. The pin router duplicator is designed to speed up the production process for the class Lean Manufacturing (MET 345), offered at Central Washington University. In the class, students learn how to work as a team to improve the way a woodshop is ran. In Lean Manufacturing, guitar bodies, necks, and fret boards are produced by using a CNC router. For this project, the motivation is to increase production by reducing production time. Accuracy and repeatability is also taken into consideration. With the use of the pin router duplicator, more than three guitar bodies will be produced in two hours, which will help with production goals. The methods that are used to arrive at the finished design are by using kinematics, stress, engineering, and static analysis. Free body diagrams, shear, and moment diagrams were used to calculate the reaction forces, in order to determine the appropriate thickness of the material. The final design that’s going to be used is a 4 bar linkage system. The final design resulted in relief of bottlenecks, which allows for increased production. By using these methods, the necessary components for the 4 bar linkage system are designed. As a result, the production process is faster by using the pin router duplicator compared to the CNC router.
# Table of Contents

**PIN ROUTER DUPLICATOR**  
1

**ABSTRACT:**  
2

**INTRODUCTION:**  
6

**MOTIVATION:**  
6

**FUNCTION STATEMENT:**  
6

**DESIGN REQUIREMENTS:**  
6

**ENGINEERING MERIT:**  
6

**SCOPE OF EFFORT:**  
7

**SUCCESS CRITERIA:**  
7

**DESIGN AND ANALYSIS:**  
7

**APPROACH:**  
7

**DESIGN DESCRIPTION:**  
8

**BENCHMARK:**  
8

**PERFORMANCE PREDICTIONS:**  
9

**DESCRIPTION OF ANALYSES:**  
9

**SCOPE OF TESTING & EVALUATION:**  
10

**ANALYSES:**  
10

1) **DESIGN ISSUE:**  
10

2) **CALCULATED PARAMETERS:**  
10

3) **BEST PRACTICES:**  
10

**DEVICE: PARTS, SHAPES, AND CONFORMATION:**  
11

**DEVICE ASSEMBLY AND ATTACHMENTS:**  
12

**TOLERANCES, KINEMATICS, AND ERGONOMICS:**  
12

**TECHNICAL RISK ANALYSIS, FAILURE MODE ANALYSES, & SAFETY FACTORS:**  
12

**METHODS AND CONSTRUCTION:**  
12

**DESCRIPTION:**  
12

**DRAWING TREE & DRAWING ID’S:**  
13

**PART LISTS AND LABELS:**  
13

**MANUFACTURING ISSUES:**  
13

**ASSEMBLY, SUB-ASSEMBLY, PARTS, & DRAWINGS:**  
14

**TESTING METHOD:**  
14

**INTRODUCTION:**  
14

**METHOD AND APPROACH:**  
14

**TEST PROCEDURES:**  
14

**DELIVERABLES:**  
15

**BUDGET/SCHEDULE/PROJECT MANAGEMENT:**  
15

**PROPOSED BUDGET:**  
15

**PROPOSED SCHEDULE:**  
15
APPENDIX E: SCHEDULE 41
APPENDIX F: EXPERTISE & RESOURCES 44
APPENDIX G: EVALUATION SHEET 45
APPENDIX H: TESTING REPORT 46
APPENDIX I: TESTING DATA 51
APPENDIX J: GANTT CHART 52
APPENDIX K: RÉSUMÉ 53
Introduction:

Motivation:

This project’s motive is a need for a pin router duplicator that will speed up the production process of guitar bodies, necks, fret boards, and get rid of bottlenecks.

Function Statement:

The Pin Router Duplicator:

- Must be able to accurately duplicate finished products
- Must be able to move in all 3 axes (X, Y, Z)

Pin Router Base Frame:

- Must be able to support the router head assembly

Design Requirements:

The duplicator as a whole must meet the following requirements:

- The duplicator must be able to trace finished products
- Duplicator must weigh less than 125lbs
- Must be easily manufactured
- Must not deflect more than .005” under a load of 10lbs
- Must cost less than $1000
- must be able to move at least 16inches in the X-Axis
- must be able to move at least 22inches in the Y-Axis

The router head must meet the following requirements:

- Pin router duplicator must have at least 6inches of travel in the Z-Axis
- Repeatability must be ±.001
- Positioning tolerance ±.005

Engineering Merit:

In order to make this device work efficiently, there will be several calculations. First, the plunging force needs to be determined to figure out how much force is being applied when making a cut. The structure of the router head needs to withstand shear stress that’s being applied on the linkage arms, so that the structure doesn’t bend or break. Secondly, the base frame must be able to withstand the weight of the router head, so it doesn’t collapse. To do this, the bending moment and shear force will be calculated to draw shear and moment diagrams. To determine the sizes of the linkage arms, base plate for the router, stylus mount, and linkage mounts, the moment of inertia needs to be determined. By using the deflection formula, the moment of inertia can be isolated and solved for. Then, by using the moment of inertia formula for rectangles, the necessary sizes will be determined. To determine what material to be used, the
deflection needs to be less than .005". Depending on the material that is chosen, the yield strength is to be considered in calculations. Additionally, the safety factor is 3 to determine the vertical movement in the design, kinematics will be analyzed.

Formulas:

Bending Moment = F x d
Where F is the force & d is the distance

\[ Y = \frac{-M}{6EI} \left[ \frac{6a-3a^2}{L-2L}x-x^3}{L} \right] \]
Where Y is the deflection
M = Bending moment
E = Young’s Modulus
I = Moment of Inertia
A = distance from the edge
L = length of the beam

Beam Deflection = \( \frac{PL^3}{3EI} \)
Where P is the plunging force
L = Length of the beam
E = Young’s Modulus
I = Moment of Inertia

Scope of Effort:

The components that will be designed are the base frame and the router head that holds the router, stylus, stylus mount, base plate for router, two plates and a spring for counterbalance. The router (2.25hp) will be provided from Central Washington University. The shafts, rods, plates, base plate for the router, mount for stylus, linkage arms, and linkage mounts can be purchased from OnlineMetals.com. Whereas, fasteners can be purchased from a hardware store. The components can also be obtained by the school. Once the necessary components are attained, then the pin router duplicator will be assembled by using hand tools such as: screwdrivers, wrenches, and hammers. However, some hand tools might be purchased to best fit the initial design.

Success Criteria:

The success of this project is dependent on the accuracy of the pin router duplicator when it cuts a guitar body, neck, and fret boards. In addition, there are hand tools that are provided by Central Washington University, which will help with the assembly of the system. Once the pin router duplicator is assembled, then the project would be deemed successful if the duplicator can meet the requirements for repeatability and positioning tolerance. Additionally, safety is paramount.

Design and Analysis:

Approach:
In order for the pin router duplicator to work efficiently, there needs to be a router and a stylus that move along three axes (X, Y, Z). To do so, the stylus will be secured in the stylus mount with a set screw, located to the right of the router. On the other hand, the router will be secured in a housing that’s bolted to a base plate. The duplicator should be as rigid as possible meaning that the two plates don’t deflect more than .005 inches. The pin router duplicator must be able to move horizontally at least 16 inches to accommodate for the average body width of a guitar, which is approximately 12-16 inches.

Design Description:

The basic structure of the router head is going to be similar to a 4 bar linkage system. There will be two plates of equal length. Each plate will have 4 linkage mounts mounted to them with a total of 4 linkage arms connecting the two plates together. There will be a rod that runs through the linkage arms and linkage mount. The rod has two holes for clevis pins to be inserted. This will allow the linkage arms and linkage mounts to stay intact, which allows the router head to pivot. The router is going to be secured in a housing (provided by Central Washington University), which is going to be bolted down onto the base plate. The stylus is going to be mounted into the stylus mount with a set screw. The set screw allows the stylus to be adjusted for different depths of cut. The router and stylus will have at least 6 inches of travel to plunge into the woodwork in the Z-axis. The router and stylus will be able to move along the shaft in the X-axis. A guitar body blank is 16 inches. There will be two bodies on the platform. Between each body, the distance is 1 inch. The router and stylus will be 16” from each other, which will provide enough clearance, so that router and stylus won’t interfere with one another.

Benchmark:

An application where of a similar layout is the Terrco T-110 Dupli-Carver that’s manufactured by Terrco Inc. The weight of the whole structure is 37 lbs. When comparing to the initial design requirements, the whole frame cannot exceed 125 lbs. The router that’s used in the Dupli-Carver, usually runs at very high speeds, approximately 20,000-30,000 RPM. The router that’s going to be provided by Central Washington University is the DeWALT DW618 2 1/4HP operating at approximately 24,000 RPM. The cost of the duplicator is $350. The budget for this project is under $1000, so this allows some wiggle room to work with. The duplicator is going to be smaller and more cost efficient. The design of the T-110 Dupli-Carver differs from the initial design because there will be a router head that’s connected to the base frame. The router head will support the router, stylus, linkage arms, linkage mounts, and an extension spring.
Performance Predictions:

From the design calculations, the predicted performance of the router is that it’s going to sustain a plunging force of 15lbs. The router head will take approximately 15-20lbs of force to lift the router head from the woodwork. The 4 bar linkage system that holds the router and stylus won’t deflect more than .005 inches under a plunging force of 15lbs.

Description of Analyses:

The initial design was based on the following:
The analysis of the project will be designed around the requirements and ensuring that they meet the requirements. Making assumptions about the weight of the wood carving duplicator as a system, and estimated dimensions of the two plates, linkage arms, linkage mounts, stylus, and the mount for the stylus, allows for an analysis to be performed. Assuming the weight of the 4 bar linkage system is 25lbs, there will be an extension spring that can counterbalance the 25lbs. This will allow the 4 bar linkage system to move back into a neutral position for repeatability. With the goal of 6 inches of travel in the Z-Axis, a model will be developed in SolidWorks. Calculations for the moment of inertia will help determine how thick the mount for the stylus, and base plate for the router. Bending moment and shear force calculations are calculated to ensure that, under failure, the router head will remain intact with the base frame.
Scope of Testing & Evaluation:

The pin router duplicator will be tested in the wood lab at Central Washington University. Once the router head is built and attached to the base frame, a test cut can be performed on a guitar body to see if there is improvement in time. The anticipated amount of travel is 6 inches (Z-Axis), so the initial design should be smaller than the amount of travel allowed. The success of the duplicator will be determined by its ability to produce an accurate guitar body, necks, and fret boards, faster than the initial time.

Analyses:

i) Design Issue:

A potential design issue is that the extension spring won’t be able to counterbalance the weight of the router head. The dimensions of the router head will need to fit within the main frame to ensure no interference. However, changes may be made. A second potential design issue is the material of the router head. The material could potentially not support the weight of the router head, which could lead to parts breaking.

ii) Calculated Parameters:

Included below are sample figures that are calculated:

- Bending Moment for Base Plate: 90lb-in
- Bending Moment for Stylus Mount: 45lb-in
- Shear Force for Base Plate: 15lbs
- Shear Force for Stylus Mount: 7.5lbs
- Moment of Inertia for Base Plate: .0399in^3
- Moment of Inertia for Stylus Mount: .0045in^3

iii) Best Practices:

As the pin router duplicator is designed for the class Lean Manufacturing (MET 345) offered at Central Washington University, it is of the utmost importance that the safety of students is ensured. When designing the duplicator, a safety factor of 3 will be used. Additionally, sources of components that are commercially available, will lead to easy maintenance and repair, if needed. By keeping up with maintenance, anticipated failures can be minimized.
Device: Parts, Shapes, and Conformation:

Part 001 – Plates for X-Axis Shafts & Router and Stylus

There are going to be two plates that are of equal length. The material of both plates are 6061 T6 Aluminum. These two plates will hold two shafts from the base frame, the linkage arms and mounts, router, base plate for router, stylus, and stylus mount.

Part 002 – Linkage Arms

There are going to be four linkage arms that are cut to length, which holds both plates together. The arms allow the plates to pivot. The linkage arms are going to be made of 6061 T6 Aluminum.

Part 003 – Linkage Mounts

There are going to be eight total linkage mounts. Four are going to be mounted on each plate. The mounts are going to secure the linkage arms from deflecting.

Part 004 – DeWALT DW618 (2 1/4HP) Router

The router is a type of power tool that has an electric-motor-driven spindle. The router is going to be secured in a housing that’s bolted to the base. It is going to have four different drill bit sizes that are inserted to plunge into the woodwork.

Part 005 – Stylus

The stylus is simply the device that traces the finished wood design. In this case, it’s the guitar bodies, necks, and fret boards.

Part 006 – Stylus Mount

The stylus mount is going to hold the stylus in place with a set screw. The set screw allows for the operator to adjust the depth of cut with ease of accessibility.

Part 007 – Base Plate for Router

The base plate for the router is going to secure the router onto the plate. There will be a housing (provided by CWU) that’s going to bolted onto the base plate.
Part 008 – Rod for Linkage Mount

The rod will secure the linkage arm and mount together. The rod goes through both holes on the arm and mount. There will be two small holes on the rod, which are meant for clevis pins.

Part 009 – Shafts

There will be four different size diameters for stylus heads. The shaft will be turned down to match with the different drill bit sizes.

Device Assembly and Attachments:

Once the necessary components have been manufactured and purchased, the assembly is quite simple. The assembly can be assembled by using hand tools. First, a plate is going to be mounted on the X-axis shafts that’s parts of the base frame. Then, four linkage mounts will be bolted onto both plates. Once the plates and mounts are mounted, then the linkage arms will be inserted into the mounts for the rod to go through. Next, the base plate will be mounted onto the plate for the router and stylus. Then, the stylus mount will be mounted 16” away from the center of the router. Towards the middle of both plates, there is going to be a spring that attached for the counterbalance. Now, the router head can be mounted onto the base frame.

Tolerances, Kinematics, and Ergonomics:

Several limitations exist, based on the dimensions of the table that’s provided by Central Washington University. The router head and the base frame’s dimension have to be within the dimensions of the table, so that there’s no hangover. When performing a cut, the positioning tolerance has to be ±.005, which allows the router to pinpoint the origin repetitively. This provides an accurate cut each time. The repeatability tolerance is ±.001 meaning that when the router/stylus finishes the cut, it can repeat the process by staying within tolerance.

Technical Risk Analysis, Failure Mode Analyses, & Safety Factors:

Financial expenses need to be handled properly for this project. The budget of this project as a whole, is $1000. The budget includes all the necessary parts needed to assemble the pin router duplicator. However, there are some components provided by Central Washington University, which are not included in the budget. Also, fasteners might be provided by off-campus resources. By choosing to work with wood, the average safety factor is 1.3. For this project, the safety factor is 3.

Methods and Construction:

Description:

This project is intended to help speed up the production for guitar bodies, necks, fret boards, and get rid of bottlenecks. First, two plates, two flat bars, base plate for router, and flat bar for stylus
mount will be purchased from OnlineMetals.com. When choosing a material for all the necessary components, the strength of the material should exceed the minimum bending stress requirements to ensure that the duplicator doesn’t fail. The two plates are going to be supporting the whole router head. Most parts will be machined in the machine shop, located in Hogue at Central Washington University. The only thing that isn’t machined is the router. However, the housing for the router needs to have holes drilled to match with the base plate. Once the router head is assembled, then it will be attached to the base frame by using nuts and bolts, which will be either provided by the school or purchased at a hardware store. By minimizing the number of custom manufactured parts, the router head will be easier to maintain throughout its design life.

Drawing Tree & Drawing ID’s:

Part Lists and Labels:

Refer to Appendix C for a detailed parts list; it contains all the information necessary to complete the build.

Manufacturing Issues:
One issue that may arrive from machining most parts, is alignment. There may be misalignment if caution is not taken when laying out hole centers. Although bolting parts together is a sufficient route, it doesn’t provide a rigid structure, and is more prone to failure over time.

Another issue that may occur is turning the outside diameter of the end mills. If the outside diameter is too large or too small, it may not sit flush in the stylus.

Assembly, Sub-assembly, Parts, & Drawings:

The router head assembly, which consists of two plates, linkage arms, linkage mounts, stylus, mount for stylus, base plate for router, and a spring. The two plates, linkage mounts, linkage arms, and shafts will be cut to the correct length by using a band saw, located in the machine lab, in Hogue. These parts will also be milled to ensure they’re within tolerance of the correct length. The shaft will be turned down by using a manual lathe in the machining shop to the correct outside diameter and length. The linkage mounts has two flanges and one slot, which will need to be milled.

Testing Method:

Introduction:

The primary testing method for this project will be comparing the different spring rates to determine whether it can be used as a counterbalance. For each operation, a spring scale is used to measure the deflection of the extension springs. Testing will take place in the wood shop, located in Hogue.

Method and Approach:

In order to run any tests, several measuring tools will be needed. The measuring tools that are needed are as follows: a spring scale, calipers, and 2ft ruler (with 1/64 increments). The spring scale is used to determine the cutting force of the router. The 2ft ruler (with 1/64 increments) is used to measure the deflection of the router head when a force is being applied.

Test Procedures:

1. Position the 4 bar linkage system in a neutral position (both plates are parallel with each other)
2. Position the 4 bar linkage system to get ready to plunge into the part (the position where the router bit is touching the MDF table)
3. Take initial measurements of the plate (that holds the router and stylus), measured from the bottom of the plate to the MDF table.
4. Measure the distance with a 2ft ruler (with 1/64 increments). This ensures the accuracy to four decimal places.
5. Put a welding wire on top of the stylus mount (the mount to the left of the router), where the hole is.
6. Attach the spring scale onto the welding wire and apply force by pulling down.
7. Do this for 10lbf, 20lbf, and 30lbf.
8. Take measurements of the deflection of the system with a 2ft ruler (with 1/64 increments).
9. Repeat steps 5-8 five times.
10. Record data and insert into an Excel spreadsheet
11. Graph Deflection vs. Applied Force

Deliverables:

Once testing is done, there will be an Excel spreadsheet that shows the amount of deflection after a force is being applied. This will allow for calculations to be made for a spring rate. If the project is successful, the pin router duplicator will be available for use in the wood shop, for the class MET 345 (Lean Manufacturing). The results of the testing are going to be located in the testing report section (Refer to Appendix H).

**Budget/Schedule/Project Management:**

**Proposed Budget:**

All components are made of 6061 T6 Aluminum. All the raw stock is going to be purchased from OnlineMetals.com. Online Metals Co. is a company that specializes in metals cut-to-size. The material will be bought in bulk to minimize cost, since shipping would be expensive if bought individually. The DeWALT DW618 (2 1/4HP) Router is provided by Central Washington University, so that will also help minimize the cost to stay under the 1000$ budget.

**Proposed Schedule:**

A tentative schedule that is subject to change was created to help organize the project and ensure that it will be completed on time. The schedule is developed to illustrate the steps of the process and time it took to build the proposal. It is broken up into major and sub tasks. The schedule has milestones that need to be reached, in order to finish the project by the end of the academic year. The estimated time to complete the project is approximately 31 days and 15 hours. Refer to Appendix E.

**Project Management:**

1) **Human Resources:**

One other student is working on this same project, but he’s designing the base frame. The two projects are going to be assembled together to create the pin router duplicator. Being able to
communicate ideas with each other is going to help develop a successful project. Additionally, Professor Pringle has provided advice on design and analysis methods.

II) Physical Resources:
The CWU machine shop located in Hogue will provide access to lathes, milling machines, drill presses, CNC machines, and other various tools. This will help manufacture all necessary components.

III) Soft Resources:
SolidWorks is a 3D modeling program that will be used to design all necessary components. In this case, the program will be used to design the router head.

IV) Financial Resources:
Hardware for this project will be purchased at a hardware store or provided by Central Washington University. Labor costs, if any, will be minimized by utilizing the MET department staff to complete specific tasks in manufacturing.

Discussion:

Design Evolution/Performance Creep:
The initial design was created based on the analysis of the two plates, linkage arms, linkage mounts, base plate for router, stylus, and stylus mounts. The majority of the system was designed by finding suitable material that best fits the needs of all necessary components.

In terms of performance creep, the project will undergo a significant amount of planning, so that during the construction of the system, time will be minimized. There may also be a waiting period, due to the materials and components being shipped after the date of purchase.

Project Risk Analysis:

For this project, risk analysis means that the system was successfully built and safe to use. There are also financial risks as well. If the system isn’t completed correctly, then there will be money that’s potentially lost. However, Central Washington University provides access to the machining lab, which will help minimize financial losses.

Success of the Project:

The success of the project is determined by its level of completion. Ideally, the proposal, pin router duplicator, and etc. will need to be completed by key milestones. When the deliverables are completed, then the long term success of this project is to perform a cut for guitar bodies, necks, fret boards, and minimize bottlenecks.
Project Documentation:

The main documentation of this project is the proposal, which consists of: appendixes that include drawings and calculations, analyses, part list, budget, schedule, resources, testing data, and resume. Additional documents may be added to support the project.

Next Phase:

Once the proposal is completed, the next step is to start building the pin router duplicator. To do so, the necessary components will be ordered, machining the components, and assembly the system.

Conclusion:

In conclusion, the pin router duplicator is dependent on critical design, analysis, and well instructed construction to ensure the system is built safely and effectively. The system should allow a minimum of 6 inches of travel when plunging into the woodwork. The Mechanical Engineering Technology department at Central Washington University, provided support in construction, material costs, and other funding necessities.

Acknowledgements:

The author of this proposal would like to thank the advising professors and assistants in the Mechanical Engineering Technology department at Central Washington University, located in Ellensburg, WA. The advising professors are as follows: Charles Pringle, Craig Johnson, Roger Beardsley, Ted Bramble, and Matt Burvee. Without the help of these professors, the project would not be completed in a timely manner.

References:


“6000 Series Aluminum Alloy; Aluminum Alloy; Metal; Nonferrous Metal” MatWeb, LLC. MatWeb. Web. 05 December 2016.
Appendix A: Calculations

Figure 1.1: Moment, Shear Diagrams, and Deflection, 1/3

Given: router = 15 lb
base plate
safety factor = 3
find: thickness of base plate

Solution:

\[ \sum F_y = 0: R_A - 151 \text{ lbs} \]
\[ 
\begin{align*}
R_A &= 151 \text{ lbs} \\
M &= 901 \text{ in} \\
\sum M_A &= 0: M - 151 \text{ lbs} \cdot 6 \text{ in} \\
M &= 901 \text{ in} \cdot \text{lb}
\end{align*}
\]
Figure 1.2: Moment, Shear Diagrams, and Deflection, 2/3

\[ y = \frac{M}{6EI} \left[ \left( \frac{3a^2}{L} - 2L \right) x - \frac{y^3}{L} \right] \]

\[ y = 0.005'' \]
\[ L = 6.00'' \]
\[ a = 1' \]
\[ x = 4.5'' \text{ from Excel} \]
\[ M = 90 \text{ lb-in} \times 5.1F \]
\[ = 10 \text{ lb-in} \times 3 \]
\[ = 270 \text{ lb-in} \]

Solve for \( I \)

\[ y = \frac{-M}{6EI} \left[ \left( \frac{3a^2}{L} - 2L \right) x - \frac{y^3}{L} \right] \]

\[ \frac{-M}{6EI} = \frac{y}{\left( \frac{3a^2}{L} - 2L \right) x - \frac{y^3}{L}} \]

\[ 6E \left[ \frac{-M}{\left( \frac{3a^2}{L} - 2L \right) x - \frac{y^3}{L}} \right] = \frac{y}{y} \]

\[ I = \frac{-M}{6E \left[ \frac{y}{\left( \frac{3a^2}{L} - 2L \right) x - \frac{y^3}{L}} \right]} \]
cont. material: aluminum 6061-T6

from matweb.com

\[ E = 10 \times 10^6 \text{ psi} \]

\[ I = \frac{270 \text{ lb-in}}{1.05 \sin} \]

\[ b \left( 10 \times 10^6 \text{ psi} \right) \left[ \frac{1}{6} \left( 4.00 \text{ in} \right) - \frac{3}{6} \left( 0.00 \text{ in} \right)^2 - \frac{2}{6} \left( 0.00 \text{ in} \right) \right] \]

\[ = 0.0399 \]

from appendix 1 p.720 (d)

\[ I_X = \frac{B h^3}{12} \]

where \( h \) is center to center for bearings

\[ h = 4.75 \text{ in} \]

\[ 0.0399 = \frac{B \left( 4.75 \text{ in} \right)^3}{12} \]

\[ 4.7588 = B \left( 4.75 \text{ in} \right)^3 \]

\[ B = 0.0044 \text{ (min thickness)} \]

\[ \text{use } 1/2'' = 0.500'' \]
Figure 1.4: Moment, Shear Diagrams, and Deflection, 1/3

- Given: stylus = 151lbs
- mounting plate
- cantilever beam
- safety factor = 3

- Find: thickness of plate
- Solution:

\[ FBD \]

\[ L_x \]

\[ 151\text{lbs} \]

\[ 3'' \quad 3'' \]

\[ R_B \]

\[ + \Sigma M_c = 0: 151\text{lbs} (3'') - R_B (6'') \]

\[ R_B = 7.51\text{lbs} \]

\[ + \Sigma F_y = 0: R_C - 151\text{lbs} + 7.51\text{lbs} \]

\[ R_C = 7.51\text{lbs} \]

\[ V(\text{lbs}) \]

\[ 0 \quad -7.5 \]

\[ M(\text{lbs}\cdot\text{in}) \]

\[ 0 \quad -48 \]

\[ M = (151\text{lbs})(3'') = 453\text{lbs}\cdot\text{in} \]
Figure 1.5: Moment, Shear Diagrams, and Deflection, 2/3

Daniel Phan

cont.) from table A14-2 (b)

\[
y = \frac{-Px^2}{6EI} (3a-x)
\]

\[y = .003"\]

\[P = 151\text{lbs}\]

\[x = 4.50" \text{ from Excel}\]

\[a = 3.00"\]

material: aluminum 6061 T6 (SS)

\[E = 10E6 \text{ psi}\]

solve for \(I\)

\[
y = \frac{-Px^2}{6EI}
\]

\[
\frac{y}{(3a-x)} = -\frac{Px^2}{6EI}
\]

\[
6E \left(\frac{y}{(3a-x)}\right) = -\frac{Px^2}{I}
\]

\[I = \frac{-Px^2}{6E \left(\frac{y}{(3a-x)}\right)}
\]

\[= \frac{-15\text{lbs}(4.50")^2}{6(10E6 \text{ psi})(\frac{.003"}{.003"+4.50"})}
\]

\[= .0045"\]

\[I = .0045"\]
Figure 1.6: Moment, Shear Diagrams, and Deflection, 3/3

\[
\text{cont.) } I = 0.045''
\]

\[
I_x = \frac{8H^3}{12}
\]

where \( B = 6.00'' \)

\[
0.045'' = \frac{(6.00''H)^3}{12}
\]

\[
0.045'' = \frac{(6.00''H)^3}{12}
\]

\[
0.049'' = H^3
\]

\[
H \cdot 0.208'' \text{ use } 1/2'' \text{ thickness}
\]
Figure 1.7: Moment, Shear Diagrams, and Deflection, 1/3

given: mounting bracket for rotator
rotor weighs 10lbs
collar mount for shaft

find: determine height of mounting bracket

Note:
FBD

\[
\begin{align*}
\sum M_M &= 0 : -R_C (6^\circ) + 10 \text{lbs} (3^\circ) \\
R_C &= 5 \text{lbs} \\
\sum F_y &= 0 : 5 \text{lbs} - 10 \text{lbs} + R_M \\
R_M &= 5 \text{ lbs} \\
V(\text{lb}) &= 0 \\
M(\text{lb}\cdot\text{in}) &= 0 \\
-30 &\quad 0 \\
\end{align*}
\]
cont. from table A14-2 (b)

\[ y = \frac{-P_x^2}{6EI} (3a-x) \]

\[ y = 0.005'' \]
\[ a = 3.00'' \]
\[ P = 101.6 \text{ lbs} \]
\[ x = 4.50'' \text{ from Excel} \]
\[ \text{material: aluminum 6061-T6 (5s)} \]
\[ \text{from matweb.com} \]
\[ E = 10E6 \text{ psi} \]

solve for I

\[ y = \frac{-P_x^2}{6EI} (3a-x) \]

\[ \frac{y}{(3a-x)} = \frac{-P_x^2}{6EI} \]

\[ 6E \left( \frac{y}{3a-x} \right) = \frac{-P_x^2}{I} \]

\[ I = \frac{-P_x^2}{6E \left( \frac{y}{3a-x} \right)} \]

\[ = 101.6 \text{ lbs} \left( \frac{4.50''}{2} \right)^2 \]
\[ = \frac{6 (10E6 \text{ psi}) \left( \frac{0.005''}{2} \text{ (3.00'') - 4.5} \right)}{6 (10E6 \text{ psi}) \left( \frac{0.005''}{2} \text{ (3.00'') - 4.5} \right)} \]
\[ = -0.0304'' \quad I = 1.00 \quad I = 1.00 \text{207}'' \]
\[ \frac{1}{2} BH^3 = 0.0202'' \]

where \( B = 6.00'' \)
\[ 0.0202'' = \frac{(6.00'') H^3}{12} \]
\[ 0.02424 = (6.00'') H^3 \]
\[ 0.02424 = \frac{1}{2} H^3 \]
\[ H = \sqrt[3]{0.02424} \]
\[ H = 1.169'' \text{ use } \frac{3}{4}'' \text{ thickness} \]
Appendix B: Drawings

Drawing 1.1: Plate for X-Axis Shafts
Drawing 1.2: Plate for Router & Stylus
Drawing 1.3: 4 Bar Linkage Arms

[Diagram of 4 Bar Linkage Arms with dimensions and annotations]
Drawing 1.4: Mount for Linkage Arms
Drawing 1.4: Rod for Linkage Mount
Drawing 1.5: DeWALT DW618 (2.25HP)
Drawing 1.6: Stylus

DESIGNER: DANIEL PHAN

STYLUS

A

REV A 8

SCALE 1:12 WEIGHT SHEET 1 OF 1
Drawing 1.7: Mount for Stylus
Drawing 1.8: 1/4” End Mill
Drawing 1.9: 3/8” End Mill
Drawing 1.10: ½” End Mill

Designer: Daniel Phan

The 1/2" END MILL

Table of Contents:

- A: 9

Scale 1:1

Weight:

Sheet 1 of 1
Drawing 1.11: ½” Ball End Mill
## Appendix C: Parts List

<table>
<thead>
<tr>
<th>Parts</th>
<th>Stock Number</th>
<th>Size</th>
<th>Dimension</th>
<th>Costs</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x Flat Bar (Aluminum 6061-T6)</td>
<td>F41412</td>
<td>22.0in</td>
<td>(1/4 x 1/2)”</td>
<td>$4.15</td>
<td>MetalsDepot.com</td>
</tr>
<tr>
<td>1x Flat Bar (Aluminum 6061-T6)</td>
<td>F4122</td>
<td>5.0in</td>
<td>(1/2 x 2)”</td>
<td>$6.54</td>
<td>MetalsDepot.com</td>
</tr>
<tr>
<td>2x Plates (Aluminum 6061-T6)</td>
<td>P314T6</td>
<td>41.0in</td>
<td>(1/4x41)”</td>
<td>$39.48</td>
<td>MetalsDepot.com</td>
</tr>
<tr>
<td>1x DeWALT DW618 (2.25HP) Router</td>
<td>DW618</td>
<td>8.38in</td>
<td>(4.48x8.38)”</td>
<td>N/A</td>
<td>CWU</td>
</tr>
<tr>
<td>1x Round Bar (Aluminum 6061-T6)</td>
<td>R338</td>
<td>13.5in</td>
<td>Diameter: 375”</td>
<td>$2.37</td>
<td>MetalsDepot.com</td>
</tr>
<tr>
<td>1x Round Bar (Aluminum 6061-T6)</td>
<td>R334</td>
<td>6.75in</td>
<td>Diameter: .750”</td>
<td>$5.04</td>
<td>MetalsDepot.com</td>
</tr>
<tr>
<td>1x Round Bar (Aluminum 6061-T6)</td>
<td>R314</td>
<td>2.50in</td>
<td>Diameter: .250”</td>
<td>$1.23</td>
<td>MetalsDepot.com</td>
</tr>
<tr>
<td>1x Round Bar (Aluminum 6061-T6)</td>
<td>R312</td>
<td>2.50in</td>
<td>Diameter: .500”</td>
<td>$2.43</td>
<td>MetalsDepot.com</td>
</tr>
<tr>
<td>1x Square Bar (Aluminum 6061-T6)</td>
<td>SQ3138</td>
<td>14in</td>
<td>(1-3/8 x 1-3/8)”</td>
<td>$26.65</td>
<td>MetalsDepot.com</td>
</tr>
<tr>
<td>Estimated Total</td>
<td></td>
<td></td>
<td></td>
<td>$87.89</td>
<td></td>
</tr>
</tbody>
</table>
## Appendix D: Budget

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x Flat Bar Aluminum 6061 T6 (1/4 x 1/2&quot;)</td>
<td>$4.15</td>
</tr>
<tr>
<td>1x Flat Bar Aluminum 6061-T6 (1/2 x 2&quot;)</td>
<td>$6.54</td>
</tr>
<tr>
<td>2x Plates Aluminum 6061-T6 (1/4x41&quot;)</td>
<td>$39.48</td>
</tr>
<tr>
<td>1x Round Bar Aluminum 6061-T6 (Diameter: .250&quot;)</td>
<td>$1.23</td>
</tr>
<tr>
<td>1x Round Bar Aluminum 6061-T6 (Diameter: .375&quot;)</td>
<td>$2.37</td>
</tr>
<tr>
<td>1x Round Bar Aluminum 6061-T6 (Diameter: .500&quot;)</td>
<td>$2.43</td>
</tr>
<tr>
<td>1x Round Bar Aluminum 6061-T6 (Diameter: .750&quot;)</td>
<td>$5.04</td>
</tr>
<tr>
<td>1x Square Bar Aluminum 6061-T6 (1-3/8 x 1-3/8&quot;)</td>
<td>$26.65</td>
</tr>
<tr>
<td>Estimated Total Cost</td>
<td>$87.89</td>
</tr>
</tbody>
</table>
### Appendix E: Schedule

#### Schedule for Senior Project

**DATE:** December 2, 2016  
**PROJECT TITLE:** Pin Router Duplicator  
**DESIGNER:** Daniel Phan

<table>
<thead>
<tr>
<th>TASK ID</th>
<th>Description</th>
<th>Time (hrs)</th>
<th>November</th>
<th>December</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Proposal</td>
<td>80</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1a</td>
<td>Problem Statement</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1b</td>
<td>Function Statements</td>
<td>3.5</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1c</td>
<td>Design Requirements</td>
<td>2.5</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1d</td>
<td>Outline</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1e</td>
<td>Introduction</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1f</td>
<td>Methods</td>
<td>10</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1g</td>
<td>Analysis</td>
<td>18</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1h</td>
<td>Discussion</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1i</td>
<td>Parts List</td>
<td>6</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1j</td>
<td>Budget</td>
<td>1.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1k</td>
<td>Drawings</td>
<td>25</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1l</td>
<td>Schedule</td>
<td>5</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1m</td>
<td>Summary &amp; Appendix</td>
<td>20</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>subtotal:</strong></td>
<td><strong>108.5</strong></td>
<td><strong>80</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Analyses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a</td>
<td>Maximum Moments</td>
<td>12</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2b</td>
<td>Shear Forces</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2c</td>
<td>Moment &amp; Shear</td>
<td>6</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2d</td>
<td>Diagrams</td>
<td>3</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2e</td>
<td>Section of Modulus</td>
<td>6</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>subtotal:</strong></td>
<td><strong>31</strong></td>
<td><strong>15</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Documentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3a</td>
<td>Plate for X-Axis Shafts</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3b</td>
<td>Plate for Router &amp; Stylus</td>
<td>2.5</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3c</td>
<td>Linkage Arms</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3d</td>
<td>Mount for Linkage Arms</td>
<td>1.5</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3e</td>
<td>Dewalt DW6318 Router</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3f</td>
<td>Stylus</td>
<td>0.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3g</td>
<td>Mount for Stylus</td>
<td>1</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3h</td>
<td>1/4&quot; End Mill</td>
<td>0.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3i</td>
<td>3/8&quot; End Mill</td>
<td>0.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3j</td>
<td>1/2&quot; End Mill</td>
<td>0.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3k</td>
<td>1/2&quot; Ball End Mill</td>
<td>0.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3l</td>
<td>Fasteners</td>
<td>0.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>subtotal:</strong></td>
<td><strong>11.5</strong></td>
<td><strong>16.5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Proposal Mod</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4a</td>
<td>Project Proposal</td>
<td>1.5</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4b</td>
<td>Project Part Inventory</td>
<td>3</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4c</td>
<td>Critical Design Review</td>
<td>4.5</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>subtotal:</strong></td>
<td><strong>9</strong></td>
<td><strong>7.5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Part Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5a</td>
<td>Buy Plate for X-Axis Shafts</td>
<td>1.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5b</td>
<td>Buy Plate for Router &amp; Stylus</td>
<td>1.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5c</td>
<td>Buy Flat Bar for Linkage</td>
<td>1.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5d</td>
<td>Mounts</td>
<td>1.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5e</td>
<td>Buy Shaft for 1/4&quot; End Mill</td>
<td>1.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5f</td>
<td>Buy Shaft for 3/8&quot; End Mill</td>
<td>1.5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*NOTE: 1 square/unit = 1 week*
<table>
<thead>
<tr>
<th>Task Description</th>
<th>Hours</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>5g Buy Shaft 1/2&quot; End Mill</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>5h End Mill</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>5i Buy Rod for Linkage</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>5j Cut both plates to</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>5k Cut flat bar to correct length for linkage arms</td>
<td>2.5</td>
<td>3</td>
</tr>
<tr>
<td>5l Cut flat bar to correct length for linkage mounts</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>5m Turn down shafts to correct diameters for</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5n Drill and tap holes on base plate for router</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>5o Drill and tap holes on mount for stylus</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>5p Drill thru holes on both plates</td>
<td>6</td>
<td>18</td>
</tr>
<tr>
<td>5q Drill thru holes for Rod</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>5r Drill thru holes for stylus</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>5s Mill out slots on linkage</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>5t Drill thru holes on linkage mounts</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td><strong>Subtotal:</strong></td>
<td><strong>78</strong></td>
<td><strong>80</strong></td>
</tr>
<tr>
<td>6a Manufacture Plan</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>6b Update Website</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>6c Assemble Plates</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>6d Assemble Linkage</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>6e Assemble Linkage Arms through Linkage Mounts</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>6f Assemble Rod through</td>
<td>1.5</td>
<td>4</td>
</tr>
<tr>
<td>6g Assemble Stylus Mount onto Plate for Router &amp;</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>6h Assemble Stylus into Stylus Mount</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6i Assemble End Mill heads into Stylus</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>6j Assemble Base plate onto Plate for Router &amp;</td>
<td>2.5</td>
<td>8</td>
</tr>
<tr>
<td>6k Mount Router Head onto</td>
<td>2.5</td>
<td>4</td>
</tr>
<tr>
<td><strong>Subtotal:</strong></td>
<td><strong>29.5</strong></td>
<td><strong>52.5</strong></td>
</tr>
<tr>
<td>7a List Parameters</td>
<td>2.5</td>
<td>1</td>
</tr>
<tr>
<td>7b Design Test &amp; Scope</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>7c Obtain Resources</td>
<td>3.5</td>
<td>1.5</td>
</tr>
<tr>
<td>7d Create Test Sheets</td>
<td>6</td>
<td>1.5</td>
</tr>
<tr>
<td>7e Plan Analysis</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>7f Instrument System</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>7g Test Plan</td>
<td>4.5</td>
<td>2</td>
</tr>
<tr>
<td>7h Perform Test 1</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>7i Perform Test 2</td>
<td>3.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Task</td>
<td>Hours</td>
<td>Rate</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>Take Photos for 7j Documentation</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>7k Update Website</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>35</strong></td>
<td><strong>14.9</strong></td>
</tr>
<tr>
<td>8a Get Report Guide</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>8b Make Rep Outline</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>8c Write Report</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>8d Make Slide Outline</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>8e Create Presentation</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>8f Make CD Deliv. List</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>8g Write 495 CD parts</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>8h Update Website</td>
<td>3</td>
<td>2.5</td>
</tr>
<tr>
<td>8i Project CD</td>
<td>2.5</td>
<td>2</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>47.5</strong></td>
<td><strong>21</strong></td>
</tr>
</tbody>
</table>

Total Est. Hours = 350 = Total Actual Hrs
Appendix F: Expertise & Resources

Manufacturing support was provided by Central Washington University by providing access to the machining and wood lab. With help from Professor Pringle, Professor Beardsley, Professor Johnson, Professor Bramble, and Matt Burvee, the project was able to be completed in a timely manner.
## Appendix G: Evaluation Sheet

<table>
<thead>
<tr>
<th></th>
<th>Applied force (lbf)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Average (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Position (in)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix H: Testing Report

Introduction:

This testing report is for a pin router duplicator, designed for Central Washington University class MET 345 (Lean Manufacturing). The requirements of the project require the spring to be used as a counterbalance to bring the four bar linkage system back to a neutral position. Professor Beardsley provided the spring. The parameters of interest in this requirement include an application of force being applied to the four bar linkage system.

For Test 1:

Predicted performance for the first test of the extension spring came out to be 15.5lbs/in for the spring rate. This will allow for an analysis to determine whether the spring could be used as a counterbalance. Data will be collected by using a 2ft ruler (with 1/64 increments) and spring scale to measure the applied force and deflection. Testing for this experiment will occur during the weekend of April 8\textsuperscript{th}, 2017.

For Test 2:

For the second test, a new extension spring was ordered because the previous spring did not work as a counterbalance. The calculations for the predicted performance were off, due to a wrong approximation of the weight of the router head. The parameters of interest in this requirement is that the new spring has a spring rate that is higher than the predicted value. After a few tests, the deflection of the system are collected. Now, the new spring rate is 18.34lbs/in. The goal is to be able to use the new extension spring as a counterbalance. Testing for this experiment will occur during the weekend of April 23\textsuperscript{rd}, 2017.

Method/Approach:

Resources for both tests will be provided by Central Washington University at no cost. The data, as mentioned above, will be collected by a 2ft ruler (with 1/64 increments). Equipment includes a spring scale (to apply force), safety glasses, 2ft ruler (with 1/64 increments), and other miscellaneous tools as needed. The spring scale will be used to apply force to the system to determine the deflection, from when the system is in its neutral position. To ensure that the system does not fail, a maximum of 30lbf will not be exceeded. Data will be collected by hand using a 2ft (with 1/64 increments) ruler, and then recorded into a spreadsheet using Microsoft Excel, where it can be stored, manipulated, and analyzed.

Testing Procedure:

Test 1:

For this test, the spring that’s provided by Professor Beardsley will be analyzed. Testing is scheduled to take place during the weekend of April 8\textsuperscript{th}, 2017. It will take approximately two to
two hours, which will be performed in the senior project room, located in Hogue at Central Washington University. However, if no unexpected issues or failures, the actual experiment could take less time.

12. Position the 4 bar linkage system in a neutral position (both plates are parallel with each other)
13. Position the 4 bar linkage system to get ready to plunge into the part (the position where the router bit is touching the MDF table)
14. Take initial measurements of the plate (that holds the router and stylus), measured from the bottom of the plate to the MDF table.
15. Measure the distance with a 2ft ruler (with 1/64 increments). This ensures the accuracy to four decimal places.
16. Put a welding wire on top of the stylus mount (the mount to the left of the router), where the hole is.
17. Attach the spring scale onto the welding wire and apply force by pulling down.
18. Do this for 10lbf, 20lbf, and 30lbf.
19. Take measurements of the deflection of the system with a 2ft ruler (with 1/64 increments).
20. Repeat steps 5-8 five times.
21. Record data and insert into an Excel spreadsheet
22. Graph Deflection vs. Applied Force

In order to ensure safety of the operators, personal protective equipment (safety glasses, gloves, and etc.) will be used. Potential failures could result in the spring snapping into pieces if not handled with care. However, according to calculations, the spring shouldn’t snap.

Test 2:

For this test, the spring that is ordered from McMaster Carr, will be analyzed. Testing is scheduled to take place during the weekend of April 22nd, 2017. It will take approximately two to two hours, which will be performed in the senior project room, located in Hogue at Central Washington University. However, if no unexpected issues or failures, the actual experiment could take less time.

1. Position the 4 bar linkage system in a neutral position (both plates are parallel with each other)
2. Position the 4 bar linkage system to get ready to plunge into the part (the position where the router bit is touching the MDF table)
3. Take initial measurements of the plate (that holds the router and stylus), measured from the bottom of the plate to the MDF table.
4. Measure the distance with a 2ft ruler (with 1/64 increments). This ensures the accuracy to four decimal places.
5. Put a welding wire on top of the stylus mount (the mount to the left of the router), where the hole is.
6. Attach the spring scale onto the welding wire and apply force by pulling down.
7. Do this for 10lbf, 20lbf, and 30lbf.
8. Take measurements of the deflection of the system with a 2ft ruler (with 1/64 increments).
9. Repeat steps 5-8 five times.
10. Record data and insert into an Excel spreadsheet
11. Graph Deflection vs. Applied Force

In order to ensure safety of the operators, personal protective equipment (safety glasses, gloves, and etc.) will be used. Potential failures could result in the spring snapping into pieces if not handled with care. However, according to calculations, the spring shouldn’t snap.

Deliverables:

The applied forces are as follows: Position w/out router (25.8lbf), neutral position 35.8lbf, 45.8lbf, 55.8lbf, and 65.8lbf. For each applied force, the deflection was measured to determine the spring rate. With the spring that is provided by Professor Beardsley, the spring rate came out to be 14lbs/in, which was under the predicted value of 15.5lbs/in. For the second test, the new spring came out with a spring rate of 18.34lbs/in, which meets the success criteria of the project. In conclusion, the purpose of this test was to determine the spring rate of the springs, to be used as a counterbalance, which came out to be a success.

Data Forms:

Test 1:

<table>
<thead>
<tr>
<th>Applied force (lbf)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Average (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Position (in)</td>
<td>25.8</td>
<td>7.0000</td>
<td>6.3437</td>
<td>6.1250</td>
<td>6.8125</td>
<td>7.0000</td>
</tr>
<tr>
<td></td>
<td>35.8</td>
<td>6.0000</td>
<td>6.0000</td>
<td>5.5000</td>
<td>5.8750</td>
<td>6.0625</td>
</tr>
<tr>
<td></td>
<td>45.8</td>
<td>2.0625</td>
<td>2.0625</td>
<td>2.0625</td>
<td>2.0625</td>
<td>2.0000</td>
</tr>
<tr>
<td></td>
<td>55.8</td>
<td>1.5000</td>
<td>1.6250</td>
<td>1.5625</td>
<td>1.5625</td>
<td>1.5625</td>
</tr>
<tr>
<td></td>
<td>65.8</td>
<td>1.1875</td>
<td>1.3125</td>
<td>1.3125</td>
<td>1.2500</td>
<td>1.1875</td>
</tr>
</tbody>
</table>
Applied Force vs. Deflection

Deflection (in) vs. Applied Force (in)

- Height (in)
- Height (in)
- Height (in)
- Average (in)
Test 2:

<table>
<thead>
<tr>
<th></th>
<th>Applied force (lbf)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Average (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Position (in)</td>
<td>25.8</td>
<td>5.6250</td>
<td>5.6250</td>
<td>5.5000</td>
<td>5.5625</td>
<td>5.6250</td>
<td>5.5875</td>
</tr>
<tr>
<td></td>
<td>35.8</td>
<td>5.2500</td>
<td>4.1875</td>
<td>4.1250</td>
<td>4.2500</td>
<td>4.3125</td>
<td>4.4250</td>
</tr>
<tr>
<td></td>
<td>45.8</td>
<td>2.5000</td>
<td>2.4375</td>
<td>2.3750</td>
<td>2.5</td>
<td>2.5000</td>
<td>2.4625</td>
</tr>
<tr>
<td></td>
<td>55.8</td>
<td>1.8125</td>
<td>1.7500</td>
<td>1.6250</td>
<td>1.7500</td>
<td>1.7500</td>
<td>1.7375</td>
</tr>
<tr>
<td></td>
<td>65.8</td>
<td>1.3125</td>
<td>1.1250</td>
<td>1.1250</td>
<td>1.3125</td>
<td>1.1250</td>
<td>1.2000</td>
</tr>
</tbody>
</table>

Procedure Checklist:

Test 1:
1. Position system in neutral position
2. Take initial measurement for reference
3. Apply force with spring scale
4. Take measurement
5. Repeat measurements with different applied forces
6. Detach spring scale and clean up

Test 2:
1. Position system in neutral position
2. Take initial measurement for reference
3. Apply force with spring scale
4. Take measurement
5. Repeat measurements with different applied forces
6. Detach spring scale and clean up
Appendix I: Testing Data

Test 1:

<table>
<thead>
<tr>
<th>Applied Force (lbf)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Average (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Position (in)</td>
<td>25.8</td>
<td>7.0000</td>
<td>6.3437</td>
<td>6.1250</td>
<td>6.8125</td>
<td>7.0000</td>
</tr>
<tr>
<td></td>
<td>35.8</td>
<td>6.0000</td>
<td>6.3437</td>
<td>6.1250</td>
<td>5.8750</td>
<td>6.0625</td>
</tr>
<tr>
<td></td>
<td>45.8</td>
<td>2.0625</td>
<td>2.0625</td>
<td>2.0625</td>
<td>2.0625</td>
<td>2.0000</td>
</tr>
<tr>
<td></td>
<td>55.8</td>
<td>1.5000</td>
<td>1.6250</td>
<td>1.5625</td>
<td>1.5625</td>
<td>1.5625</td>
</tr>
<tr>
<td></td>
<td>65.8</td>
<td>1.1875</td>
<td>1.3125</td>
<td>1.3125</td>
<td>1.2500</td>
<td>1.1875</td>
</tr>
</tbody>
</table>

Test 2:

<table>
<thead>
<tr>
<th>Applied Force (lbf)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Height (in)</th>
<th>Average (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutral Position (in)</td>
<td>25.8</td>
<td>5.6250</td>
<td>5.6250</td>
<td>5.5000</td>
<td>5.5625</td>
<td>5.6250</td>
</tr>
<tr>
<td></td>
<td>35.8</td>
<td>5.2500</td>
<td>4.1875</td>
<td>4.1250</td>
<td>4.2500</td>
<td>4.2125</td>
</tr>
<tr>
<td></td>
<td>45.8</td>
<td>2.5000</td>
<td>2.4375</td>
<td>2.3750</td>
<td>2.5</td>
<td>2.5000</td>
</tr>
<tr>
<td></td>
<td>55.8</td>
<td>1.8125</td>
<td>1.7500</td>
<td>1.6250</td>
<td>1.7500</td>
<td>1.7500</td>
</tr>
<tr>
<td></td>
<td>65.8</td>
<td>1.3125</td>
<td>1.1250</td>
<td>1.1250</td>
<td>1.1250</td>
<td>1.1250</td>
</tr>
</tbody>
</table>
Appendix J: Gantt Chart

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Start Date</th>
<th>Finish Date</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>PURCHASE SQUARE HOLLOW TUBING</td>
<td>Mon 11/7/16</td>
<td>Tue 11/8/16</td>
<td>2 days</td>
</tr>
<tr>
<td>SQUARE HOLLOW TUBES SHAPING</td>
<td>Wed 11/9/16</td>
<td>Fri 11/11/16</td>
<td>8 days</td>
</tr>
<tr>
<td>CUTTING SQUARE HOLLOW TUBING'S</td>
<td>Mon 11/14/16</td>
<td>Mon 11/14/16</td>
<td>4 hrs</td>
</tr>
<tr>
<td>WELDING SQUARE HOLLOW TUBING'</td>
<td>Tue 11/15/16</td>
<td>Wed 11/16/16</td>
<td>2 days</td>
</tr>
<tr>
<td>PURCHASE CYLINDRICAL ROD</td>
<td>Wed 11/16/16</td>
<td>Fri 11/18/16</td>
<td>3 days</td>
</tr>
<tr>
<td>CYLINDRICAL ROD SHAPED</td>
<td>Fri 11/18/16</td>
<td>Thu 11/21/16</td>
<td>4 days</td>
</tr>
<tr>
<td>CUT CYLINDRICAL ROD</td>
<td>Tue 11/22/16</td>
<td>Wed 11/23/16</td>
<td>8 hrs</td>
</tr>
<tr>
<td>TURNING CYLINDRICAL ROD</td>
<td>Wed 11/23/16</td>
<td>Thu 11/24/16</td>
<td>8 hrs</td>
</tr>
<tr>
<td>PURCHASE STYLIST</td>
<td>Mon 11/28/16</td>
<td>Mon 11/28/16</td>
<td>1 day</td>
</tr>
<tr>
<td>STYLIST SHAPING</td>
<td>Wed 11/30/16</td>
<td>Wed 12/01/16</td>
<td>7 days</td>
</tr>
<tr>
<td>PURCHASE COUNTER BALANCE WEIGHTS</td>
<td>Wed 12/7/16</td>
<td>Wed 12/8/16</td>
<td>1 day</td>
</tr>
<tr>
<td>COUNTER BALANCE WEIGHTS SHIPPING</td>
<td>Fri 12/9/16</td>
<td>Fri 12/10/16</td>
<td>6 days</td>
</tr>
<tr>
<td>PURCHASE SWING UP HINGES</td>
<td>Fri 12/16/16</td>
<td>Fri 12/17/16</td>
<td>1 day</td>
</tr>
<tr>
<td>SWING UP HINGES SHAPED</td>
<td>Mon 12/19/16</td>
<td>Wed 12/21/16</td>
<td>8 days</td>
</tr>
</tbody>
</table>
Appendix K: Résumé

DANIEL PHAN
7236 Rixie St. SE | Olympia, WA 98501
daniel.phan@cwu.edu | (360) 970-0718

JOB OBJECTIVE
Seeking a full-time engineering position that utilizes my academic and engineering background to jump start my career and to continue to learn and advance my skills.

EDUCATION
- **Central Washington University, Ellensburg, WA** | Bachelor of Science in Mechanical Engineering Technology | GPA: 3.20
- **South Puget Sound Community College, Olympia, WA** | Associate of Science | GPA: 3.10
- **Tumwater High School, Tumwater, WA** | High School Diploma | GPA: 3.70

TECHNICAL SKILLS
- Experienced in Advanced Machining/CNC programming, SolidWorks, Mechanical Design, Application in Strength of Materials, Lean Manufacturing, Statics, Thermodynamics, Dynamics, Basic Machining, Metallurgy, Casting, AutoCAD
- Efficient with lathes, milling machines, and drill presses
- Proficient with Microsoft Word, Power Point, Excel, Access, and Publisher
- Fluent in Vietnamese and English

PROJECT EXPERIENCE

**Senior Mechanical Engineering Culminating Project** 09/2016 – Present
- Collaborate with team member to manage and budget resources including time and money
- Manage tight deadlines to ensure key milestones are met in a timely manner
- Research and prepare technical proposals to provide detailed product development information
- Develop new product ideas through sketching, creating 3D models, prototyping, and testing
- Document project records throughout project lifecycle including updated drawings and spreadsheets

**Advanced Machining – Computer Numeric Control (CNC)** 01/2015 – 03/2016
Project 1 (CNC Manufactured Hammer)
- Developed engineering drawings according to American National Standards Institute (ANSI) Y14.5 requirements
- Studied engineering drawings to determine sequence of operations and finished dimensions of workpiece
- Created 3D parts and assembled them in SolidWorks to create prototypes that are ready for testing
- Prepared program codes for each specific cut and material
- Met all key milestone dates and successfully delivered final product to customer

Project 2 (CNC Manufactured Bottle Openers)
- Took lead in project management for scheduling meetings, events, labs, and tours with organizations
- Determined necessary materials and costs for product development using stress and engineering analysis
- Planned and assigned work tasks to meet production goals efficiently
- Measured mechanical parts with precise measuring tools to ensure dimensions are within tolerance

**Basic Machining – Lathes, Milling Machines, and Drill Presses** 09/2015 – 12/2016
- Positioned raw materials onto machines and secured them with clamps, bolts, and fixtures
- Hand tapped and drilled with detailed fixtures to assemble components
- Performed quality inspection on parts to ensure product met specifications of engineering drawings
- Kept work area and machine shop clean by regularly performing daily cleaning and maintenance to machinery

WORK EXPERIENCE

**Best Buy, Olympia, WA**
- **Sales Associate** 09/2012 – 12/2014
  - Recognized as top salesman and top performer for generating high revenue
  - Built rapport and positive relationships with customers to identify and recommend products that best fit their needs
  - Demonstrated products and educated customers with product knowledge
  - Worked in several departments within the store with great success and cross-trained employees
  - Ensured inventory on sales floor was always stocked and regularly set up marketing displays