

Washington University in St. Louis

## Washington University Open Scholarship

---

Mechanical Engineering Design Project Class

Mechanical Engineering & Materials Science

---

Fall 2014

### Treadle Driven Lathe

Eleanor B. Mullard

*Washington University in St Louis*

Daniel Kronthal

*Washington University in St Louis*

Aaron Cohn

*Washington University in St Louis*

Robert Borovsky

*Washington University in St Louis*

Follow this and additional works at: <https://openscholarship.wustl.edu/mems411>



Part of the [Mechanical Engineering Commons](#)

---

#### Recommended Citation

Mullard, Eleanor B.; Kronthal, Daniel; Cohn, Aaron; and Borovsky, Robert, "Treadle Driven Lathe" (2014).

*Mechanical Engineering Design Project Class*. 15.

<https://openscholarship.wustl.edu/mems411/15>

This Final Report is brought to you for free and open access by the Mechanical Engineering & Materials Science at Washington University Open Scholarship. It has been accepted for inclusion in Mechanical Engineering Design Project Class by an authorized administrator of Washington University Open Scholarship. For more information, please contact [digital@wumail.wustl.edu](mailto:digital@wumail.wustl.edu).

# **MEMS 411 Final Report**

## **Treadle Driven, Metal Cutting Lathe**

---

**Robert Borovsky, Aaron Cohn, Dan Kronthal, and Ellee Mullard**

## Table of Contents

List of Figures.....	4
List of Tables.....	6
1 Introduction.....	7
1.1 Project problem statement.....	7
1.2 List of team members.....	7
2 Background Information Study.....	7
2.1 Design brief.....	7
2.2 Relevant background information.....	8
3 Concept Design and Specification.....	8
3.1 User needs, metrics, and quantified needs equations.....	8
3.1.1 Record of the user needs interview.....	8
3.1.2 List of identified metrics.....	9
3.1.3 Table/list of quantified needs equations.....	11
3.2 Four concept drawings.....	12
3.3 A concept selection process.....	17
3.3.1 Concept scoring.....	17
3.3.2 Preliminary analysis of each concept's physical feasibility.....	17
3.3.3 Final summary.....	19
3.4 Proposed performance measures for the design.....	19
4 Embodiment and fabrication plan.....	21
4.1 Embodiment drawing.....	21
4.2 Parts List.....	22
4.3 Draft detail drawings for each manufactured part.....	25
4.4 Description of the design rationale for the choice/size/shape of each part.....	29
5 Engineering analysis.....	31
5.1 Engineering analysis proposal.....	31
5.1.1 A form, signed by your section instructor.....	31
5.2 Engineering analysis results.....	32
5.2.1 Motivation.....	32
5.2.2 Summary statement of analysis done.....	32
5.2.3 Methodology.....	33

5.2.4	Results.....	33
5.2.5	Significance.....	34
5.2.6	Summary of code and standards and their influence.....	34
6	Working prototype.....	34
6.1	A preliminary demonstration of the working prototype.....	34
6.2	Prototype photos.....	35
6.3	A short videoclip that shows the final prototype performing.....	55
7	Design documentation.....	55
7.1	Final Drawings and Documentation.....	55
7.1.1	A set of engineering drawings that includes all CAD model files and all drawings derived from CAD models.....	55
7.2	Final Presentation.....	56
7.2.1	A link to a video clip of final presentation.....	56
7.3	Teardown.....	56
8	Discussion.....	57
8.1	Using the final prototype produced to obtain values for metrics, evaluate the quantified needs equations for the design. How well were the needs met? Discuss the result.....	57
8.2	Discuss any significant parts sourcing issues? Did it make sense to scrounge parts? Did any vendor have an unreasonably long part delivery time? What would be your recommendations for future projects?.....	57
8.3	Discuss the overall experience:.....	58
8.3.1	Was the project more of less difficult than you had expected?.....	58
8.3.2	Does your final project result align with the project description?.....	58
8.3.3	Did your team function well as a group?.....	58
8.3.4	Were your team member's skills complementary?.....	58
8.3.5	Did your team share the workload equally?.....	58
8.3.6	Was any needed skill missing from the group?.....	58
8.3.7	Did you have to consult with your customer during the process, or did you work to the original design brief?.....	59
8.3.8	Did the design brief (as provided by the customer) seem to change during the process?.....	59
8.3.9	Has the project enhanced your design skills?.....	59
8.3.10	Would you now feel more comfortable accepting a design project assignment at a job?	59



8.3.11 Are there projects that you would attempt now that you would not attempt before?  
59

9	Appendix A - Parts List.....	60
10	Appendix B - Bill of Materials.....	61
11	Appendix C - CAD Models.....	62
12	Annotated Bibliography.....	70

## List of Figures

Figure 1: Concept Design #1.....	12
Figure 2: Concept Design #2A.....	13
Figure 3: Concept Design #2B.....	14
Figure 4: Concept Design #3.....	15
Figure 5: Concept Design #4.....	16
Figure 6: User Needs Metrics Table.....	17
Figure 7: Embodiment Drawing.....	21
Figure 8: Flywheel.....	24
Figure 9: Wood Lathe.....	24
Figure 10: Flywheel system concept drawing.....	25
Figure 11: Frame concept drawing.....	26
Figure 12: Pedal concept drawing.....	27
Figure 13: Rod-wheel sub assembly drawing.....	28
Figure 14: Analysis Tasks Agreement.....	31
Figure 15: Treadle system front view.....	35
Figure 16: Lathe gears and V-belt.....	36
Figure 17: Full prototype photo.....	37
Figure 18: Treadle to table connection and supports.....	38
Figure 19: Rear view.....	39
Figure 20: Chuck-key tool holder.....	40
Figure 21: Top-down view of Flywheel.....	41
Figure 22: Top-down view of lathe to flywheel connection.....	42
Figure 23: Treadle System.....	43
Figure 24: Pedal to pedal wheel connection.....	44
Figure 25: Pedal close-up.....	45
Figure 26: Flywheel (right) and drive-wheel (left).....	46
Figure 27: Flywheel belt connections.....	47
Figure 28: Flywheel.....	48
Figure 29: Holes and pins for gear changes.....	49
Figure 30: Gear change holes full view.....	50
Figure 31: Lathe and custom cutting tool.....	51
Figure 32: Custom cutting tool.....	52
Figure 33: Chuck and working piece.....	53
Figure 34: Pedal with springs and strap.....	54
Figure 35: Pedal springs.....	55
Figure 36: Pedal Wheel Assembly.....	62
Figure 37: Treadle Connector.....	63
Figure 38: Treadle.....	64
Figure 39: Treadle Assembly.....	65
Figure 40: Pedal Wheel Support.....	66
Figure 41: Pedal Wheel.....	67
Figure 42: Wheel and Belt Assembly.....	68
Figure 43: Full Treadle System.....	69



## List of Tables

Table 1: Critical Questions, customer statements and interpreted needs Table.....	8
Table 2: Needs Importance value table.....	9
Table 3: List of identified needs and metrics.....	10
Table 4: Parts List.....	22
Table 5: Parts list with costs and quantities.....	22
Table 6: Detailed parts list.....	59
Table 7: Bill of materials.....	61

## 1 Introduction

### 1.1 Project problem statement

The main objective of this senior design project was to design and build a treadle-driven, metal-cutting lathe that has the ability to cut 3/4" diameter material and produce small parts up to 3" long. The main challenge in this project was to successfully generate enough power through the treadle driven system to successfully cut metal at the proper specifications, while simultaneously meeting all of the user-needs. The entire system needed to be operated and pedaled by a single person, which put constraints on the location of the treadle relative to the lathe itself so the user can comfortably operate both at the same time. Furthermore, in order to generate adequate power and RPM to cut metal, implementing an energy-storage element to the treadle system was crucial. A heavy flywheel (salvaged from an old exercise bike) was the main source of energy storage in the system. The flywheel, coupled with a drive-wheel and a proper gear ratio proved to generate enough power to drive the system. To further aid the user, especially when initially pedaling the treadle to get started, springs were added at the pivot point of the pedal to help the treadle make full revolutions while getting up to speed. Wood and metal supports were placed in critical locations in order to reduce vibrations and increase the structural rigidity of the system in order to withstand the continual input forces from the user. Once the treadle-driven lathe was in working condition, the last step was to ensure that the lathe could operate at multiple speeds. Holes were drilled in the support table at specifically measured locations for each gear. The lathe is then moved over the holes of the desired gear, pins are dropped in place to secure the lathe in that position, and the v-belt is adjusted accordingly. We were successfully able to meet all of our key design metrics and user needs.

### 1.2 List of team members

Treadle Driven, Metal Cutting Lathe 1:

Robert Borovsky, Aaron Cohn, Dan Kronthal, and Eleanor Mullard

## 2 Background Information Study

### 2.1 Design brief

The goal of our project was to design and fabricate a lathe that is able to cut a 3/4 inch diameter material and produce small parts up to three inches long without the use of electricity. More specifically, our lathe must be treadle driven using human power and be able to cut metal of the given dimensions.

## 2.2 Relevant background information

There were a number of existing devices that are similar to what we wanted to design. Because there are many websites with manuals on the construction of a treadle lathe, we included the most relevant sources; these sources are listed and described below.

The VintageProjects website provides an overview of how to build a treadle-driven, ball-bearing woodturning lathe. It includes labeled diagrams with sizing and spacing of the design.  
<http://www.vintageprojects.com/machine-shop/woodlathe-treadle.pdf>

The ManyTracks website includes a step-by-step manual for purchase to build a treadle lathe which has similar specifications to our project. <http://manytracks.com/lathe/default.htm>

“Chop with Chris” is a YouTube user who has a passion for traditional woodworking using only hand tools; the video URL included shows him making a foot powered lathe.  
<http://youtu.be/eG9R0q9QJQc>

The Blood and Sawdust website has a step-by-step process to build a lathe; it also lists a number of other references regarding lathe construction.  
<http://www.bloodandsawdust.com/sca/lathes2.html>

There is also a patent (US 1500672 A) for a portable treadle lathe filed in 1922. Most other patents that we found in our research were filed before 1922.  
<http://www.google.com/patents/US1500672>

## 3 Concept Design and Specification

### 3.1 User needs, metrics, and quantified needs equations.

#### 3.1.1 Record of the user needs interview

Table 1: Critical Questions, customer statements and interpreted needs Table

Questions	Customer Statement	Interpreted Need	Importance
How many feet are required to power the treadle?	Only one foot can be used to power the treadle.	One foot powers treadle	5
How many speeds does the lathe need to operate at?	The lathe must operate at 3 different speeds or is continuously adjustable	Lathe operates at a minimum of 3 speeds	5

Can the lathe be operated by multiple people?	No, one person should be able to operate the lathe by himself.	Lathe operated by one person	5
Does the lathe need to store energy incase additional power is needed?	Yes, the lathe needs a method of power storage.	Lathe must store power mechanically	4
Can the lathe spin in both directions?	Yes, it must spin both clockwise and counter-clockwise	Lathe spins in both directions	4
Can the lathe be operated using electricity?	No, the lathe must be powered entirely by the treadle.	Lathe is powered mechanically by a treadle	5
Does the Lathe need to be lightweight and portable?	No, it is intended to be a permanent fixture in a machine shop.	Lathe is lightweight and portable	1
What material should the lathe be able to cut?	The lathe must be able to cut metal.	Lathe can cut metal	5

Table 2: Needs Importance value table

Need Number	Need	Importance
1	One foot powers treadle	5
2	Lathe operates at a minimum of 3 speeds	5
3	Lathe can be operated by one person	5
4	Lathe must store power mechanically	2
5	Lathe spins in both directions	4
6	Lathe is powered mechanically by a treadle	5

7	Lathe is lightweight and portable	1
8	Lathe can cut metal	5

### 3.1.2 List of identified metrics

Table 3: List of identified needs and metrics

Metric Number	Associated Needs	Metric	Units	Min Value	Max Value
1	1	One foot to power	binary	1	0
2	2, 8	Number of speeds	Integer	1	inf.
3	2, 8	Angular velocity	RPM	300	3000
4	7	Weight of flywheel	Lbs	5	50
5	4	Energy stored	Joules	2,000	10,000
6	4	Counter weight	Lbs	25	200
7	5	Spin direction	binary	1	0
8	6	Mechanical Input	binary	1	0
9	3	Number of people to operate lathe	Integer	1	2



3.1.3 Table/list of quantified needs equations

Treadle Driven Lathe		Metric																									
		One foot to power # of 5 speeds	Angular Velocity	Weight of Flywheel	Energy Stored	Counter Weight	Spin Direction	Mechanical Input	# of people to operate lathe										Need Happiness 1	Need Happiness 2	Need Happiness 3	Need Happiness 4	Importance Weight	Happiness Value 1	Happiness Value 2	Happiness Value 3	Happiness Value 4
Need #	Need	1	2	3	4	5	6	7	8	9																	
1	One foot powers treadler	1																1.000	1.000	1.000	1.000	0.156	0.156	0.156	0.156	0.156	
2	Lathe operates at minimum 3 speeds		0.8	0.2														0.017	0.600	0.850	0.083	0.156	0.003	0.094	0.133	0.013	
3	Lathe operated by one person									1								1.000	1.000	1.000	1.000	0.156	0.156	0.156	0.156	0.156	
4	Lathe must store power mechanically					0.8	0.2											0.000	0.710	0.000	0.160	0.063	0.000	0.044	0.000	0.010	
5	Lathe spins in both direction							1										1.000	1.000	1.000	1.000	0.125	0.125	0.125	0.125	0.125	
6	Lathe is powered mechanically by a treadle								1									1.000	1.000	1.000	1.000	0.156	0.156	0.156	0.156	0.156	
7	Lathe is lightweight and portable				1													0.667	0.444	0.000	0.556	0.031	0.021	0.014	0.000	0.017	
8	Lathe can cut metal		0.5	0.5														0.042	0.750	0.625	0.208	0.156	0.007	0.117	0.098	0.033	
	<b>Units</b>	binary	integer	RPM	Lbs	J	Lbs	binary	binary	integer								<b>Total</b>				0.440	0.863	0.824	0.667		
	<b>Best Value</b>	1	5	1500	5	10000	200	1	1	1																	
	<b>Worst Value</b>	0	1	300	50	0	0	0	0	2																	

3.2 Four concept drawings

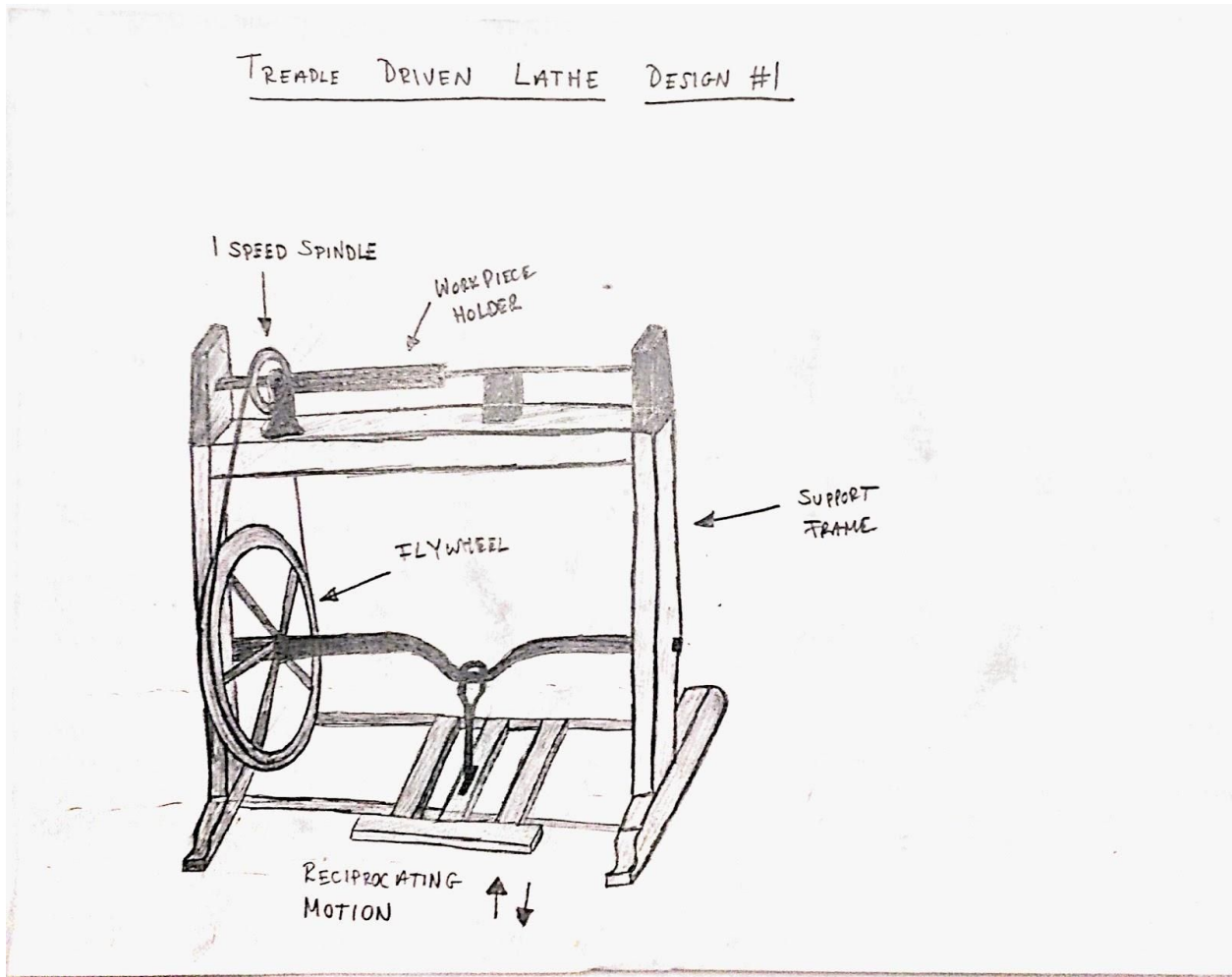


Figure 1: Concept Design #1

# TREADLE DRIVEN LATHE DESIGN 2A

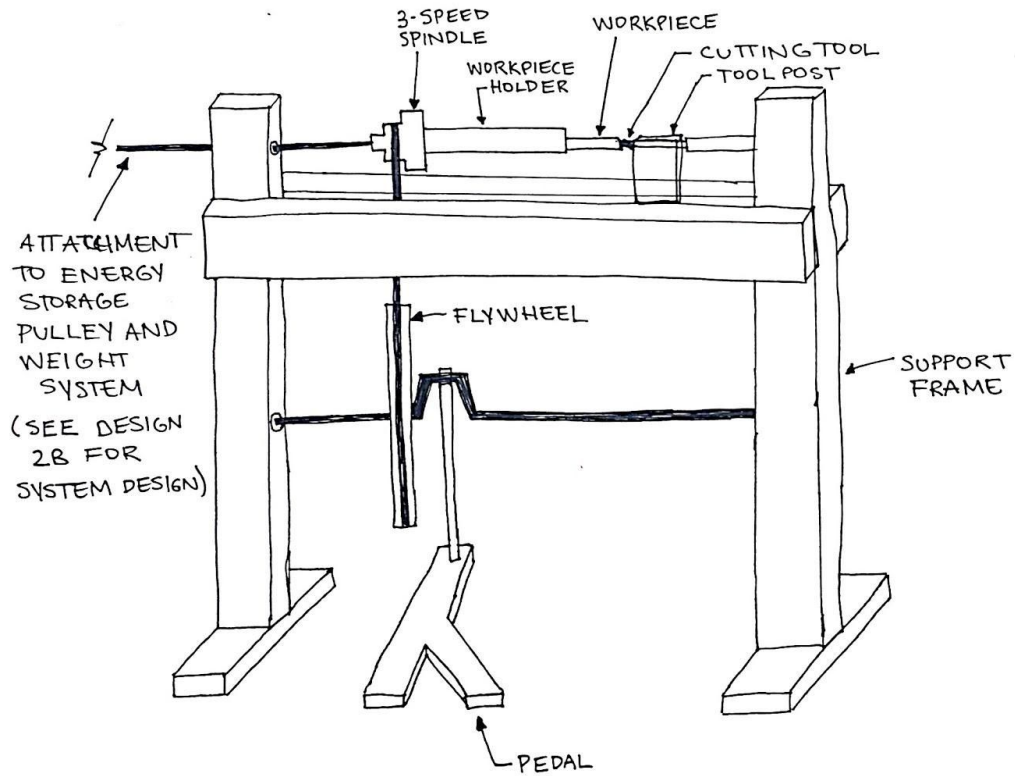


Figure 2: Concept Design #2A

TREADLE DRIVEN LATHE  
DESIGN 2B

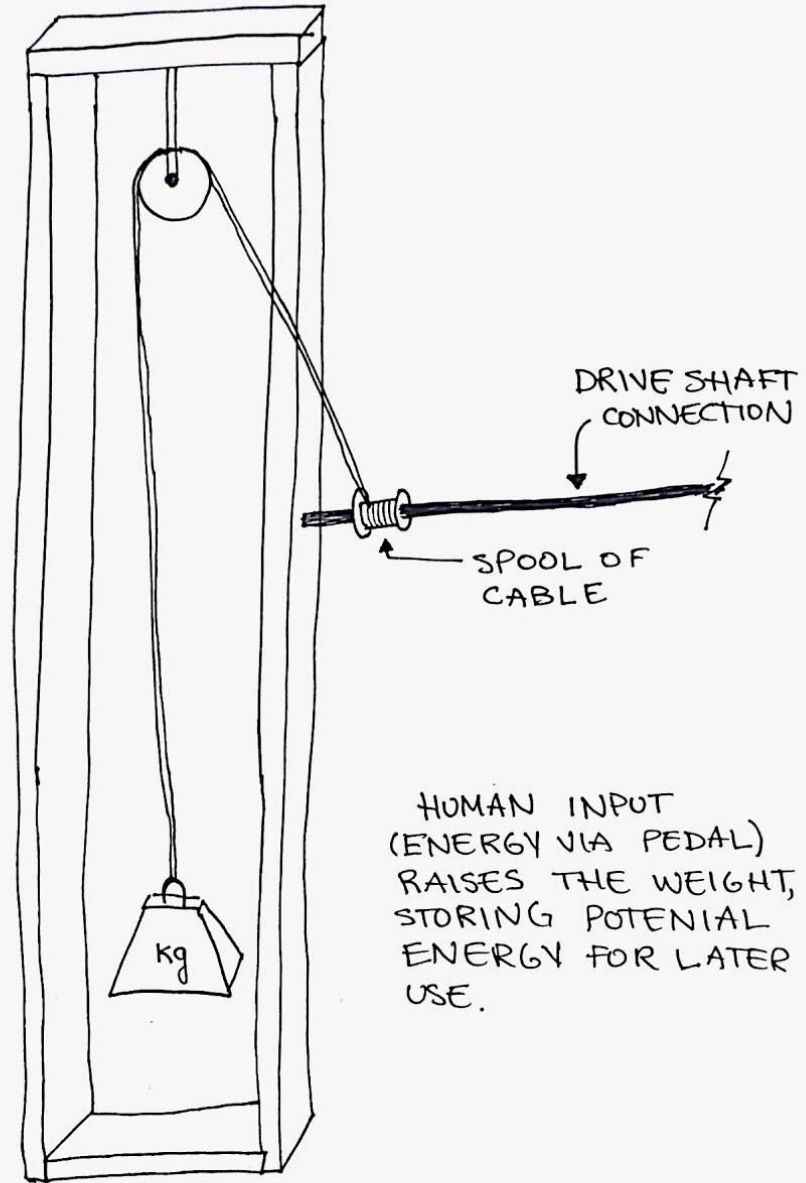


Figure 3: Concept Design #2B

TREADLE DRIVEN LATHE : CVT DESIGN #3

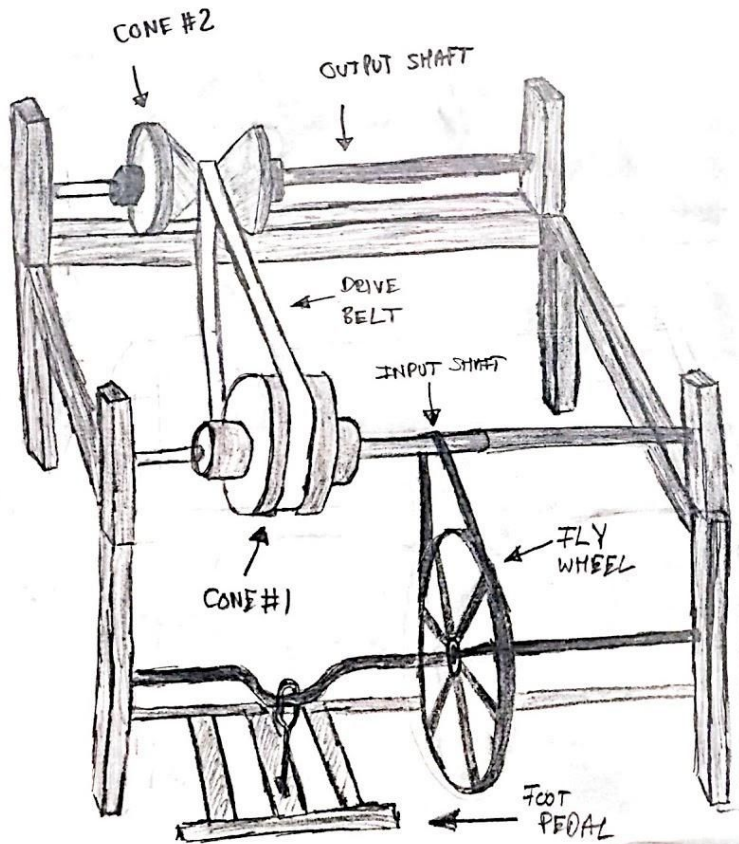


Figure 4: Concept Design #3

TREADLE DRIVEN LATHE  
DESIGN 4

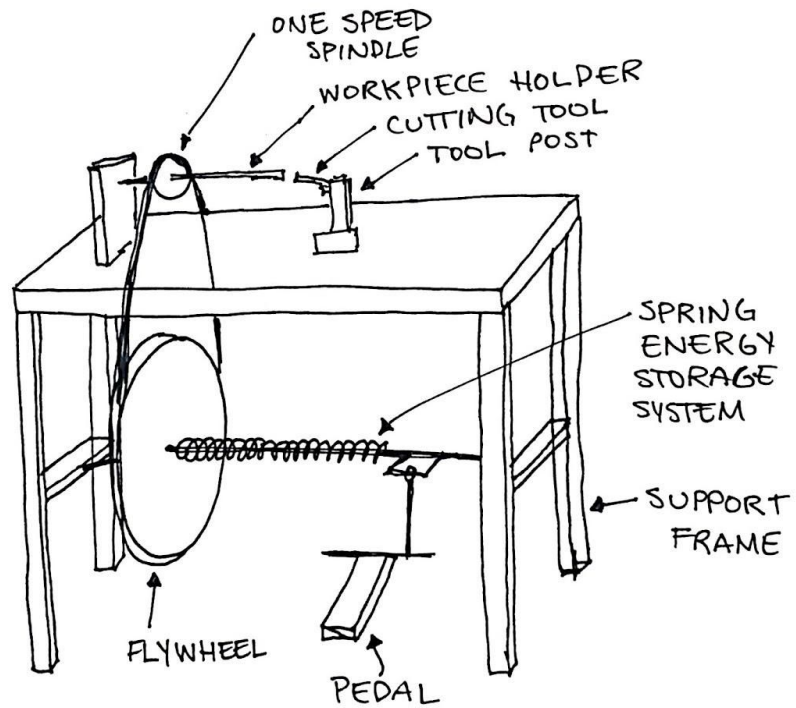


Figure 5: Concept Design #4



### 3.3 A concept selection process

#### 3.3.1 Concept scoring

Need #	Need	Metric																							
		1	2	3	4	5	6	7	8	9							Need Happiness 1	Need Happiness 2	Need Happiness 3	Need Happiness 4	Importance Weight	Happiness Value 1	Happiness Value 2	Happiness Value 3	Happiness Value 4
1	One foot powers treadler	1															1.000	1.000	1.000	1.000	0.156	0.156	0.156	0.156	0.156
2	Lathe operates at minimum 3 speeds		0.8	0.2													0.017	0.600	0.850	0.083	0.156	0.003	0.094	0.133	0.013
3	Lathe operated by one person									1							1.000	1.000	1.000	1.000	0.156	0.156	0.156	0.156	0.156
4	Lathe must store power mechanically					0.8	0.2										0.000	0.710	0.000	0.160	0.063	0.000	0.044	0.000	0.010
5	Lathe spins in both direction									1							1.000	1.000	1.000	1.000	0.125	0.125	0.125	0.125	0.125
6	Lathe is powered mechanically by a treadle												1				1.000	1.000	1.000	1.000	0.156	0.156	0.156	0.156	0.156
7	Lathe is lightweight and portable				1												0.667	0.444	0.000	0.556	0.031	0.021	0.014	0.000	0.017
8	Lathe can cut metal		0.5	0.5													0.042	0.750	0.625	0.208	0.156	0.007	0.117	0.098	0.033
	<b>Units</b>	binary	integer	RPM	Lbs	J	Lbs	binary	binary	integer							<b>Total</b>				0.440	0.863	0.824	0.667	
	Best Value	1	5	1500	5	10000	200	1	1	1															
	Worst Value	0	1	300	50	0	0	0	0	2															
	Actual Value 1	1	1	400	20	0	0	1	1	1															
	Metric Happiness 1	1	0	0.08	0.7	0	0	1	1	1															
	Actual Value 2	1	3	1500	30	7000	150	1	1	1															
	Metric Happiness 2	1	0.5	1	0.4	0.7	0.8	1	1	1															
	Actual Value 3	1	5	600	50	0	0	1	1	1															
	Metric Happiness 3	1	1	0.25	0	0	0	1	1	1															
	Actual Value 4	1	1	800	25	2000	0	1	1	1															
	Metric Happiness 4	1	0	0.42	0.6	0.2	0	1	1	1															

Figure 6: User Needs Metrics Table

#### 3.3.2 Preliminary analysis of each concept's physical feasibility

##### Design 1:

The biggest challenge that we faced in designing the treadle driven lathe is delivering enough power to the lathe to achieve a workable RPM range. Design 1 is the most simple of our four designs. It is driven by a treadle and a large fly wheel that is connected to a one-speed spindle. The obvious challenge of using a one-speed spindle is generating enough torque to keep the workpiece spinning while the cutting tool comes in contact with it. A one speed design would require a nearly perfect gear ratio between the flywheel and the spindle, which is very difficult to achieve while also keeping user power input to realistic human capabilities. The treadle portion of design 1 is definitely a useful design baseline because it lays out the general foot powered reciprocating motion that ultimately powers the lathe. There are different ways to use reciprocating motion, however, in this design we use a foot-powered pedal that has a rod that is connected to a shaft that is connected to a large flywheel. The shaft has a specific bend that converts the up/down motion from pedal into rotational motion of the flywheel. The large diameter flywheel has a belt that connects it to the much smaller diameter spindle, causing the spindle to rotate at a high RPM value. This design is easy and intuitive to use, but may require excessive user input power.

##### Design 2:

The main differences between designs 1 and 3 are as follows:

- 3-speed spindle
- Different foot-pedal configuration
- Energy storage pulley/weight system

First of all, the 3-speed spindle allows for more variability in terms of gear ratios and torque. This gives the user more options when operating the lathe, and has the potential to help minimize user power input while still achieving the workable RPM range of the lathe. Next, the new foot pedal configuration focuses more on ergonomics and comfort of the user. The goal of the pedal style is to maximize power output while still maintaining user ease and comfort. Furthermore, the energy storage pulley/weight system is what truly sets this design apart from the first design. The reciprocating motion of the foot pedal will cause the flywheel to rotate, which in turn will raise a large weight upwards a certain height through the mechanical advantage of a series of pulleys. Once the weight is at its maximum height, the user will stop pedaling, and allow the weight to slowly drop, causing the lathe to spin at the desired RPM range based on calculations of the gear ratios and pulley system. The main challenges that go along with this energy storage system are as follows:

- Safety
- Weight raising time
- Weight drop time
- Consistent RPM
- Max RPM
- Ease of use

The biggest concern next to safety considerations is ensuring that the weight falls slowly enough to allow for the user to have ample time to actually use the lathe before the weight drops to the ground, while simultaneously ensuring that the lathe is spinning within the working RPM range. Balancing “work-time” with RPM range will be the biggest challenge with this design, however, it is possible through experimentation of gear ratios paired with the pulley-system.

### **Design 3:**

This design is similar to design 1 in terms of the treadle and lack of energy storage, however, the flywheel is connected to a CVT (continuously variable transmission). The advantage of the CVT is that it allows for an infinite number of gear ratios, which in turn gives the user many options for operation of the lathe that balances foot power with output RPM. The CVT is a system of two “cones” that are able to change the diameter in which the belt rides between them through translational motion, which in turn changes the gear ratio. The main challenge with the CVT is ease of use. Changing the gear ratios requires the user to move the cones inwards/outwards. The belt may slip during this process, which may cause the lathe to stop spinning. While the advantages of having a working CVT are clear, the disadvantages in terms of complexity and user-ease may be enough to stay away from this design.

### **Design 4:**

This design is similar in structure to design 1 but differs in the pedal design and has an energy storage system. In this design, the pedal works more like a pump, or stair-master type element, for ease of use. This method is much more likely to reduce user fatigue and produce more energy. Also unlike the other designs, this design has a spring energy storage system. When the pedal is pumped, the



spring tightens and then once the spring has reached maximum tightness, the release will power the motion of the lathe even when the user is no longer pumping the pedal.

### 3.3.3 Final summary

Winner: **Design 2**

Design 2 has several advantages over the other three designs. It includes an energy storage system that is more plausible and powerful than the energy storage system in design 4 and a more ergonomic pedal design. The energy storage system is what truly sets this design apart from the others. With proper experimentation with gear ratios and a pulley system, this design has the potential to be powered solely by the power generated by one's foot to raise the large counterweight, and the counterweight's own potential energy will power the lathe to a working RPM range. The three speed spindle also adds more variability to this design which makes it superior to designs 1 and 4. The 3-speed spindle is also less complex and easier to use than the CVT in design 3. However, using a flywheel as a mechanical energy storage system for the prototype is also a viable option that could replace the dropping weight; this would likely be easier to implement and safer.

## 3.4 Proposed performance measures for the design

### Performance Goals:

1. Machines a cylindrical part in less than 3 minutes
2. Amount of counter weight is adjustable per operator's desire
3. Various speed spindle can be changed within a matter of seconds
4. Counter weight can be removed from main axle for "recharging"
5. Counterweight mechanism is compatible with various types of weights
6. Lathe outputs enough torque to cut through metal easily
7. The pulley-flywheel system allows for maximum torque
8. The support frame is sturdy enough for the heavy weights associated with the design and will not shake during operation
9. Design allows a pre-owned lathe to be modified with the treadle for power input
10. Operator can stand or sit while operating the lathe and treadle

## **4 Embodiment and fabrication plan**

### **4.1 Embodiment drawing**

# TREADLE-DRIVEN LATHE EMBODIMENT

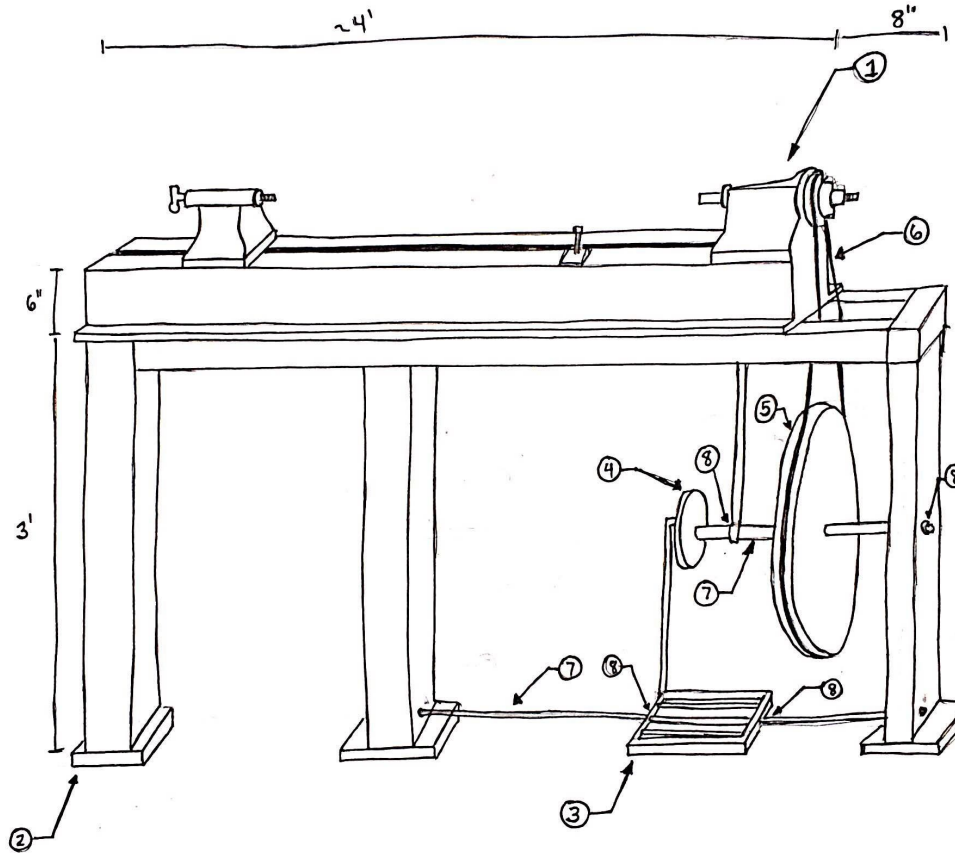


Figure 7: Embodiment Drawing

## 4.2 Parts List

Table 4: Parts List


<i>Part Number</i>	<i>Part</i>
<b>1</b>	Lathe
<b>2</b>	Frame
<b>3</b>	Pedal
<b>4</b>	One-Way Locking Steel Needle Roller Bearing
<b>5</b>	Flywheel
<b>6</b>	Drive belt
<b>7</b>	Drive and Pedal shafts
<b>8 (x4)</b>	¾" diameter ball bearings

Table 5: Parts list with costs and quantities

<i>Part</i>	<i>Use</i>	<i>McMaster Carr Part No. or website</i>	<i>Cost per part</i>	<i># of part needed</i>
¾" diameter One-Way Locking Steel Needle Roller Bearing	Free Wheel bearing	2489K6	\$13.84	1
Plain Open ¾" Shaft Diameter Steel Ball Bearing	Allow low friction spinning	6383K49	\$7.20	4
Plain Open ½" Shaft Diameter Steel Ball Bearing	Allows low friction spinning	6383k34	\$7.36	2
Lathe	Machines parts	<a href="https://stlouis.craigslist.org/tls/4635188328.html">https://stlouis.craigslist.org/tls/4635188328.html</a>	\$75	1

Flywheel	Stores rotational energy	<a href="http://www.ebay.com/itm/15-034-Primitive-Antique-Cast-Iron-Fly-Wheel-Industrial-Machine-Age-Steam-punk-/231320915929?_trksid=p2054897.l4275">http://www.ebay.com/itm/15-034-Primitive-Antique-Cast-Iron-Fly-Wheel-Industrial-Machine-Age-Steam-punk-/231320915929?_trksid=p2054897.l4275</a>	\$29.95	1
3/4" diameter 48" Drive shaft	Supports Pedal, Flywheel, and freewheel	1346K34	\$45.57	2
Flat Belt	Transmits energy from flywheel to lathe	9485T12	\$.64 per inch	75 inches
Wood 2x4	frame and pedal construction	(scavenged from machine shop if available)	\$0	undetermined
Nails	frame and pedal	(scavenged from machine shop if available)	\$0	undetermined
Lathe cutting tools and chuck	Cuts metal and holds piece	(borrow from machine shop)	\$0	whatever is available to borrow
Total			\$301.25	

15" Primitive Antique Cast Iron Fly Wheel Industrial Machine Age



Here is a large, 21" cast iron hand cranked fly wheel, fresh from the farm. Has nice original rusty patina plus a little dirt. Hub has an 3/4" opening and outside edge is 1 1/4" ...

See more details at eBay »

**\$29.95** eBay  
+\$15.87 shipping. No tax

Used

Save to Shortlist

Figure 8: Flywheel



Figure 9: Wood Lathe

4.3 Draft detail drawings for each manufactured part

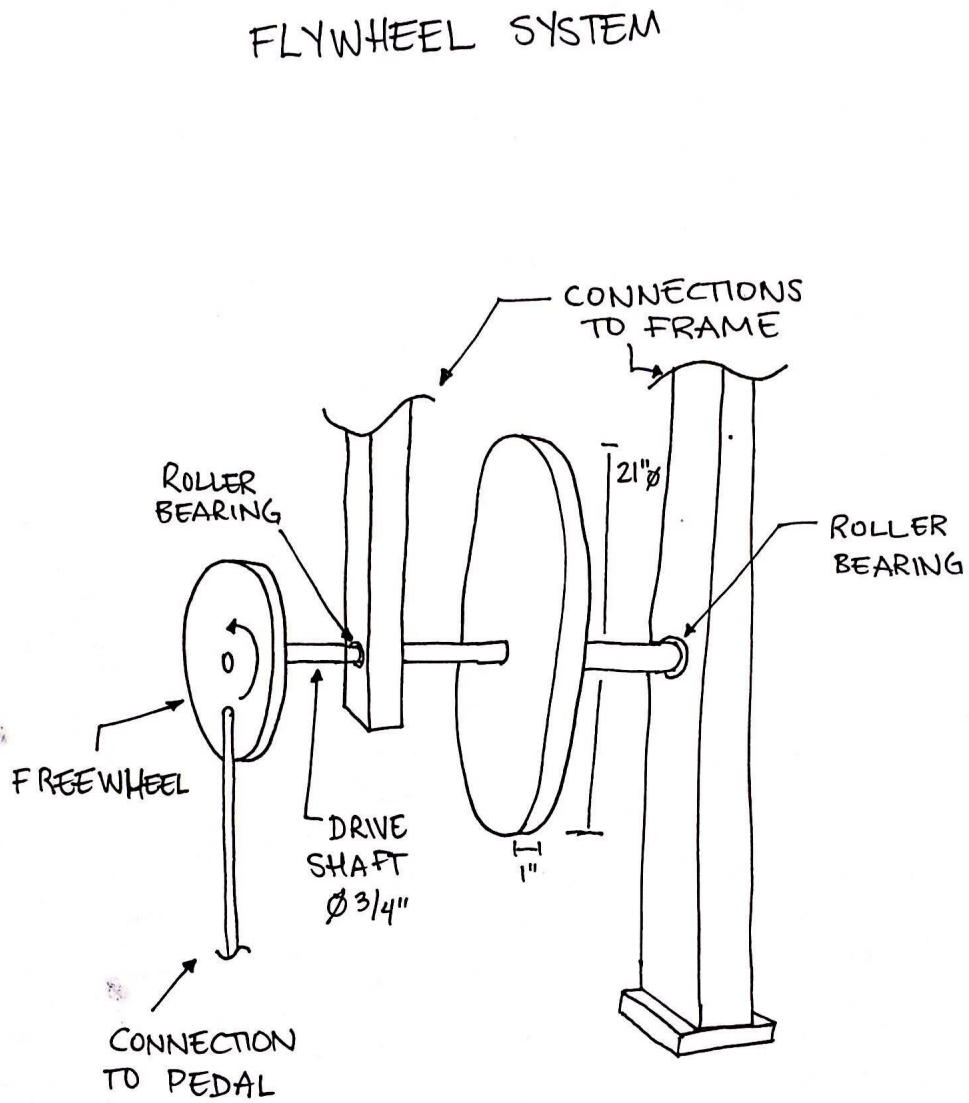


Figure 10: Flywheel system concept drawing

# FRAME

## MATERIALS

- WOOD
- NAILS
- 2 BEARINGS
- POSSIBLY L-SHAPED BRACKETS FOR ADDITIONAL SUPPORT

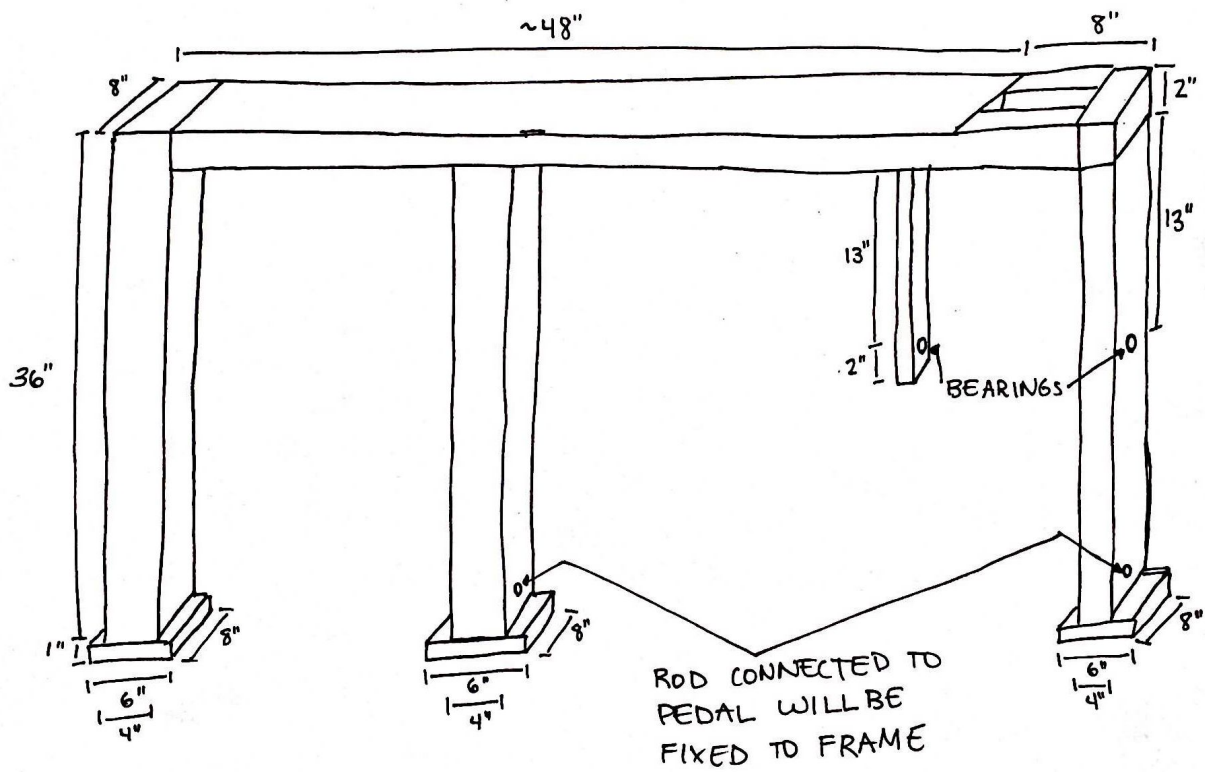


Figure 11: Frame concept drawing



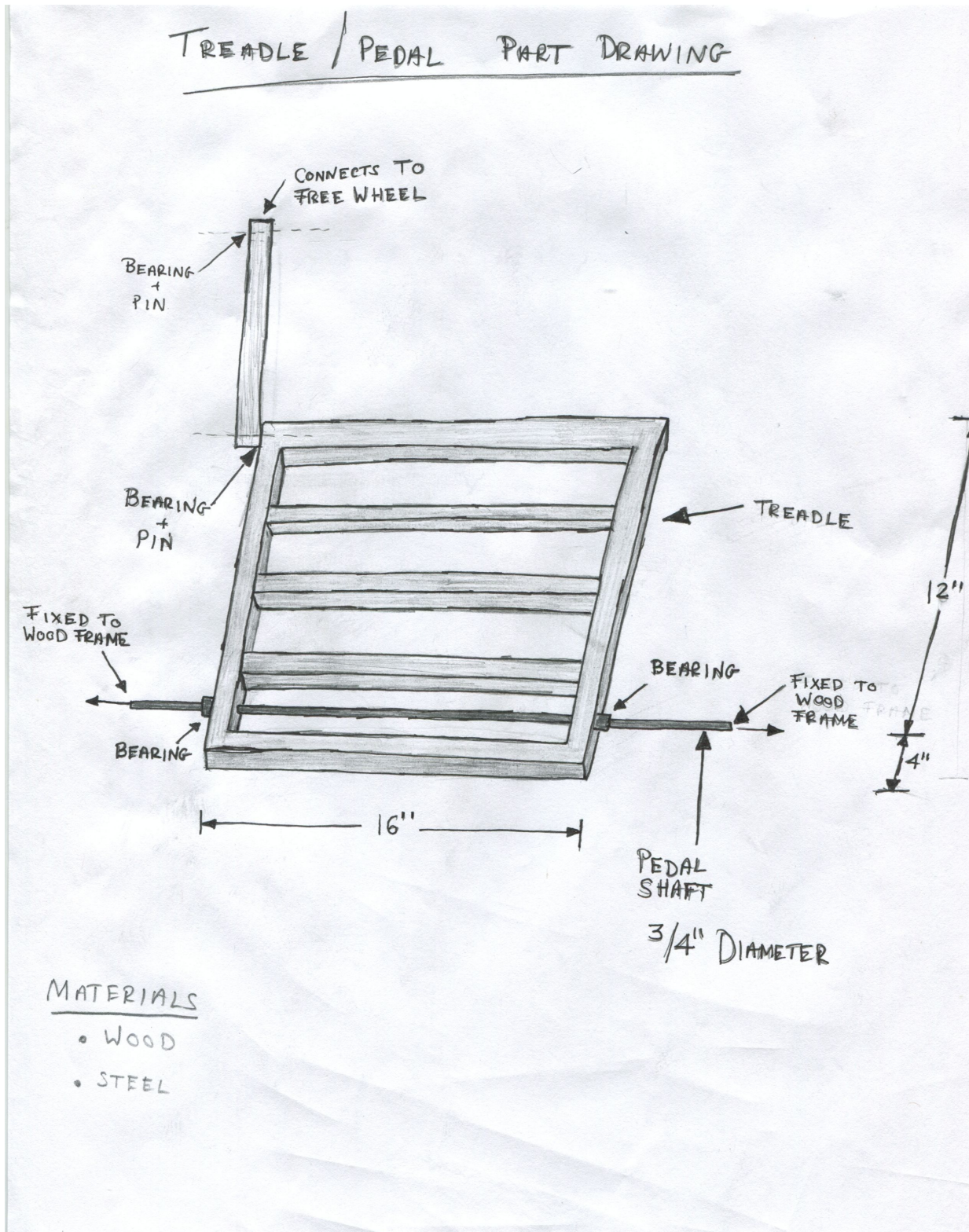


Figure 12: Pedal concept drawing



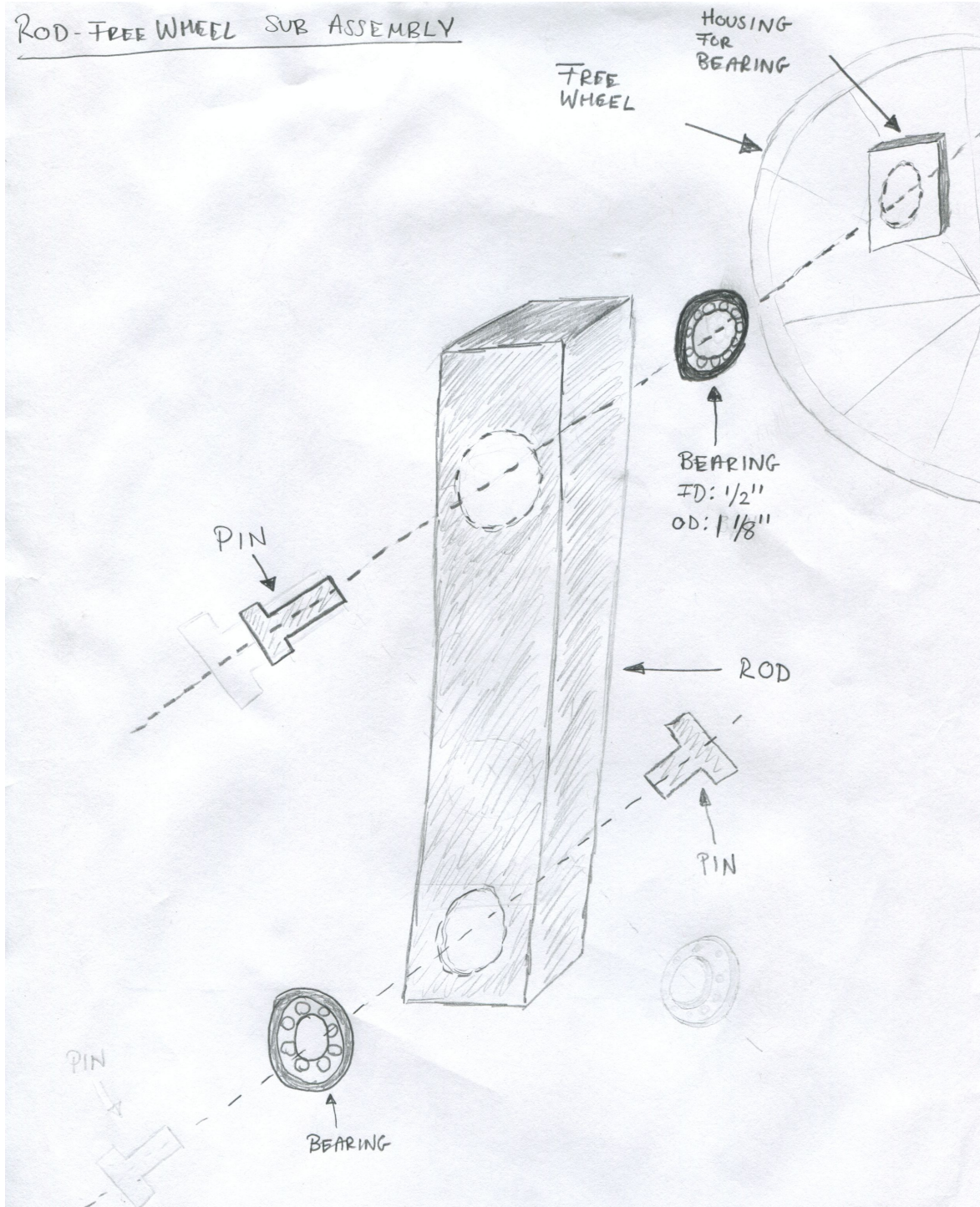


Figure 13: Rod-wheel sub assembly drawing

#### 4.4 Description of the design rationale for the choice/size/shape of each part

For the most effective flywheel, we determined it was necessary to have a large mass and a large diameter. We wanted a flywheel with a large moment of inertia so that the wheel would not stop spinning even when the pedal no longer had an input of power and would be capable of storing mechanical energy for a long period of time. We calculated the mass and radius of the flywheel necessary to achieve a power output able to drive a shaft fast enough to cut metal; these calculations are below.

Power needed to cut Aluminum:

Estimate of cutting speed needed: 250 ft/min

Estimate of Feed Rate: .01 Feed per Revolution

Diameter=  $\frac{3}{4}$  in

RPM= (Cutting speed \* 4)/Diameter

RPM= (250 ft/min \* 4)/(.75) = 1333.33 RPM

Angular velocity= 1333.33 RPM = 139.6 rad/s

Density of aluminum: .098 lb/in<sup>3</sup>

.098 lb/in<sup>3</sup> \* ((3.14\*.75)/4 in<sup>2</sup> \* 3 in) = 1.77 lbs

$I = (\frac{1}{2})mr^2 = .5*1.77*(1/16)^2 = .0035 \text{ lbm-ft}^2$

Energy=  $\frac{1}{2}IW^2 = \frac{1}{2}*.0035*139.6^2 = \mathbf{34.1}$  foot-pound force

Mass estimation for chosen flywheel:

Diameter = 21"

Width = 1.25"

Density of gray cast iron = .258 lb/in<sup>3</sup>

Most of volume in 1" lip of wheel

Volume =  $(\pi/4)(21^2-20^2)(1.25) = \sim 32 \text{ in}^3$

Mass of wheel = (32)(.258) = **~8lbs**

Moment of Inertia calculation:

$I = \frac{1}{2} m (r_o^2 - r_r^2) = \frac{1}{2} (8)(0.875^2 - 0.833^2) = \mathbf{0.287 \text{ lbm-ft}^2}$

Angular Velocity of Flywheel needed to cut metal:

$$E_{\text{rotational}} = \frac{1}{2} I \omega^2$$

$$34.1 = (\frac{1}{2})(.287)(\omega^2)$$

$$\omega = 15.4 \text{ rad/s} = \mathbf{147 \text{ RPM}}$$

The above theoretical calculation is the RPM of the flywheel necessary to provide enough energy to cut a piece of aluminum of specific dimensions. Once we purchase the lathe with its various fixed gear ratios on the drive shaft, we will be able to further calculate the exact RPM of the flywheel necessary for each gear speed. Once we know the mass of the chuck and the gears attached to the lathe we purchase, we can adjust our calculation for the spinning parts. Using this new moment of inertia, we will calculate a new energy required. Using this new energy, we will calculate a more accurate value of RPM that the flywheel needs to spin.

We plan to attach the treadle to an additional wheel that contains a one-way locking steel needle roller bearing, as opposed to attaching the pedal directly to the flywheel. This is a crucial design choice because it allows the flywheel to continue spinning even when the treadle/pedal is not receiving power input from the user. In other words, the flywheel can “coast” much like a bicycle wheel keeps spinning even when the rider stops pedaling. This will allow the user to input power to the treadle, which then spins the free wheel, which is fixed to the shaft with the one-way bearing, which then directly powers the flywheel, which ultimately powers the lathe. Without this one-way bearing, the lathe may not be an efficient.

We chose to build the frame for the lathe out of wood. Wood was chosen because it is a lighter and cheaper material than metal. The frame needs to be strong enough to support the weight of the lathe and the wood will be more than strong enough to do this. The exact design of the frame is entirely dependant on the lathe we purchase. The dimensions of the lathe, as well as the location of the gears, will drive the shape of our frame. The lathe listed above in the parts list has not yet been purchased, and no dimensions were provided in its description.

## 5 Engineering analysis

### 5.1 Engineering analysis proposal

#### 5.1.1 A form, signed by your section instructor

**ANALYSIS TASKS AGREEMENT**

PROJECT: Treadle Lathe NAMES: Robert Borovsky <sup>RB</sup> INSTRUCTOR: Juhvelo  
Aaron Cohen AC  
Don Kramlich DK  
Elise Mullund EM

The following engineering analysis tasks will be performed:

- Flywheel will be used to store energy
- we will need to calculate the mass and radius of the flywheel to achieve the power needed
- we will have to calculate the amount of energy needed to cut metal to be exact specs of our lathe problem.
- we will need to calculate the proper "gear ratios" for the drive belt in order to obtain the RPMs desired
- we will calculate the power output of a human pushing a treadle, so we know the max input power into our system
- we need to determine the appropriate Free wheel set up (attached to flywheel) to allow continuous spinning of the flywheel when the pedal is not being pedaled

Figure 14: Analysis Tasks Agreement

The work will be divided among the group members in the following way:

We will all specialize in one aspect of the design:

Bobby: Flywheel

Aaron: Gears

Dan: Drive Shaft

Ellec: Treadle mechanism

Instructor signature: TJB; Print instructor name: T. BEVER

(Group members should initial near their name above.)

## 5.2 Engineering analysis results

### 5.2.1 Motivation

Primarily, we need to determine the energy carried by the flywheel. In order to efficiently cut metal, the spinning lathe needs to have high RPM and significant torque. This torque is due to the heavy flywheel spinning rapidly and thus carrying tremendous inertia. Should the flywheel not have enough inertia, the lathe would slow down or stop once the cutting tool is applied to the spinning piece of metal.

Secondly, we need to analyze the transmission ratio of the lathe. Since our design does not include a freewheel, the pedal will move continuously when the flywheel is spinning. In order for the pedal to maintain a safe speed of operation, there must be a very high transmission ratio between the pedal and the spinning chuck of the lathe. If the ratio were low, the pedal would pump at a dangerously high speed when the desired RPM of the chuck were reached.

Moving forward, we will measure our experimentally achieved transmission ratio and energy output from the flywheel to see if we can safely operate the lathe to cut metal. If we fail, we know we need to either increase the transmission ratio or implement a larger or more massive flywheel.

### 5.2.2 Summary statement of analysis done

First, we measured the diameters of all of the wheels used in the design. Knowing that transmission ratios are directly proportional to the ratio of the diameters of the wheels, we were able to calculate the theoretical transmission ratio of our lathe for all possible gear ratios speeds.

Transmission ratio =  $(r_1/r_2)$



Next, we measured the mass of the flywheel, and measured its dimensions. Using this information, we calculated the moment of inertia and energy using the following equations:

$$I = \frac{1}{2}mr^2 \quad \text{and} \quad E = \frac{1}{2}IW^2$$

The energy estimate compares favorably to the energy required to cut metal. The calculations can be seen below in the “results” section.

### 5.2.3 Methodology

The first thing calculated was the transmission ratio of the flywheel and lathe. To do this we measured the diameters of the pedal, flywheel, and lathe. The ratio of these diameters was used to find the transmission ratio between the pedal wheel and lathe.

To do the analysis of the energy stored in the flywheel, we first had to calculate the RPM of the flywheel. To find the RPM of the flywheel, the RPM of the pedal wheel had to be estimated through estimation; we observed how many times the pedal wheel completed a full rotation in a minute. Using this RPM, it was possible to calculate the RPM of the flywheel by using the transmission ratio between the flywheel and pedal that had already been calculated. The RPM was then converted to angular speed and the energy then calculated using the equation  $T = 0.5 * I * \omega^2$ .

### 5.2.4 Results

Through observation of our final product and calculations in our analysis study, we determined the following results. Initially, we were unsure if a human powered lathe would be able to produce enough power to cut metal, but through observation of our final product, we determined that human power is sufficient to spin the lathe at a sufficient rate. We also calculated the RPM of the chuck using gear ratio equations. From these calculations, we know that the chuck can spin at approximately 560 RPM. Using the mass (11.34 kg) and the radius (0.1524 m) of the flywheel, we calculated the inertia of the flywheel using the equation  $I = \frac{1}{2} MR^2$  to be 0.1317 kg m<sup>2</sup>. The higher the inertia of the flywheel, the more resistant the flywheel will be to changes in rotational speed, which helps to preserve the rotation speed of the flywheel even when the system is not being pedaled. We also calculated the kinetic energy, or stored mechanical energy, of the flywheel using the calculated inertia and the angular momentum (58.64 rad/s) using the equation  $\frac{1}{2} I * \omega^2$  to equal 226.44 J. All of these results make sense and are plausible.

### 5.2.5 Significance

The results of the analysis will affect the final prototype in a number of ways. First, we need to make structural improvements. The initial prototype is essentially three separate units: the lathe, the pedal system, and the sawhorse supports. The final prototype will need to have a permanent and more structurally sound frame that connects all of these elements securely. Secondly, to ensure the pedal will reach the top of the stroke each time, we will need to add springs beneath the pedal and a foot strap atop the pedal. Thirdly, the belt on our initial prototype was slipping when too much force was applied. Applying belt dressing, as well as increasing the tension of the belt will decrease the slippage an adequate amount. Lastly, the connection piece between the pedal and the pedal wheel was not secure, nor was it frictionless. For the final prototype, this connection will need to be redesigned to improve its stability and reduce the amount of friction (and therefore energy loss) in the system.

### 5.2.6 Summary of code and standards and their influence

The primary standard that we followed during revision of our design was to ensure the safety of the user. Our design initially featured a falling weight that would have driven the spinning of the lathe. We rejected this idea in favor of a spinning flywheel because we felt that a heavy weight falling from a high height could potentially lead to safety concerns. We also revised our prototype by adding more support for our flywheel system to increase the stability of the treadle. Initially the treadle was unstable while spinning at high speeds so cross supports were added to prevent the treadle's frame from breaking which could have injured a user. We also added Loctite to many of our critical nuts so that we could ensure that the system was sturdy under the load of the spinning flywheel.

## 6 Working prototype

### 6.1 A preliminary demonstration of the working prototype

This video (<http://youtu.be/i59I6SRlgaw>) shows one of the earliest working prototypes. Initially, the lathe was placed on two sawhorses and the treadle system placed next to it, connected with a v-belt going around the flywheel. We had a lot of issues with the belt slipping off the flywheel and also maintaining tension.

This video (<http://youtu.be/LIK0jur-oFw>) shows an improved version of our prototype. We used epoxy to adhere a gear system on the side of the flywheel that both improved the tension and fixed the slipping problem. The lathe setup, however, has not yet been improved.



This video (<http://youtu.be/GuTR5AuP8qU>) shows the treadle system disconnected from the lathe. It shows the ease-of-use of the system and how fast the flywheel can get spinning in a short amount of time.

## 6.2 Prototype photos



Figure 15: Treadle system front view



Figure 16: Lathe gears and V-belt

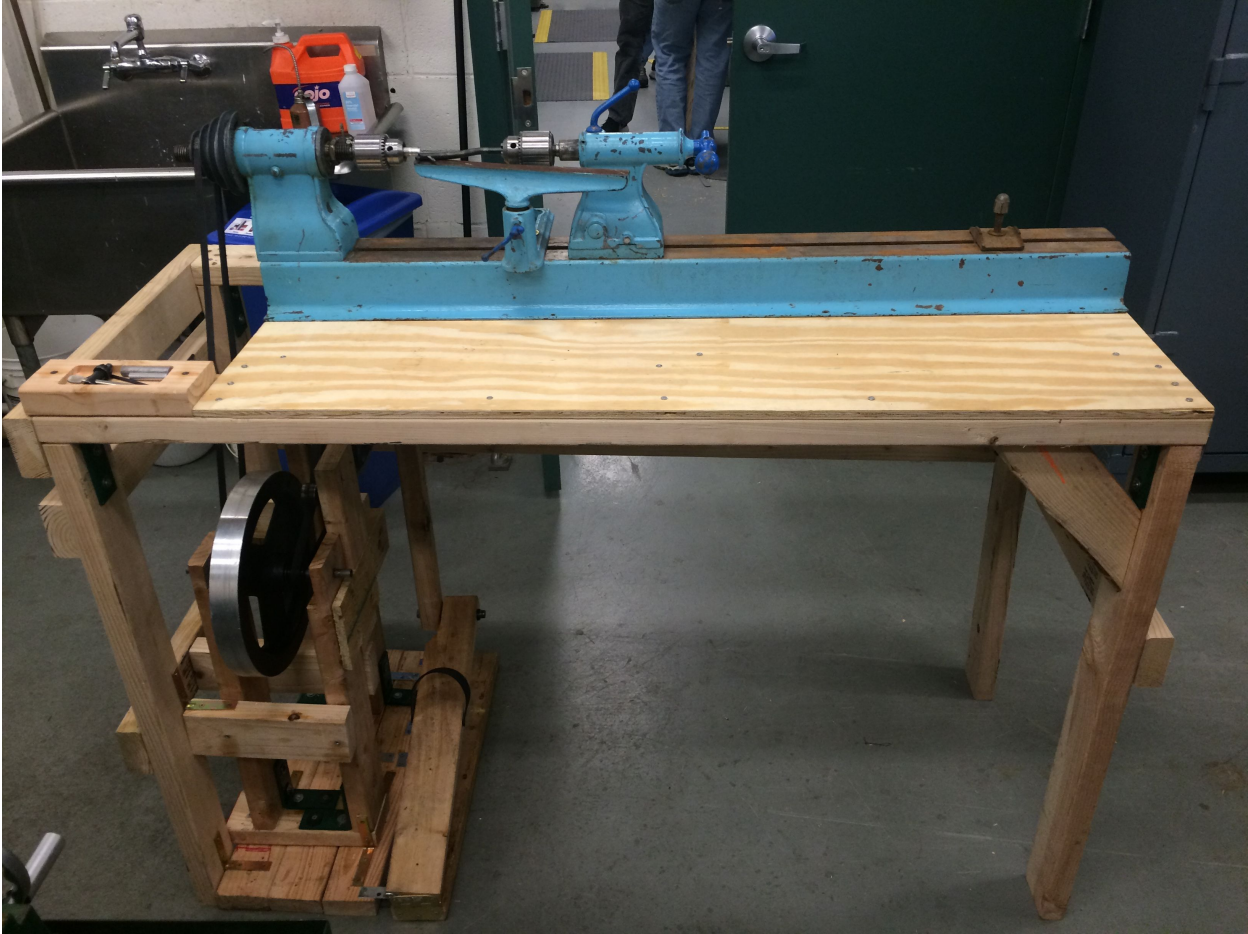


Figure 17: Full prototype photo





Figure 18: Treadle to table connection and supports



Figure 19: Rear view



Figure 20: Chuck-key tool holder





Figure 21: Top-down view of Flywheel



Figure 22: Top-down view of lathe to flywheel connection



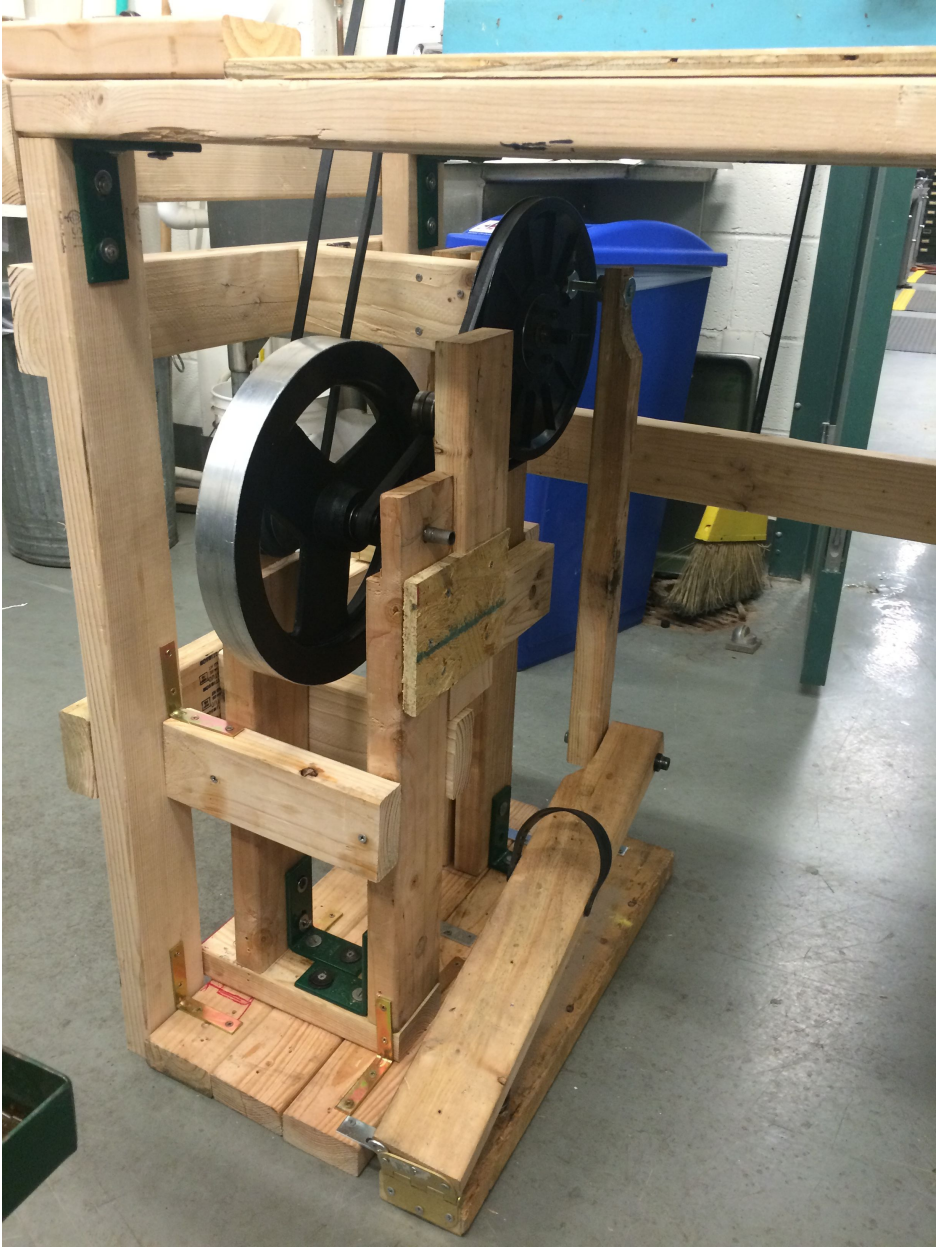


Figure 23: Treadle System

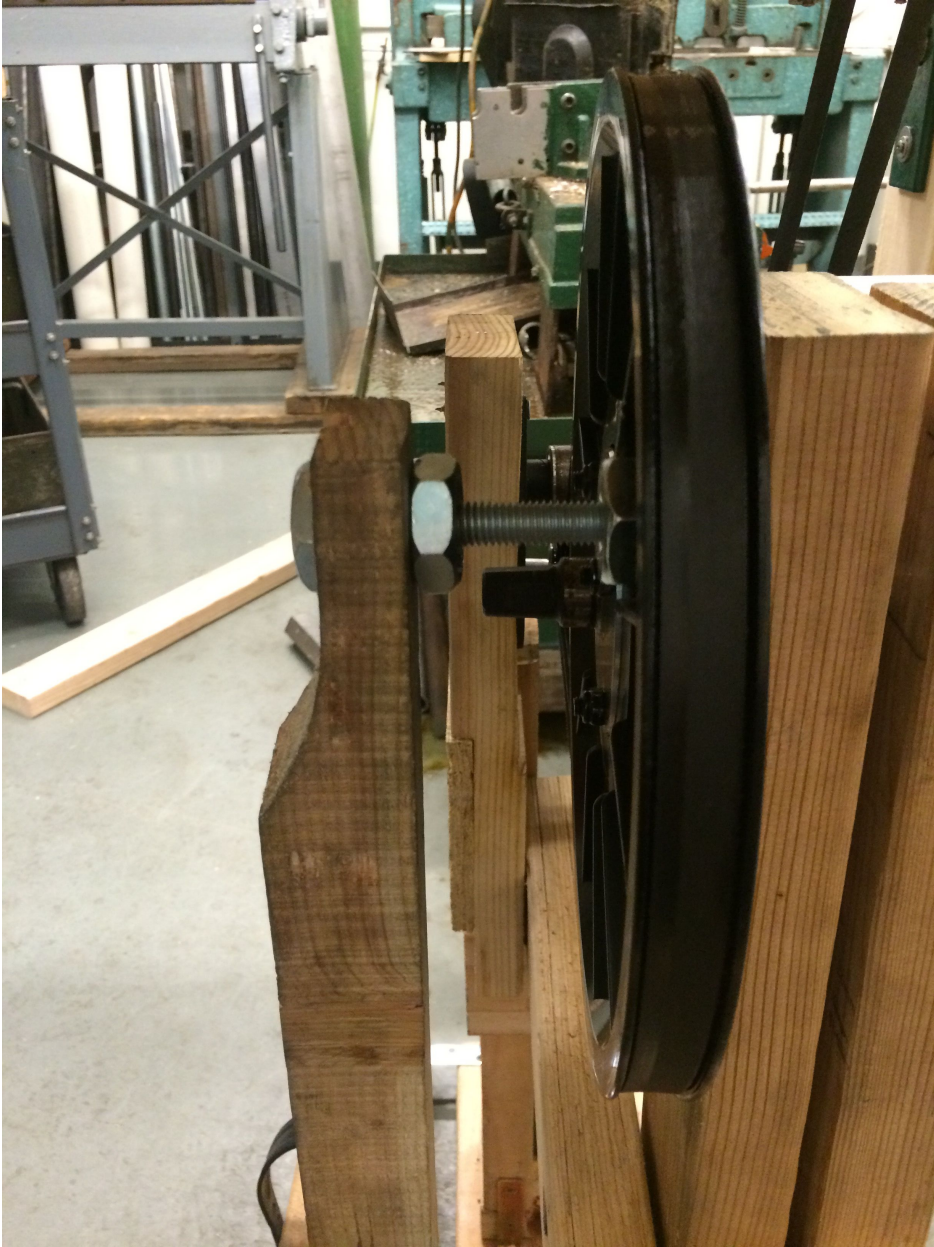


Figure 24: Pedal to pedal wheel connection



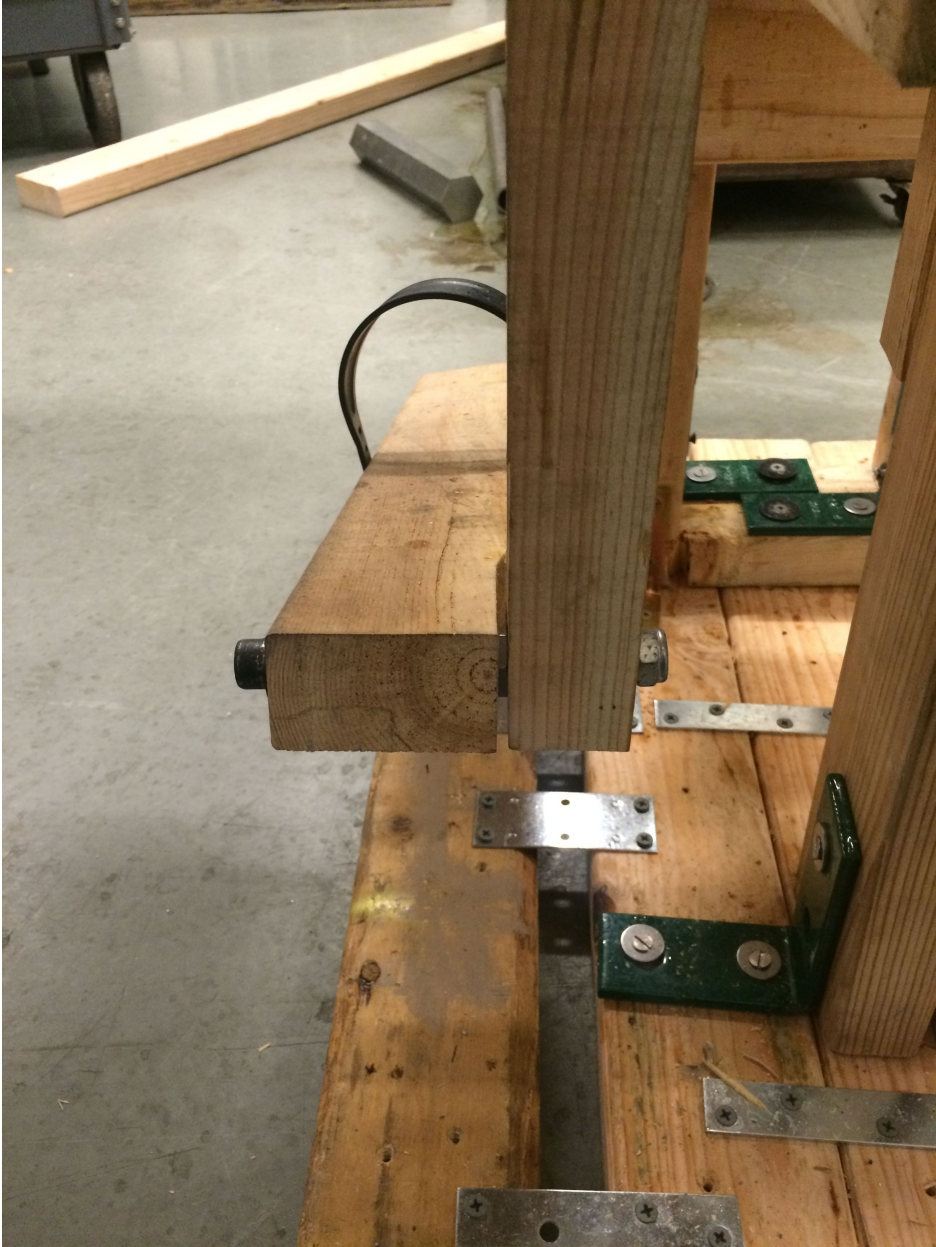


Figure 25: Pedal close-up



Figure 26: Flywheel (right) and drive-wheel (left)

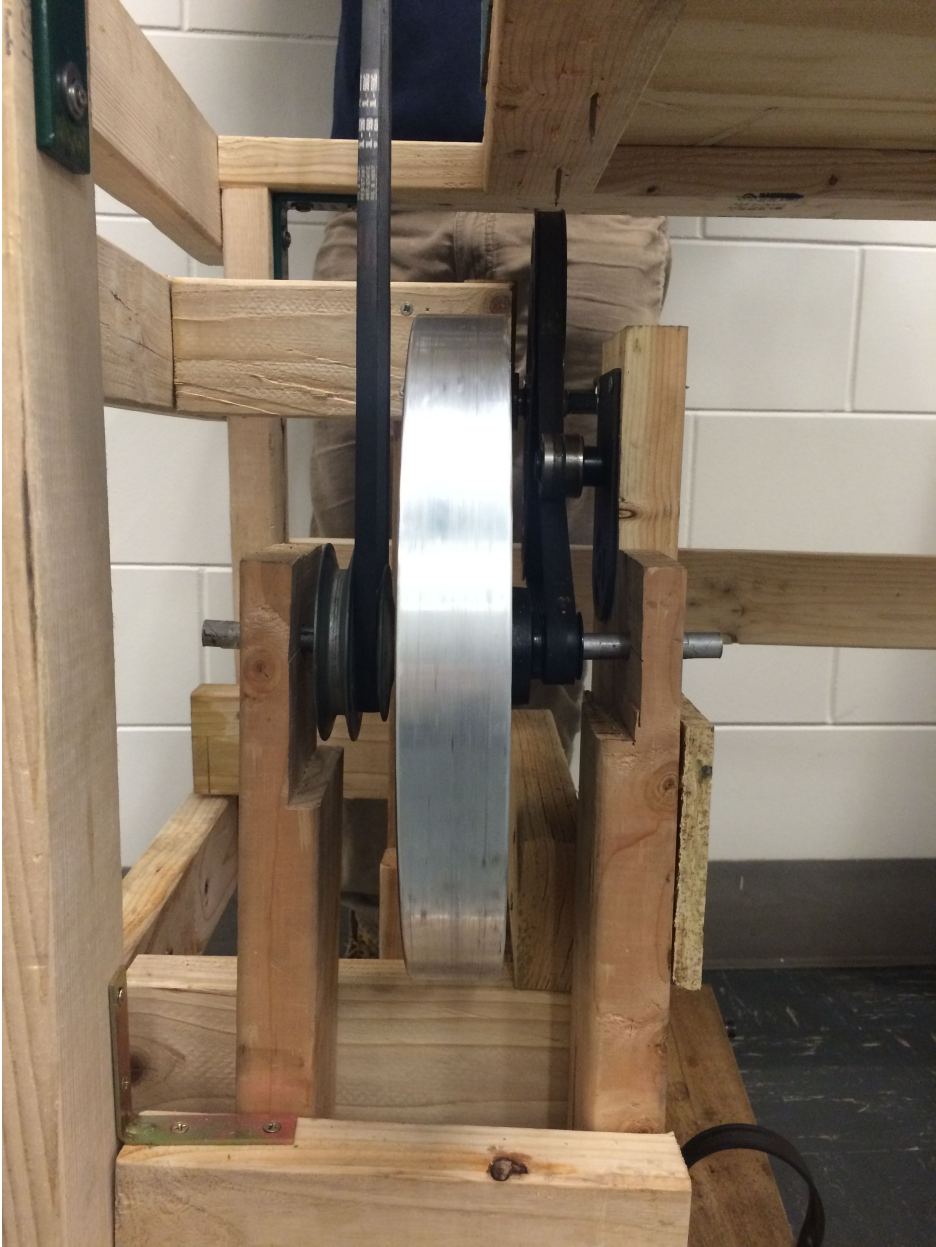


Figure 27: Flywheel belt connections





Figure 28: Flywheel



Figure 29: Holes and pins for gear changes



Figure 30: Gear change holes full view





Figure 31: Lathe and custom cutting tool

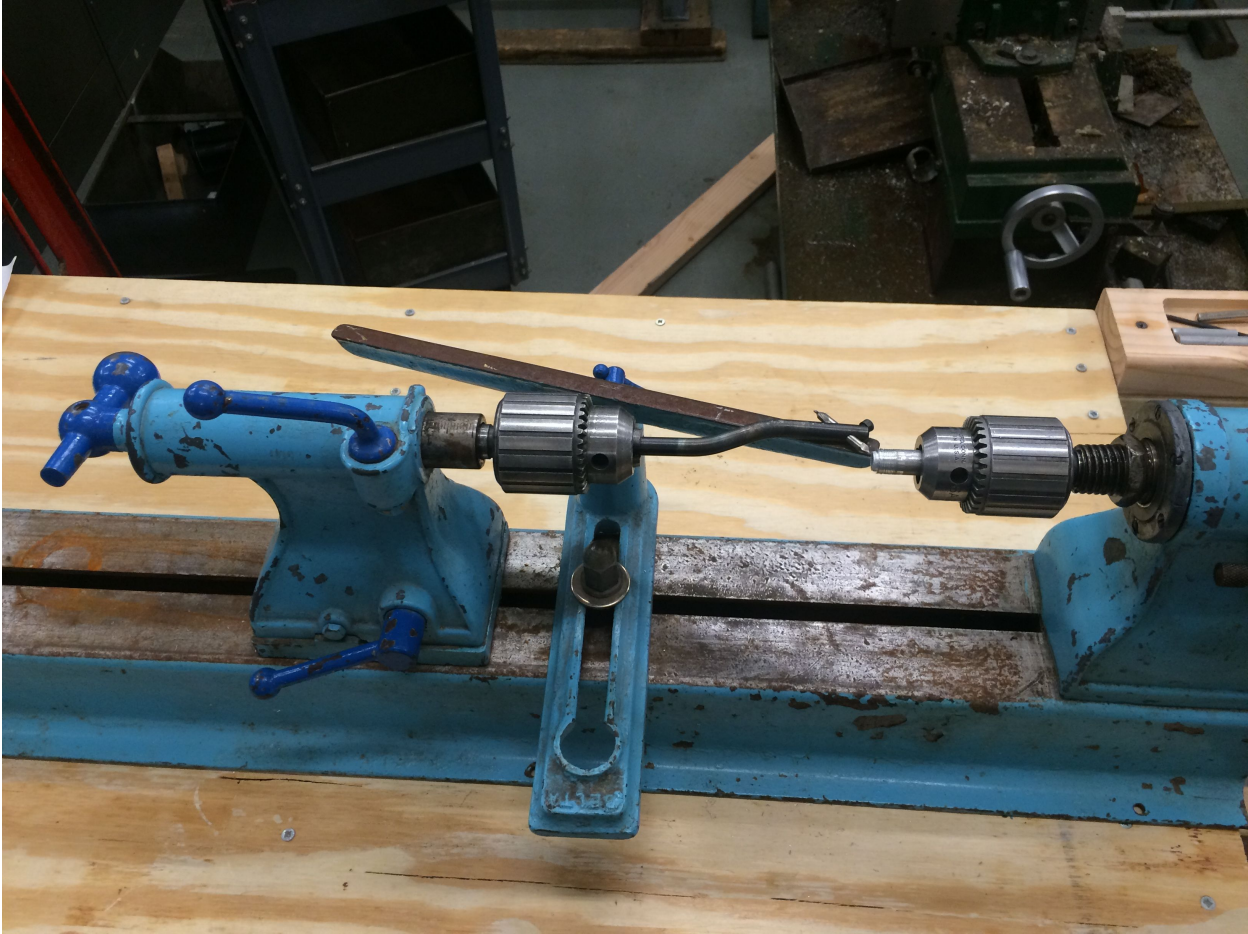


Figure 32: Custom cutting tool





Figure 33: Chuck and working piece



Figure 34: Pedal with springs and strap





Figure 35: Pedal springs

### 6.3 A short videoclip that shows the final prototype performing

This video clip (<http://youtu.be/TrB5E72RbT8>) shows our final working prototype in use. It can be seen that it fulfills 3 of our 4 key design metrics. It can be powered and operated by one user, it does not use or store electricity, and it cuts metal to the specified dimensions. The fourth metric (the lathe can be operated at three different speeds) cannot be seen in the video, but can be seen in the photos above.

## 7 Design documentation

### 7.1 Final Drawings and Documentation

#### 7.1.1 A set of engineering drawings that includes all CAD model files and all drawings derived from CAD models.

The CAD drawings can be found in Appendix C.

## 7.2 Final Presentation

### 7.2.1 A link to a video clip of final presentation

Our powerpoint presentation with audio is uploaded to the file exchange on blackboard.

## 7.3 Teardown

Instructor comments on completion of teardown/cleanup tasks:

Instructor signature: Mary Madest; Print instructor name: Mary Madest  
Date: 12/8/14

## 8 Discussion

### 8.1 Using the final prototype produced to obtain values for metrics, evaluate the quantified needs equations for the design. How well were the needs met? Discuss the result.

Our final prototype met all of our user needs metrics as expected. The lathe can be operated easily by one foot pedaling the treadle. Our lathe can operate at three speeds, as well as being able to be pedaled and operated by a single person, all of which were of highest importance. The lathe is able to store some power mechanically through the flywheel, which was originally given an importance value of 2. When the user stops pedaling, the flywheel continues to spin, but slows down and comes to a full stop within 30 seconds. The flywheel stores energy but is hindered by multiple points of friction losses, such as the belt connections and the weight of the pedal moving through its stroke. Furthermore, the entire mechanism is relatively heavy and large, which means that it isn't necessarily lightweight and portable (however much lighter than a normal lathe) but this metric had the lowest importance value of 1. Finally, the last user need that was met was for the ability of the lathe to cut metal, which was accomplished with a retrofit cutting tool, as well as ample RPM produced from the treadle system.

### 8.2 Discuss any significant parts sourcing issues? Did it make sense to scrounge parts? Did any vendor have an unreasonably long part delivery time? What would be your recommendations for future projects?

Our largest part sourcing issue was acquiring a sufficient flywheel. All of the flywheels online were either too expensive and out of the scope of our budget, or they were simply not a sufficient model of flywheel that we needed for our design. Another large sourcing issue we had was purchasing an actual lathe to retrofit into our design. Most used metal cutting lathes cost over \$1000, so we decided to purchase an old rusty wood lathe from Craigslist.com.

For most of our parts, we successfully scrounged for parts. We were able to purchase a used stationary bicycle for \$5. From this, we obtained a perfect flywheel, another wheel, a flat belt, and several bearings. This scavenging purchase was a tremendous step for us in acquiring parts. This left us with only purchasing another belt from Grangers, wood and screws from Home Depot, and the lathe from Craigslist.com. We successfully scavenged a few other parts, including "L" brackets, springs, and miscellaneous screws and washers from the basement room in Jolley.

All of the parts we purchased were acquired in a store, not via online delivery. Thus, we had no issues with unreasonably long part delivery time.

For future projects, I would recommend first scavenging through the storage room in the basement of Jolley. There is an excess of useful parts that can be acquired for free in there. Only then would I turn to purchasing parts. In terms of purchasing parts, I would highly recommend going to stores like Grangers and Home Depot first. This allowed my group to work with our parts immediately, as opposed to ordering a part from online, waiting for it to arrive, and then work with it.

### 8.3 Discuss the overall experience:

#### 8.3.1 Was the project more or less difficult than you had expected?

We think the project was more difficult than we initially expected. There were many small problems we ran into during the design that we did not expect which caused this project to be more difficult than we had anticipated. Going into the project we chose a relatively simple design and were expecting our main difficulties to be acquiring enough RPM to cut the metal. In practice, our design had plenty of RPM and we had to adjust our design to acquire more torque and reduce friction. We also had difficulty lining up the drive belts for the flywheel and lathe, since any minor misalignment caused issues with friction and wobbling.

#### 8.3.2 Does your final project result align with the project description?

Our final project met all aspects of the project description. Our lathe was able to cut 3/4 inch diameter metal and was capable of producing parts longer than 3 inches. Our lathe was entirely mechanically driven and did not use any electricity.

#### 8.3.3 Did your team function well as a group?

Our team worked very well together. All conflicts about the design of our project were resolved by group decision. All members of the group were willing to spend as much time as necessary on the project and we all ended up putting in a lot of hours. The group also split up the work effectively and fairly with each member given a portion of the work that fit with their skill set.

#### 8.3.4 Were your team member's skills complementary?

The skills of our team members complimented each other very well. Some of the members were very good at working in the machine shop and did a lot of the more technical machine shop work. Other members were good at CAD and design and were instrumental in designing our project.

#### 8.3.5 Did your team share the workload equally?

All members of the team did an equal amount of work on the project. We all met up and worked on the project as a group so each member worked equal amount of hours. Although often times the team was split and working on multiple sections at once, we all felt that the workload was split fairly.

#### 8.3.6 Was any needed skill missing from the group?

No very important skills were missing from our group. The only help we needed on the project was outfitting the wood lathe with a cutting tool which required bending a piece of metal which Professor Harkins helped us with. Our group's skills were fairly well rounded otherwise as some of our members were good with design and CAD and other members were good at working with the tools in the machine shop.



### **8.3.7 Did you have to consult with your customer during the process, or did you work to the original design brief?**

We consulted many of the class professors during the process of building our lathe but also attempted to stay as true as possible to the original design brief. We ended up using a pedal mechanism instead of a traditional treadle and we consulted with Professor Jakiela about the specifics of the pedal. We also consulted with Professor Jakiela about the use of a large transmission ratio instead of a free wheel.

### **8.3.8 Did the design brief (as provided by the customer) seem to change during the process?**

The design brief remained fairly consistent during our project. Our project works as specified by the initial design brief and cuts to the specifications that were initially given to us. We did change our design a few times to keep the design simple. With the help of Professor Jakiela we decided a free wheel was not necessary for our design because of the large transmission ratio of our treadle. We also had initially planned to add an automated clutch and instead decided to change the RPM of the lathe by manually moving the drive belts instead.

### **8.3.9 Has the project enhanced your design skills?**

Yes, the project certainly enhanced our design skills. Before this project, we had never encountered an academic project with this much depth and complexity. We had little to no experience coordinating a project amongst group members, as well as several faculty members. Now we have a greater understanding of the design process, and the multiple revision steps required in order to conceive a final design.

### **8.3.10 Would you now feel more comfortable accepting a design project assignment at a job?**

Yes, we all would feel more comfortable accepting a design project assignment at a job. We now have a better understanding of the process required to complete an assignment with so many parts. We now appreciate the inevitability of obstacles in any project, and have a newfound patience in working through these obstacles. We even were able to work efficiently together, keep perspective on the final product, and have fun while doing so.

### **8.3.11 Are there projects that you would attempt now that you would not attempt before?**

Yes, there are several projects we would attempt now that we have completed the Treadle Driven Lathe project. Every project will inevitable have many design obstacles. Having overcome numerous design obstacles in our project, we now are much more confident as a team in overcoming any obstacle. We feel that we now have the experience to break down any of the larger projects, work

systematically to overcome smaller obstacles, and slowly piece together a final product.

## 9 Appendix A - Parts List

Table 6: Detailed parts list

Part	Size	Number
plywood table top	2'x4'	1
2x4 wood	1.5" x 3.5"	70ft
L-bracket (gold)	3" x 0.725"	8
L-bracket (green)	4" x 1.64"	8
mending plates (4 hole)	0.8" x 4"	6
double wide mending plates (6 hole)	2.375" x 0.75"	2
hinge	1.25" x 3"	1
springs	2" high, 1" diameter	2
hand made boring bar		1
high speed steel cutting tool		1
#2 MORSE tapered lathe drill chuck		2
aluminum pipe	Do = .5" Di = 0.425" L=2.6"	2
tension bearing support plate		1
tension bearing	1.375" diameter	2
threaded rod for pedal connection	0.375" diameter, L=3.5"	1
pedal connection washers	1"	4
screws	1-1/4", 2", 2-1/2"	

foot pedal strap		1
flywheel	12" diameter, 1.5" width	1
pedal wheel	9.5" diameter, 3/4" width	
Prestone belt dressing		1
v-belt	55" circumference	1
ripped flat belt		1
Loctite		
wood cutting lathe		1
chuck key		1
allen wrench key		1
Pins for lathe positioning	3.25"	4
3-speed gear plate		1
bearing (pedal wheel support)	Do = 1.5" Di = 0.625"	2

## 10 Appendix B - Bill of Materials

Table 7: Bill of materials

Part	Use	From/Part #	Cost/part	# part needed	total cost
Box of 1 1/4" screws	Frame construction	Home Depot	\$9.28	1	\$9.28
V-Belt, 3L550	Connect flywheel to	Grainger	\$13.08	1	\$13.08

	lathe				
2X4-84" KD Whitewood Stud	Frame construction	Home Depot	\$2.32	10	\$23.20
2-1/2" PG + 10 exterior screw 1 LB	Frame Construction	Home Depot	\$8.47	1	\$8.47
Wood Lathe	Lathe	<a href="http://Craigslist.com">Craigslist.com</a>	\$70.00	1	\$70.00
2" Galvanized Corner Braces (4 pack)	Frame Construction	Home Depot	\$4.68	2	\$9.36
3" Zinc Plated Mending Plate (4 pack)	Frame Construction	Home Depot	\$2.97	1	\$2.97
3-1/2" Zinc Plated Double Wide Mending Plates( 4 pack)	Frame Construction	Home Depot	\$4.36	1	\$4.36
Stationary Excercise Bicycle	Scavenge Flywheel, bearings, pedal wheel	GoodWill	\$5	1	\$5
2' X 4' Sanded Plywood	Table Top	Home Depot	\$12.05	1	\$12.05
					<b>Total</b>
					<b>\$157.77</b>

## 11 Appendix C - CAD Models

**Figure 36: Pedal Wheel Assembly**



**Figure 37: Treadle Connector**

**Figure 38: Treadle**

**Figure 39: Treadle Assembly**

**Figure 40: Pedal Wheel Support**

**Figure 41: Pedal Wheel**



**Figure 42: Wheel and Belt Assembly**

Figure 43: Full Treadle System

## 12 Annotated Bibliography

Leckey, W.C. *Treadle-driven, Ball-bearing Woodturning Lathe*. N.p.: n.p., n.d. PDF. <http://www.vintageprojects.com/machine-shop/woodlathe-treadle.pdf>

The Vintage Projects website provides an overview of how to build a treadle-driven, ball-bearing woodturning lathe. It includes labeled diagrams with sizing and spacing of the design.

"The Foot Powered (Treadle) Lathe." *YouTube*. N.p., n.d. Web. 07 Dec. 2014. <https://www.youtube.com/watch?v=eG9R0q9JQc&feature=youtu.be>

"Chop with Chris" is a YouTube user who has a passion for traditional woodworking using only hand tools; the video shows him making a foot powered lathe out of only wood. We used many similar principles in our design of our treadle system.

Rettie, Tom. "Building a Flywheel Treadle Lathe." *Building a Flywheel Lathe*. N.p., 2006. Web. 07 Dec. 2014. <http://www.bloodandsawdust.com/sca/lathes2.html>

The Blood and Sawdust website has a step-by-step process to build a lathe; it also lists a number of other references regarding lathe construction. Our treadle works on a similar principle to the treadle on this site.

Coullery, Henri. "Patent US1500672 - Portable Treadle Lathe." *Google Books*. N.p., 8 July 1924. Web. 07 Nov. 2014. <http://www.google.com/patents/US1500672>

This is a patent (US 1500672 A) for a portable treadle lathe filed in 1922. Most other patents that we found in our research were filed before 1922. This lathe also uses a flywheel for energy storage and we drew inspiration from some of the design features.