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JME 4110 Mechanical Engineering Design Project - Combination Machining Tool

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Joint Engineering Program

University of Missouri–St. Louis ▪ Washington University in St. Louis

ELEVATE YOUR FUTURE.
ELEVATE ST. LOUIS.

Our project is to design and build a portable sized tool for machining relatively small parts out of metal. Ideally, a student could keep it in their dorm and bring it to an appropriate work space when he/she is ready to use it.

JME 4110
Mechanical Engineering
Design Project

Machining Combination Tool

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1 Introduction

1.1 Value proposition / project suggestion

Access to the machine shop in Lopata hall of Washington University is often very limited, particularly during the regular school year. Yet, a great number students are expected to take classes there and make parts with equipment for prototyping, modeling, or testing. It was proposed that students could have their own smaller versions of the major equipment in a machine shop, being much lighter, cheaper, and more portable, while maintaining the majority of the machining power desired from professional grade tools. Specifically, it should combine a lathe, mill, and drill press.

Our team was asked to design and build such a tool. The main ideas were that a single student should be able to transport the product, assemble it quickly on a table or desk, and use it to machine reasonably small parts. The lathe would be able to hold a part 4 inches in diameter and 12 inches long, while the mill would hold a part with a 4 inch height, width, and depth.

1.2 List of team members

Ephraim Abrams
Menasha Abrams
Kevin Le
Brian Mayfield
Ashley Newton
Pete Patton
Thomas Poon
Trevor Potter
Alex Rich
Richard Russell
Parker Stovall

1.3 Subsystem Breakdown

The large size of the engineering team required the designation of subsystems to improve the team's efficiency. The team was divided into these three subsystems: Mill/Drill, Lathe, Movement and Transport.

1.3.1 Subsystem: Mill/Drill

The Mill/Drill group is responsible for determining the best configuration for a Mill and a Drill Press. This will include investigation of cutting forces that the machine will be subjected to. The Mill and Drill team shall consider an emergency shut off and other possible safeties for its cutting tools.

1.3.2 Subsystem: Lathe

The Lathe group is responsible for obtaining information on the physical requirements of the combination tool for it to achieve the recommended criteria. This will include investigation of the necessary torque applied to a drill bit to cut the specified steel at the specified rates. Particular focus will be on maximizing available output power per size and weight. Special care will need to be taken in eliminating any vibrational effects. Similar to the Mill and Drill team, the Lathe group shall consider an emergency shut off and other possible safeties.

1.3.3 Subsystem: Movement and Transport

The Movement and Transportation group is responsible for the designing and building of a stage capable of 3-Degrees of freedom (x-y-z linear motion), and a general structure to support all components and materials of the combination mill/drill/lathe tool.

2 Background Information Study

2.1 Design Brief

In the modern world almost everything is at our fingertips, Computers, 3-D printers, but one thing that is lacking is the access to a machine shop whenever needed. Our goal for this project was to design a portable, lightweight, Mill/Drill/Lathe that could be used by a student on the go.

2.1.1 Mill/Drill Criteria

- Mill:
  - Allow part/specimen that has a minimum of a 4” x 4” footprint
  - Hold ¼” milling cutter
  - Can cut a ¼” wide groove, ¼” in depth at a rate of .001”/Revolution
  - Cut mild steel to above requirements
  - Design should be as light and inexpensive as possible
- Drill Press:
  - Drill ¼” diameter hole in mild steel
  - Hold ⅜” drill bits
  - Cut to a depth of 2”
  - Variable speed
  - Design should be as light and inexpensive as possible

2.1.2 Lathe Criteria

- Should allow turning a 4” diameter cylinder
- Should allow turning a 12” long cylinder
- 100 - 1000 rpm
- Should provide torque needed to 0.020” depth of cut at 2” radius
- Actual toolstock cross slide providing controlled movement in the feed and plunge directions
- If possible, feed and plunge electrically controlled

2.1.3 Movement and Transport Criteria

- 3 Degrees Of Freedom
- Support weight of itself, components, and up to 200 pounds of mild steel
- Collapsed footprint must be no bigger than 22 x 22 x 12
- Full assembly should be light enough for a student to move it without assistance
- Stage must be a minimum of 4” x 4”
- Stage travel must permit cutting at any point on the stage
- Attempt electronic controllers for motion where possible

2.2 Background summary

After several web searches of mini/small lathe mill drill combo, each result showed several machines that fit the performance aspect but failed the dimensional aspect. Nearly all the devices were easily twice the allowed dimensions. First, finding a base device that would fit inside the given dimensions was the main task. Second, would be finding motors and components that would be able to perform the all the given tasks while being small to fit within our dimensional capacity. Having a lathe at a maximum length of 22" while needing in handle a cylinder of 12" leaves the design with only 10" of room for the mechanical aspect of the device.

The following sections detail the results of the team's web searches.

2.2.1 Mill/Drill Subsystem

Below are examples of existing products that closely fit the design requirements for the Mill/Drill Subsystem:

Patent for Milling Machine Lathe Attachment

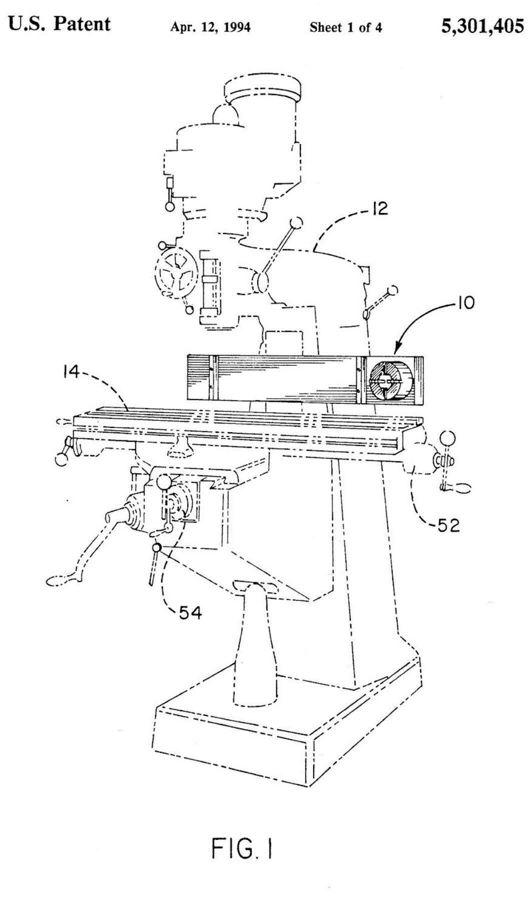


Fig. 1 - US Milling Machine Patent

Inventor: Richard A. Maker

Priority date: 1993-01-11 Status: Expired

Application Number: US08002967

URL Link:
https://patents.google.com/patent/US5301405

Patent for Combined Lathe, Drilling and Milling Machine

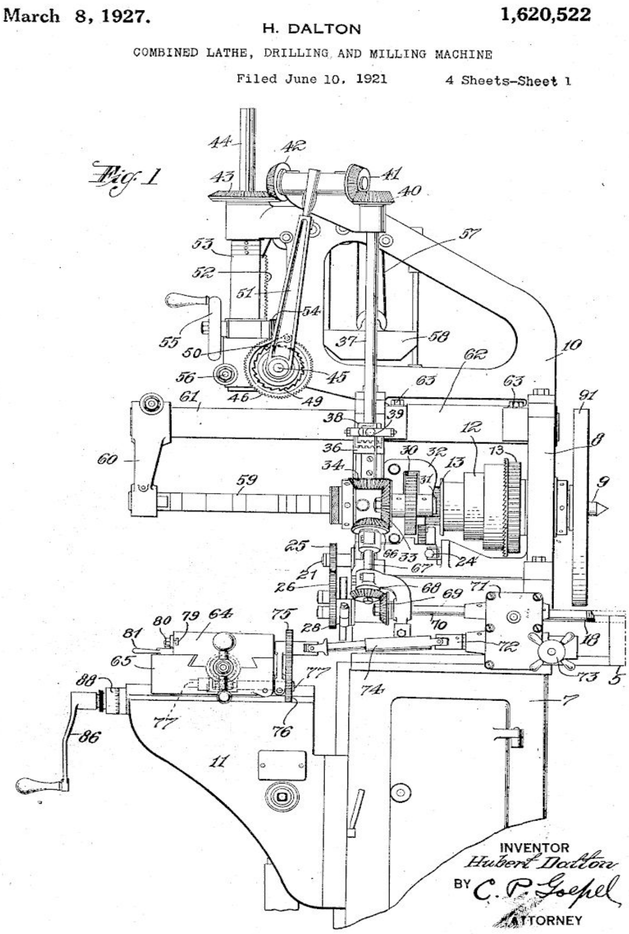


Fig. 2 - US Combination Lathe, Milling, and Drilling Machine

Inventor: Dalton Hubert
Priority date: 1921-06-10 Status: Expired
Application Number: US1620522A

URL Link:
https://patents.google.com/patent/US1620522

2.2.2 Lathe Subsystem

Below are examples of existing products that closely fit the design requirements for the Lathe Subsystem:

Mini Metal Lathe

This machine was constructed by taking apart a power drill, this gave the lathe power while being small. The extruded member is 45X90 and 14” long, this leaves room for improvements. This lathe is also relatively light being able to pick up with just one hand. However, the chuck used is still too small to handle a 4” diameter piece. This could be modified by increasing the height and width of the device. Other than that, this lathe would very closely fit all of the required criteria.

URL Link:
http://www.instructables.com/id/Mini-Metal-Lathe-1/

M1 250mm Micro Multi-function Machine Drilling and Milling Lathe machine 220V

This machine fits majority of the dimensional specifications required (length is 24" not 22") at around 90 lbs. The device also allows for interchangeable gear for various speeds. The base should be one whole connection from the lathe to the mill. This could be modified to allow for the mill to turn 90º to make it more collapsible or even attach/detachable.

List of specifications:
https://www.shengwon.com/YSP/M1_specification.jpg

URL Link:
https://www.ebay.com/itm/M1-250mm-Micro-Multi-function-Machine-Drilling-and-Milling-Lathe-machine-220V-Y-/172792015251?_trksid=p2141725.m3641.l6368

2.2.3 Movement and Transport Subsystem

Given the significance of the linear movement devices to the machine's operability, web searches for this team focused only on this aspect of their subsystem. Below are examples of existing products that closely fit the design requirements for the movement portion of the Movement and Transport Subsystem:

Mini CNC Devices from ZenCNC

This company produces many small CNC devices for modeling and manufacturing. The designs of this company demonstrate the various ways in which x-y-z linear motion can be achieved, and how it can be maintained in a small package. It doesn't appear that any direct translations can be made to this tool design, but the general concepts are helpful.

Fig. 3 - Sample Product From ZenCNC

URL Link:
http://zencnc.com

CNC Router Builds from OpenBuilds

This website shows many CNC devices and instructions or notes on their construction. This should provide much needed aid in the design and build stages of the tool design process.

URL Link:
https://openbuilds.com/?id=286

3 Concept Design and Specification

3.1 User Needs and Metrics

3.1.1 Record of User Needs Interview

Table 1 - User Needs Interview

Project/Product Name: Lathe, Mill/Drill (Portable)			
Customer: Mark Jakiela Address: Washington University Willing to do follow up? Yes Type of user: End User/Operator Currently uses: Separate Mill and Drill Press that is stationary and not portable.		Interviewer(s): Ephraim Abrams, Menasha Abrams, Kevin Le, Brian Mayfield, Ashley Newton, Pete Patton, Thomas Poon, Trevor Potter, Alex Rich, Richard Russell, Parker Stovall Date: 06/25/2018	
Question	Customer Statement	Interpreted Need	Importance
Would you prefer Digital Reading or Manual Readings?	Digital Readings are nice but not necessary.	Mill to have markers to determine distance traveled. Nice if there is a digital readout.	2
How do you define a portable device?	When collapsed no larger than guitar case. (22x22x12) Can have wheels for portability.	Device needs to be portable, so it can be easily transported by one individual.	5
What is the maximum weight?	40lbs	Overall device needs to be light	4
What is the max setup time?	Under 20 minutes	Device needs to go from portable mode to fully operational in under 20 minutes	5
What is the maximum size of the device when fully	4’X8’	Device needs to fit in a 4’ x 8’ footprint when fully deployed and functional	5

operational?			
How would you like the device to interface with the surface it is on?	Ability to secure without permanently affecting surface or table?	Device needs to secure to a desk or table without any modifications that would permanently affect the surface.	5
Would you prefer the device be operated with batteries or wall power?	Preference is for plug	Device to be powered with 120Vac outlet plug.	3
Can the device have deflection?	No deflection	Materials and joints to be sized to handle appropriate loads so that the device does not have deflection that will effect the final result of the product	4
Does the device need to have the ability to hold a part securely in place?	Yes	Device to have some sort of clamp, to hold parts securely in place while being modified.	5
Does the device need a dedicated lubricant pump?	Nice but not necessary	Device can be operated by the user manually applying lubricant. Would be nice to automate the process.	1
How easy should the cleanup be for the operator?	Easier to clean then machine shop	Device to have quick method to clean chips and excess lubricant.	3
Does the device need an E-Stop?	yes	Device to have E-Stop.	5
Should the device automatically power on when plugged in?	In case of outage, there should be a switch o the device does not power back up when power is restored.	Device to have on/off switch so user has to intentionally power it on	3
Does the device need safety shielding?	Wear Glasses	User to be expected to wear glasses and follow ordinary shop safety measures. Shielding nice but not necessary.	1

Does the mill need to be variable speed?	It should work for multiple bits and materials but not necessarily all of them.	Mill to be variable speed.	3
How much should the device cost?	$1000	Device should cost under $1000.	6
What is the number one thing you are looking for in this product?	Portability and ease of set up.	Device to be portable and have a quick easy setup.	5
How important is the setup up difficulty level?	Not as important as set up time. Should be obvious how it is set up.	Device to assemble with relative ease. Complicated assembly should be accompanied with instructions.	2
How tight of a tolerance should the device produce?	+/-.001	Device to produce parts with accuracy of =/-.001".	3
Should the device have backup human input power?	Would be nice but not necessary.	If power is lost, manual input would allow for device to still function.	1
How important are overall aesthetics?	Not.	Device needs to be functional over visually pleasing.	1
What is the maximum sound the machine should emit when operating.	Standard dorm room tolerance.	Device should be quiet enough to not disturb occupants in other door rooms.	3
Does the mill need a 2" plunge independent of Z axis movement?	Yes.	Mill should have dedicated plunging feature independent of XYZ movements.	5

3.1.2 Table of Needs (Simplified)

Table 2 - Needs

Need #	Need Description	Importance
1	Digital Readouts	2
2	Device to be easily portable.	5
3	Device to be lightweight.	4
4	Device to have minimal overall footprint when deployed.	5
5	Secure to table or surface without permanent modification.	5
6	Device to be powered by 120Vac plug in.	3
7	Device to have automated lubricant system, if needed.	1
8	Device to have easy cleanup system to control debris.	3
9	Device to be safe.	5
10	Mill to be variable speed.	3
11	Cost under $800.	6
12	Device to assemble with relative ease.	2
13	Device to produce parts with accuracy of +/-.001”.	3
14	Device to have backup human input power.	1
15	Device to be aesthetically pleasing.	1
16	Device to be quiet.	3
17	Mill to have plunge of 2” independent of XYZ movement.	5

3.1.3 Table of Identified Metrics

Table 3 - Identified Metrics

Metric Number	Associated Needs	Metric	Units	Min Value	Max Value
1	2,4	Length	in	P:0; O:0	P:22; O:96
2	2,4	Width	in	P:0; O:0	P:22; O:48
3	2,4	Height	in	P:0; O:0	P:12; O:48
4	1,13	Accuracy	in	.001	.005
5	1,7,12	Automation	Integer	0	10
6	2,3	Weight	lb	0	40
7	2	Time	min	0	20
8	10	Motor Speed	RPM	0	3000
9	17	Plunge Depth	in	0	2
10	1,2,4,5,7,8	Ease of use	Integer	0	10
11	11	Cost	Dollars	0	1000
12	2	Portability	Binary	0	1
13	9	Safety systems	Integer	0	Inf
14	5,8,12	Ease of setup/takedown	Integer	0	10
15	10	Variable speed	Binary	0	1
16	16	Sound	Decibels	0	150
17	6,14	Power Sources	Integer	0	3

3.1.4 Tables of Quantified Needs Equations

Mill/Drill

The Mill/Drill needs equations are shown in the figure below.

Mill/Drill Press		Length	Width	Height	Accuracy	Automation	Weight	Time	Plunge Depth	Ease of Use	Cost	Saftey Systems	Ease of Setup & Takedown	Variable Speed	Sound	Power Sources			Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	9	10	11	13	14	15	16	17					
1	Digital Readout					0.50				0.50									0	0.025	0
2	Portable	0.10	0.10	0.10			0.40						0.30						0	0.1	0
3	Lightweight						1.00												0	0.075	0
4	Minimum Deployed Footprint	0.25	0.25	0.25									0.25						0	0.025	0
5	No Effect on Mounting Surface												1.00						0	0.025	0
6	Wall Power															1.00			0	0.05	0
7	Automated Lubricant					0.75				0.25									0	0.025	0
8	Easy Cleanup									0.25			0.75						0	0.05	0
9	Safe											1.00							0	0.1	0
10	Variable Speed													1.00					0	0.1	0
11	Under $333										1.00								0	0.1	0
12	Easy Assembly						0.25	0.25					0.50						0	0.025	0
13	Accuracy to .001"				1.00														0	0.05	0
14	Backup Operating Power															1.00			0	0.025	0
16	Quiet														1.00				0	0.025	0
17	Independent Plunge Feature								1.00										0	0.05	0
18	Handeling of different materials									0.25				0.75					0	0.05	0
19	Depth of milling cut													1.00					0	0.05	0
Units		in	in	in	in	integer	lb	min	in	integer	Dollars	integer	integer	Binary	Decibels	integer			Total Happiness		0
Best Value		P:0; O:0	P:0; O:0	P:0; O:0	.001"	10	0	0	3	10	0	inf	10	1	0	inf					
Worst Value		P:22; O:96	P:33; O:48	P:12; O:43	inf	1	20	20	0	0	333	0	0	0	60	0					
Actual Value																					
Normalized Metric Happiness																					

Fig. 4 - Mill/Drill Needs Equations

Lathe

The Lathe needs equation are shown in the figure below.

Lathe		Metric															
		LENGTH	Width	Height	Accuracy	Set up time	Motor speed	ease of use	hollow stick	cost	portability	safties	cleanup	chuck diameter	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13			
1	Needs to be 40 lbs	0.25	0.25	0.25										0.25	0	0.1	0
2	needs to take 20 min to set up					0.75		0.25							0	0.05	0
3	needs to be "usable"							1							0	0	0
4	Needs to spin at 3000 RPM						0.9							0.1	0	0.1	0
5	needs to fit long parts	0.5							0.5						0	0.1	0
6	needs to cost 1000$ or less									0.9		0.05		0.05	0	0.1	0
7	Needs to be portable										1				0	0.1	0
8	needs safteys											1			0	0.05	0
9	Needs effective clean up												1		0	0.05	0
10	Needs to fit HxLxW req	0.33	0.33	0.33											0	0.1	0
11	Needs to cut with .005" accuracy				1										0	0.1	0
12	Needs to be secured to table	0.25	0.25								0.25	0.25			0	0.1	0
13	Needs to be plugged in					0.25	0.25				0.25	0.25			0	0.05	0
Units		IN	IN	IN	IN	min	RPM	BIN	BIN	$	BIN	BIN	BIN	IN	Total Happiness		0
Best Value		22	22	12	0.005	0	4000	1	1	0	1	1	1	4			
Worst Value		0	0	0	0.001	20	0	0	0	1000	0	0	0	0			
Actual Value																	
Normalized Metric Happiness																	

Fig. 5 - Lathe Needs Equations

Movement and Transport

The Movement and Transport group evaluated the customer needs and translated them into design requirements/needs. These design requirements were determine in such a way that the relevant metrics do not overlap. This is why the need-to-metric ratio is always 1, as shown in the figure.

	Movement and Transport Needs Equations Table	Metric											
		Accuracy	Collpsibility	Weight	Setup Time	Footprint	Secures?	Run/Maint. Time	Part Clamping	Cost	Portable	Sound	
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	Importance Weight
1	The X, Y, and Z motion is accurate within +/-.001.	1											0.067
2	The tool can fit within a 22x22x12 envelope when collapsed.		1										0.111
3	The device weighs less than 13.3lbs.			1									0.112
4	The tool can be set up in less than 20 minutes.				1								0.111
5	The un-collapsed tool fits within a 4' x 8' footprint.					1							0.111
6	The tool secures to a table without damaging it.						1						0.111
7	The tool is sturdy enough to withstand typical operations.							1					0.089
8	The tool includes a mechanism or device for securing typical work parts.								1				0.111
9	The device costs less than $333.									1			0.111
10	The tool has an effective method of transport.										1		0.022
11	The tool produces less than 60dB of audible noise at a distance of 1 meter.											1	0.044
	Units	inch	binary	lbs	min	binary	binary	ratio	ternary	USD	binary	dB	
	Best Value	0.001	1	5	1	1	1	1	2	100	1	40	
	Worst Value	0.01	0	13.3	20	0	0	0	0	333	0	60	

Fig. 6 - Movement and Transport Needs Equations

3.2 CONCEPT DRAWINGS

3.2.1 Mill/Drill Concepts

Fig. 7 - Concept 1: Lead Screw

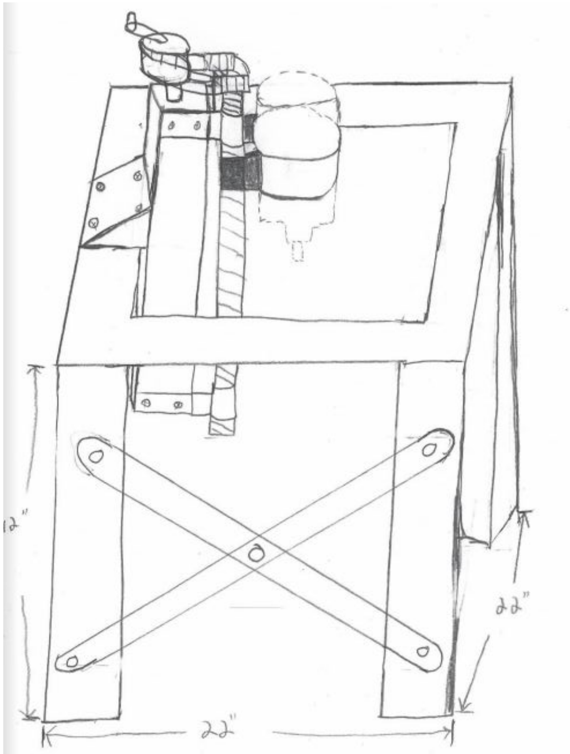


Fig. 8 - Concept 2: Rack and Pinion

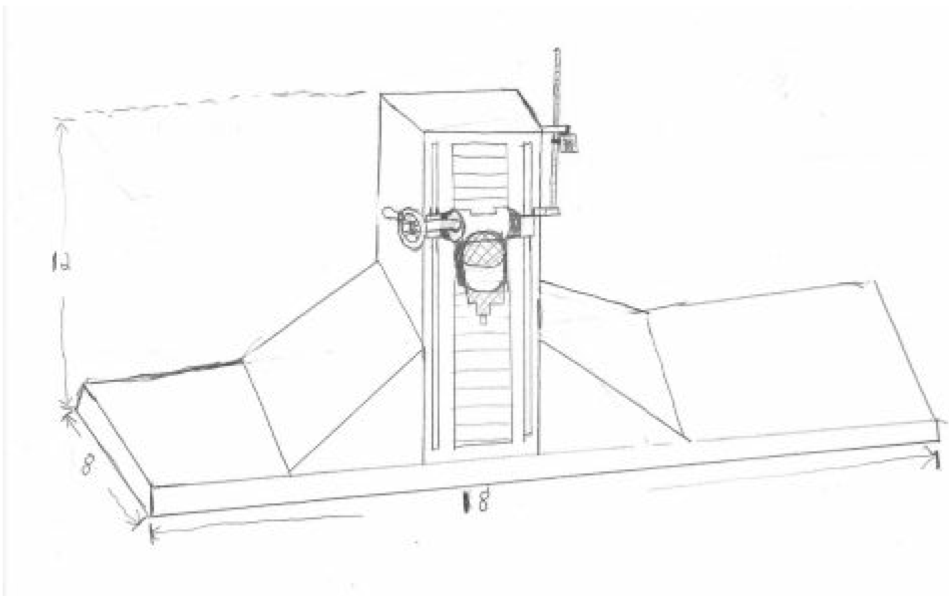


Fig. 9 - Concept 3: Overhead, Integrated Rack and Pinion

This design uses an angle stock frame with welding cross braces of flat stack. This adds rigidity to the frame as well as makes the design easily integratable with the rest of the system. The motor and Z-motion is a "standard" spindle and quill design. This is good if we are able to salvage parts but making or buying the parts will be very time consuming and expensive. The design will need low friction bearings, rack and pinion, handles, set screws and much more that will quickly become expensive.

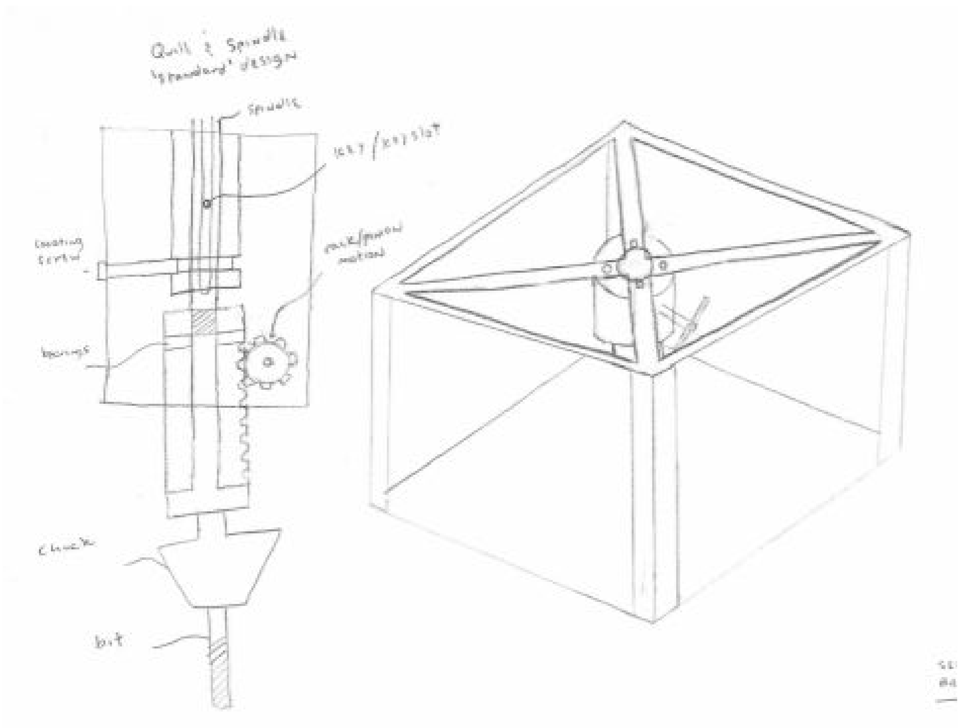
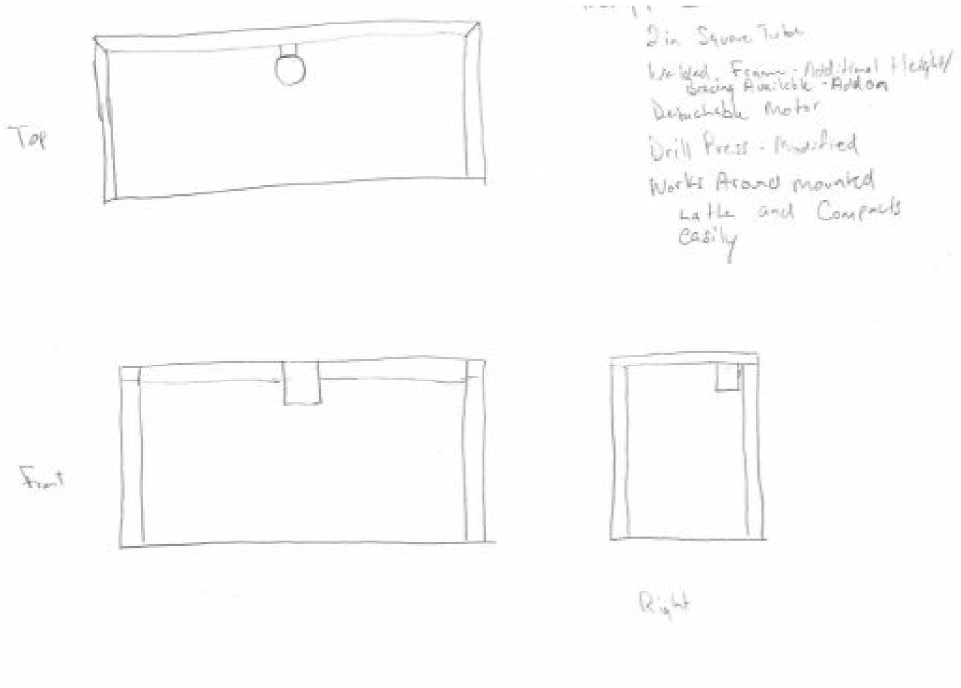


Fig. 10 - Concept 4: Modified Standard Drill Press Mounting



3.2.2 Lathe Concepts

Fig. 11 - Concept 1: Hollow Tailstock/Horizontal Flywheel

Concept 1 is a horizontal lathe set up with a chuck fastened to a flywheel. The head stock is hollow so a part can slide through making us able to work on larger parts if necessary. The tailstock is hand cranked in order to move forward and backward to hold the part.

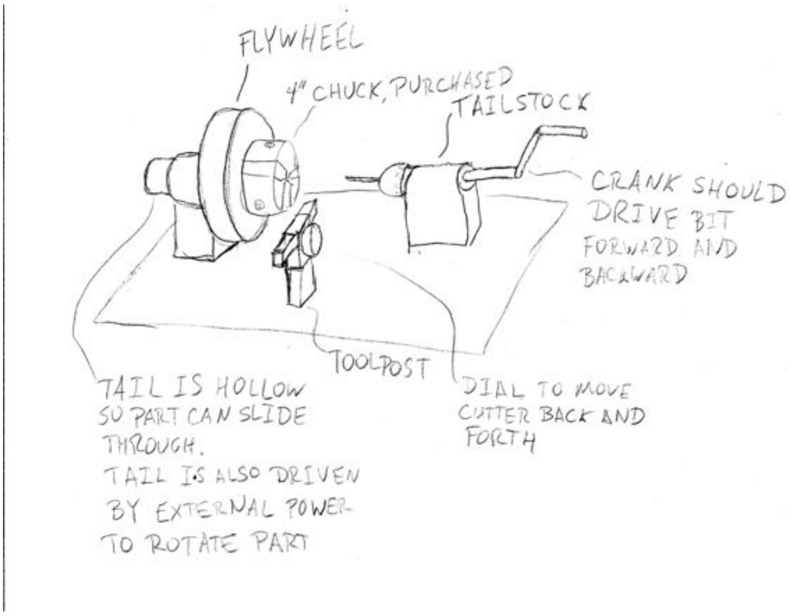


Fig. 12 - Concept 2: Horizontal Flywheel

This concept is the horizontal configuration of the lathe that is also fitted with a flywheel. The chuck is instead a hallowed shaft with set screws. This reduces weight but also causes trouble with having the part be centered in the shaft. The tool post and cutter are able to move up and down the y axis as needed and the tailstock as well.

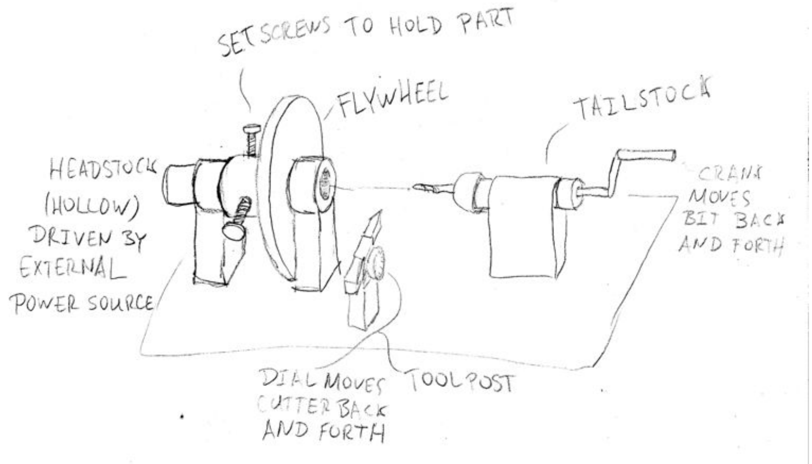


Fig. 13 - Concept 3: Vertical Flywheel

This concept uses a flywheel, as well as a vertical configuration. The idea here is to be able to somehow mix this design with the mill/drill design that is typically vertical. This will allow us to only use one motor and reduce weight of our device. This particular drawing also shows the use of a hand crank, for our tailstock.

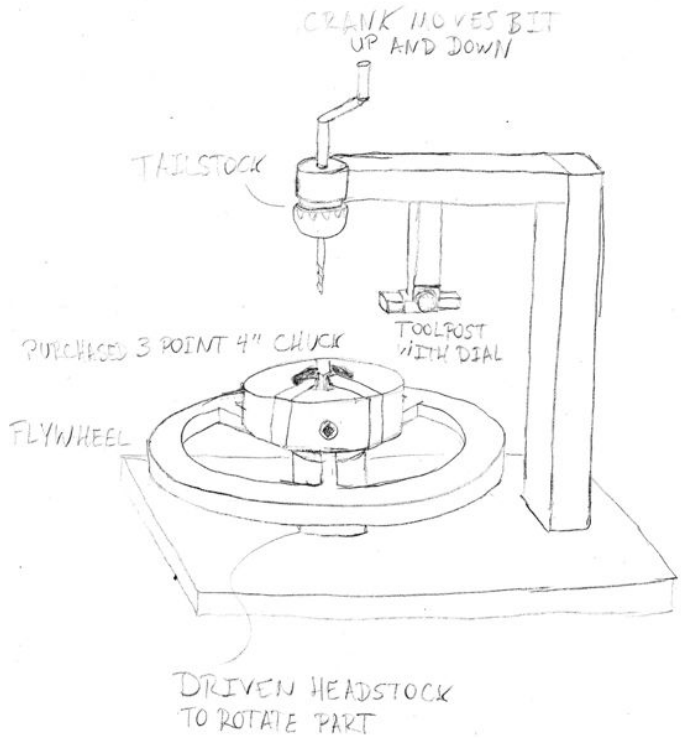
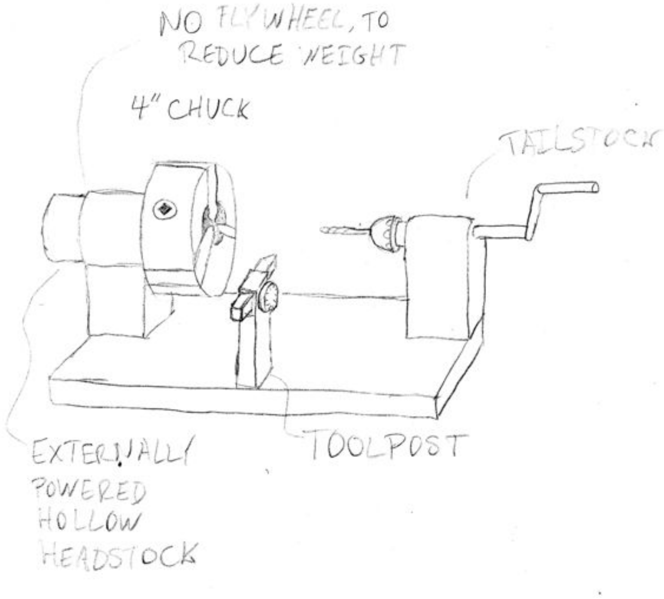


Fig. 14 - Concept 4: Horizontal Hollow Headstock (No Flywheel)

This concept has removed the flywheel in order to reduce weight. Other than that it is much like the previous horizontal designs, and is much like a normal lathe configuration.



3.2.3 Movement and Transport Concepts

Again, since the importance of movement trumped the importance of transport, the concepts for the linear motion devices were sketched and detailed more carefully.

Fig. 15 - Concept 1: Rack and Pinion

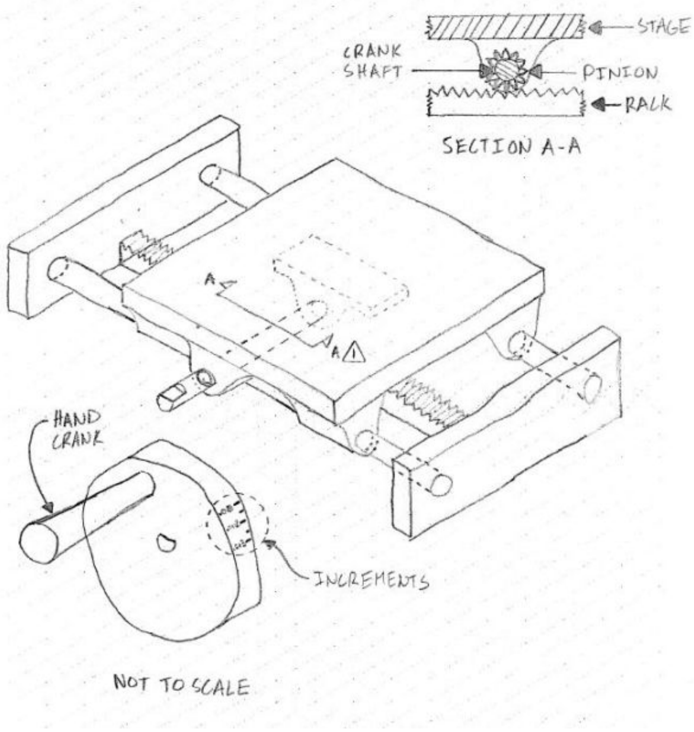


Fig. 16 - Concept 2: Belt Drive

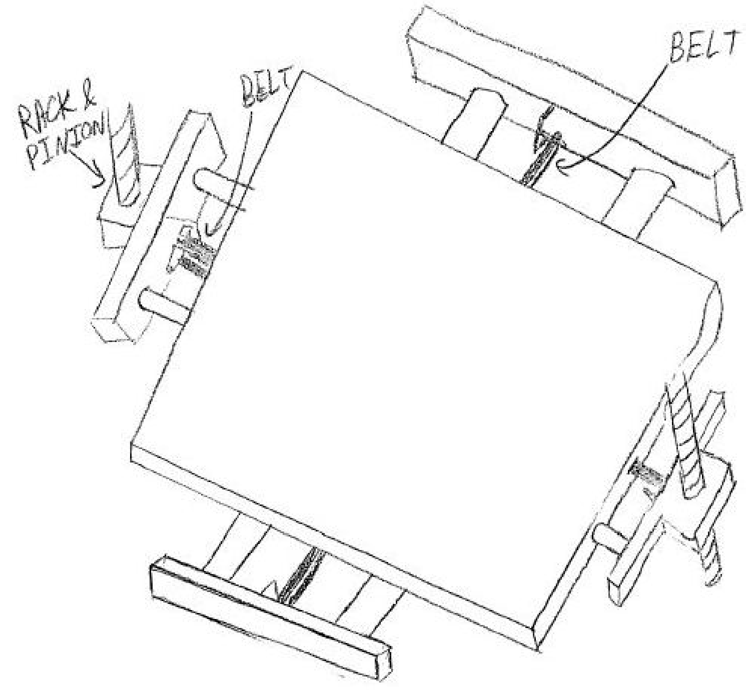


Fig. 17 - Concept 3: Lead Screw

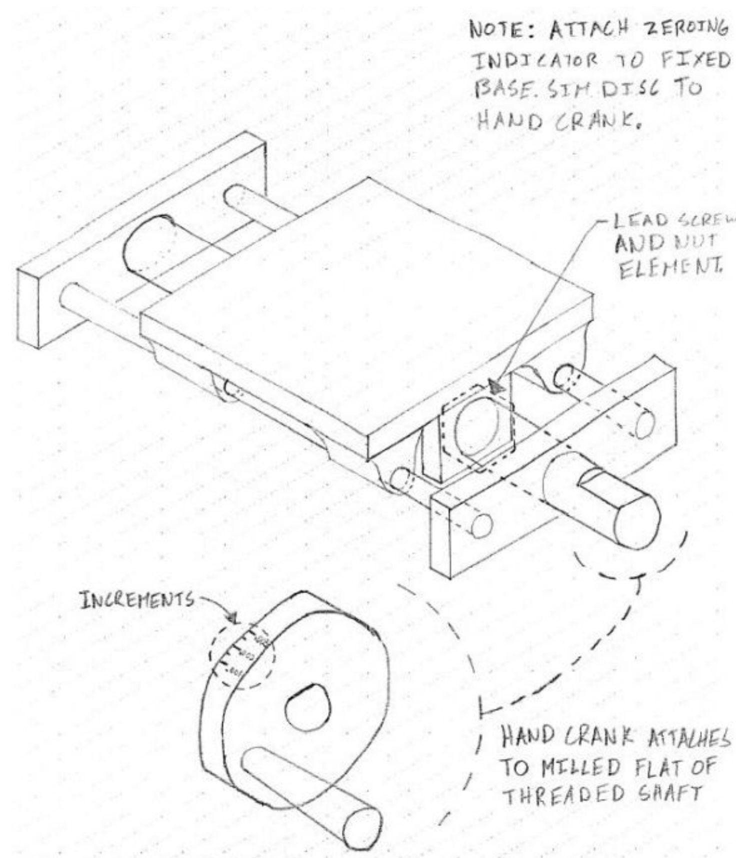


Fig. 18 - Concept 4: Friction

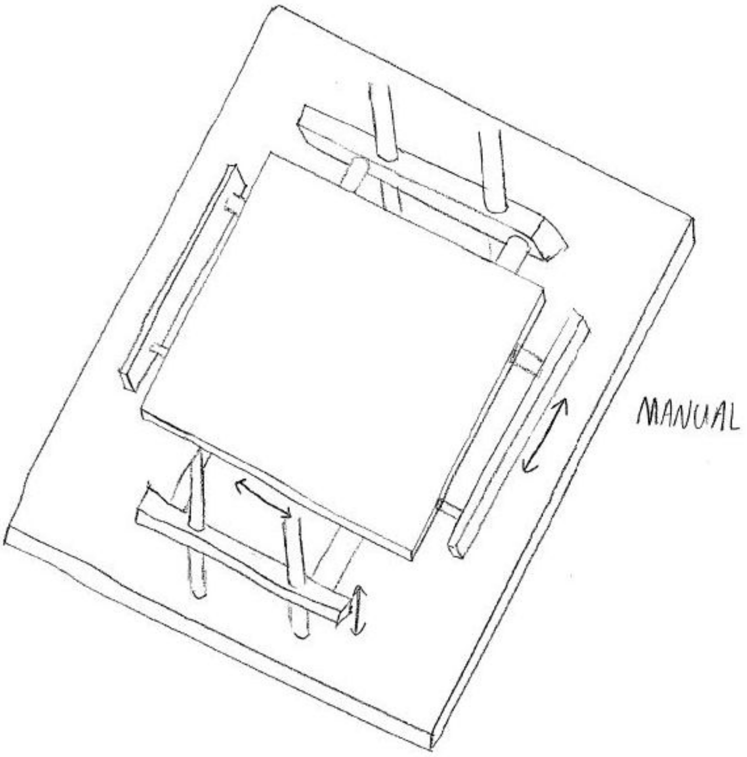
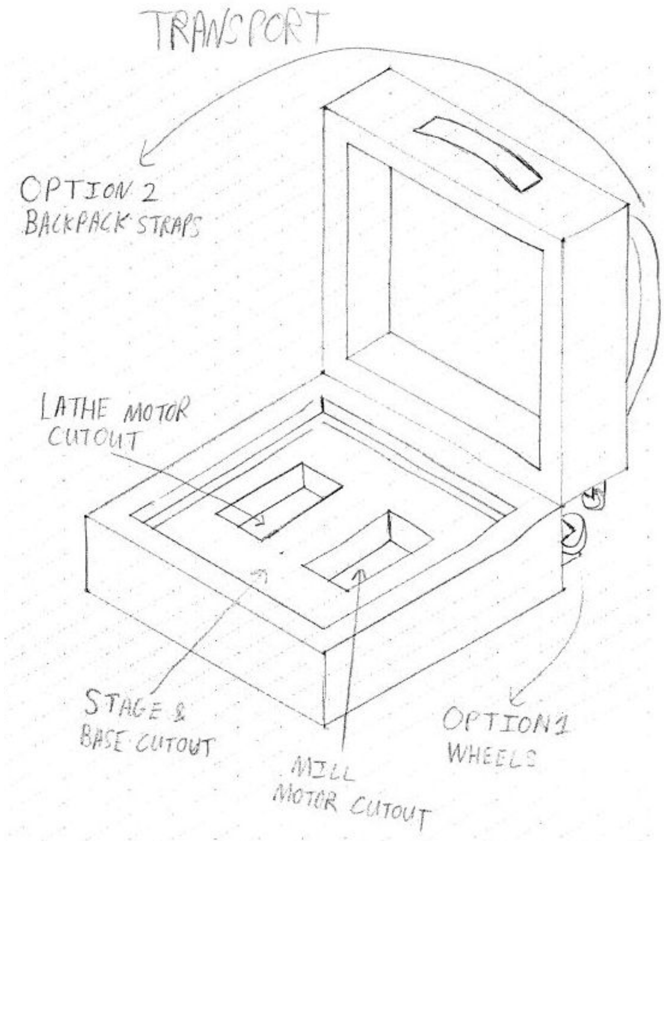


Fig. 19 - Transport Concepts



3.3 Concept Selection

3.3.1 Concept Scoring

Concepts were scored using the equation sheets shown in section 3.1.4.

Table 4: Concept Scores

Group	Concept 1	Concept 2	Concept 3	Concept 4
Mill/Drill	Lead Screw	Rack and Pinion	Overhead Int. Rack and Pinion	Modified STD Drill Press
	.595	.692	.552	.866
Lathe	Hollow Tailstock with Flywheel	Horizontal Flywheel	Vertical Flywheel	Horiz. Hollow Headstock
	.792	.884	.723	.889
XYZ	Rack and Pinion	Belt Drive	Lead Screw	Friction
	.808	.814	.831	.811

3.3.2 Analysis of Feasibility

Mill/Drill Concepts

The Mill/Drill group did not analyze for feasibility.

Lathe Concepts

Concept 1: Hollow Tailstock/Horizontal Flywheel

Due to the physical headstock being hollow to allow for 12-inch-long rods, an external power to rotate the chuck will be needed. How that will be powered would be some sort of motor or system to allow for hand powered. Given that it's hollow we would have to figure out the inner diameter of the head stock. If the piece must be 4" diameter and 12" long rod, then the headstock diameter has to at least be 4".

With some vice to would go inwards for smaller diameter materials, the vice would have to be wide or at both ends to handle the large/heavy material. Aside from the usual lathe components seen there is an additional flywheel on the headstock. This is to help maintain torque when cutting and to reduce the power needed from the motor. However, the flywheel would greatly increase the overall weight of the lathe. This would only be the case if the motor is too small and doesn't have enough output. The reason for the small motor would be the overall size restriction.

The tailstock would have a crank to drive bit back and forth, while physically being on the rails to move closer. The tool post would also be on a set of rails to move left and right. The housing of the tool would also be on a rail section to allow for deep cuts.

Concept 2: Horizontal Flywheel

Similarly, to the 1stdesign, the head stock is hollow and the flywheel in also incorporated. The only change would be the chuck, having a homemade/makeshift vice using set screws to hold the part. So, this would mean the part is inside a cylinder and held in place with screws then spun to speed.

Concept 3: Vertical Flywheel

This design is a vertical lathe with a normal chuck, but with a larger flywheel. The headstock is also driven to rotate the material. The only other major difference from the previous two would be the long column to hold the tailstock and tool post. This would cut into the size department, therefore the only way to incorporate this would be having the column detachable.

For this to be possible it would be best if the column and horizontal beam to have rails to allow for the tailstock and tool post to move up, down, and left to right. To do this the tailstock and tool post would need to be very light weight that way the column wouldn't lean inward messing up the cut measurements.

Another option would be having some sort of cable anchor to counteract the weight. Also, since the tailstock would be facing downward it would have to be able to clamp the drill bit or piece, so it doesn't fall.

Concept 4: Horizontal Hollow Stock

This design has the basic essence of a lathe, the only difference is the hollow headstock. However, different from all the previous designs is that there will be no flywheel. This would require the motor to be both small and powerful enough to handle the minimum requirements.

Movement and Transport Concepts

Concept 1: Rack and Pinion

Over this concept provides a good support for the stage, however a big flaw in it. is that the rack and opinion would not provide the accuracy that we need. However with a set-up of a rack and pinion, the navigation of the controls would be more intuitive. Maintenance would be easy for this as well.

Concept 2: Belt Drive

The belt system may provide a smooth motion, but most likely could not handle the load of the system. This would cause the belts slip, wear, and/or elongate. This would be a cheap method.

Concept 3: Lead Screw

Provides a smooth and accurate translation of the stage. However, they can be heavy and pricey. Lead screws are easy to do maintenance on.

Concept 4: Friction

This design has significant safety flaws, namely that pushing the stage by hand could cause you to slip and hit the cutting blade. In addition, this would be very inaccurate. However, given that this option does not require any additional moving components, this is the cheapest of all the designs.

3.3.3 Summary Statements

Mill/Drill

So, we chose design 4 over the other 3 for many reasons. The over the top frame allows use of the lathe and detachable motor to keep out of the when not needed. The use of a purchased drill press and modified will be a cheaper option as well. Only downside is a little more involved and slightly heavy option. This does add the benefit of pre-designed plunge feature, multiple speed system, and quick access to available parts. It is a rigid frame but can add simple braces for added stability or height if necessary. This compacts well with the design and can be packaged easy using the rigid frame provided by the mill.

Lathe

Overall the design that would best fit the requirements without going overboard would be the fourth design. This design has no flywheel which would decrease the overall weight, and the needed motor power to spin the extra weight. Also keeping this horizontal would eliminate the necessary rails and cables to hold a tailstock up, as shown in design three. Plus, with the chuck being a standard chuck and not a homemade set screw holder this would allow for better securement of the piece and reduce the need for inconsistent setting that goes with the screws.

The headstock, tailstock, and tool post can be on the same rail system to have more accurate movement and cutting. Plus, if it would be possible we would place another smaller rail set perpendicular to allow for the tool post to move in a cross position.

Movement and Transport

Concept #3 is the best solution. The reason for this is, if looking at the happiness equations, it came up with the highest value. In addition, the predicted precision of the rack and pinion made the idea undesirable. This also go for the manual option. The manual option was also predicted to be too dangerous as the machinist's hand could slip off the stage and hit the rotating tool. The belt seemed like an reasonable idea, but in the end, it would wear too easily. And looking into it, would most likely not be able to handle the stresses of the system. The lead screws have proven in existing models of mills and lathes to be a efficient form of controlling position. These are the reasons that the lead screw option is the winner.

Integrated Design Summary Statement

Given the discussion above, the final design shall have three distinct components. The first is a modified drill press to act as a mill and drill. The second is a horizontal lathe without a flywheel, and with a commercial chuck. The third component is a lead-screw based linear motion system.

3.4 Integrated Design Concept Sketch

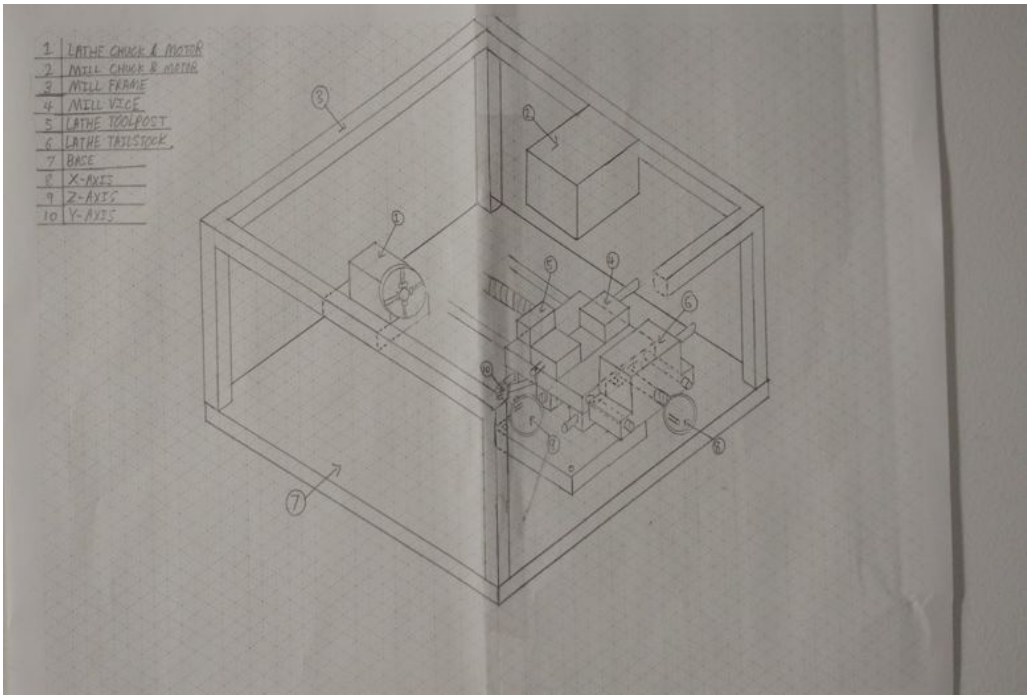


Fig. 20 - Preliminary Integrated Design Sketch

Above is the image of the integrated design of the stage, mill/drill press, and lathe. The machine will be broken into these parts: Base, stage, lathe motor, lathe tool post, lathe tailstock, mill motor, mill frame, and mill vice. The stage and the lathe motor will be mounted to the base as seen in the image. The tailstock of the lathe will be mounted to the same rails as the X-axis of the stage.

The lathe tool post will be mounted onto the left side of the stage when needed. The mill frame will be mounted to the base with the mill motor mounted on the frame. Lastly the vice will be mounted onto the center of the stage. There will be a zero-point set onto the up and down motion of the stage so that when being used as a lathe after being used as the mill, the tool post will be level with the lathe chuck.

4 Embodiment and Fabrication Plan

4.1 Embodiment/Assembly Drawing

After scavenging items from the trash, the team determined it would make use of a wood lathe to assemble the prototype. While other individuals may not be able to rescue such an item from the dump for free, the commercial equivalent is still within budget, and therefore the team found it as an acceptable replacement. Therefore, the following embodiment will focus primarily on concepts for converting a wood lathe and other items to produce a mill/drill/lathe tool for oneself.

Finalizing work in modeling components of the initial design shown in Section 3.4, as well as integrating the changes in concept described above, the team was able to produce a complete assembly in Solidworks, shown in the figure below.

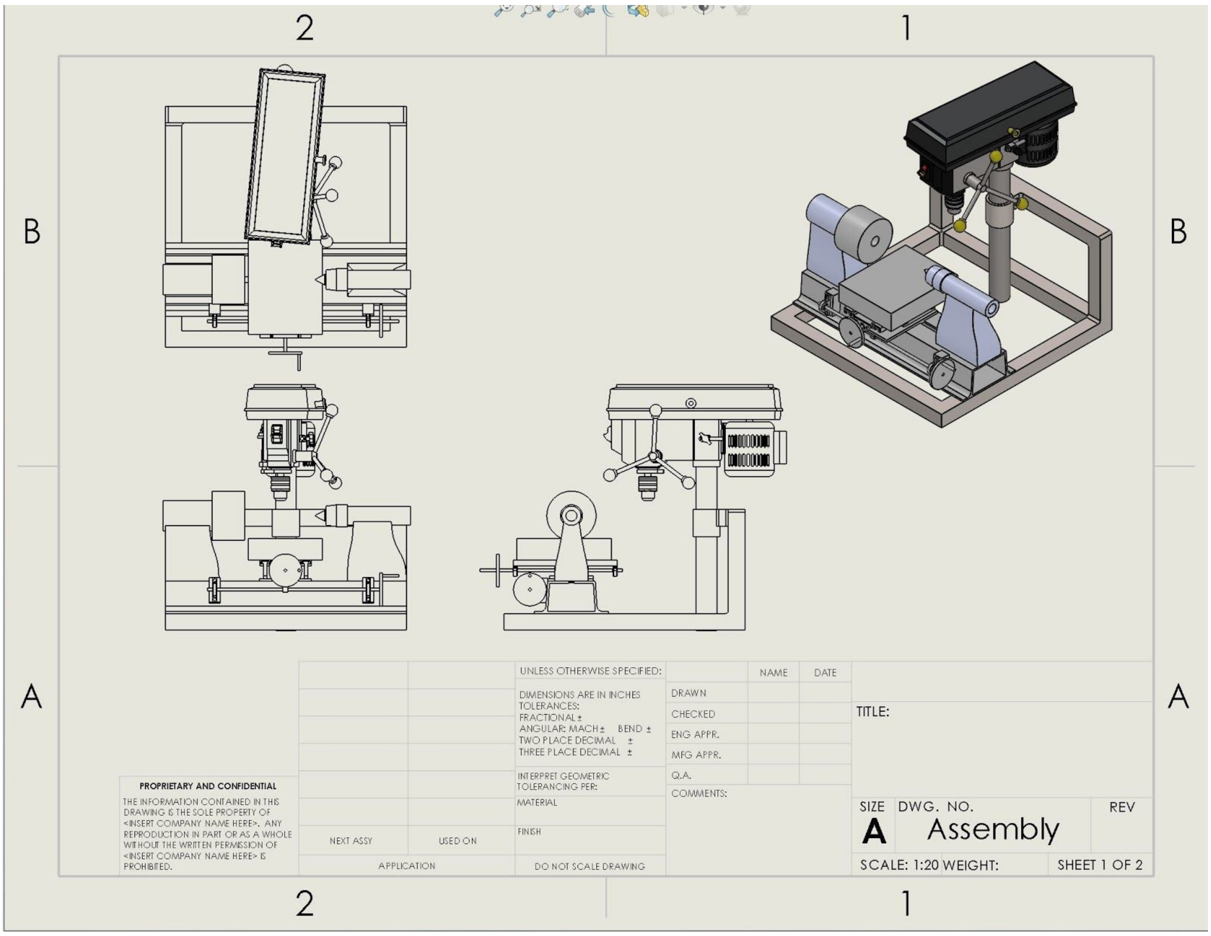


Fig. 21 - Finalized Preliminary Embodiment Assembly Drawing

4.2 Parts List

Table 5 - Preliminary Embodiment Parts List

Detail #	Description	Part No	Source	QTY	Each	Total
1	Lead Screw	93410A606	McMaster Carr	2	$18.97	$37.94
2	Pillowblock Bearing	5912K100	McMaster Carr	2	$9.83	$19.66
3	Bolt	92865A537	McMaster Carr	8	$7.38	$7.38
4	Vise	30999	Harbor Freight	1	$17.99	$17.99
5	Aluminum Stock	8975K215	McMaster Carr	1	$38.85	$38.85
6	Track	N/A	Scrap	1	Free	$0.00
7	Dial			3	$4.00	$12.00
8	Rigid Caster wheel	78155T18		2	$6.42	$12.84
9	Chuck	M1057	Optics Planet	1	$82.79	$82.79
10	Tailstock	N/A	Scrap	1	Free	$0.00
11	Spindle			1	$50.00	$50.00
12	Tool post	120034	Ebay	1	$30.80	$30.80
13	Bits	40641	Harbor Freight	1	$4.49	$4.49
14	Live center	MT2	Amazon	1	$17.99	$17.99
15	Motor	68288	Harbor Freight	1	$159.99	$159.99
16	Drill Press		Harbor Freight	1	$64.99	$64.99
17	Tapered Bearing	30202	NEWEGG	2	$7.97	$15.94
18	Dial	7901	Website	1	$85.00	$85.00
19	Worm Gear and HLTL	g-1027 HLTL	ebay	1	$28.00	$28.00
20	ER16 Collet		Amazon	1	$29.36	$29.36
21	Square Tubing	STOCK	Shapiro/ Work	6	Free	$0.00
					TOTAL:	$716.01

4.3 Draft Detail Drawings

Given that many of the items are salvaged or commercially available, the team did not produce drawings of these items. Instead, the team will provide insight into use and installation for this application. For these drafts, most commercial items with minor modification may not be shown.

The main piece of the y-linear motion device is the t-slot track, which will not be shown in drawing form below. This is because they are a commercial item. Refer the the following image for reference on the item.

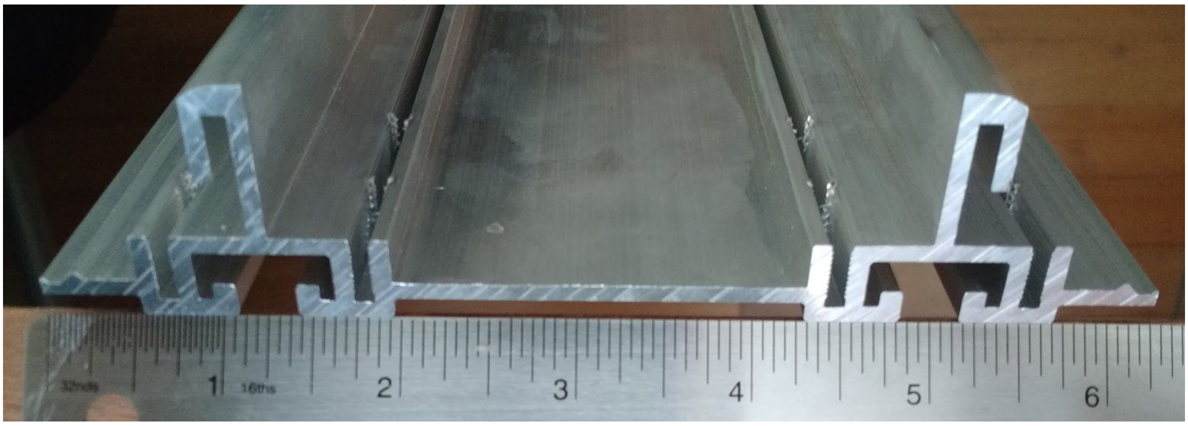


Fig. 22 - Preliminary Design Track with Scale

The modified I-Beam shown below is used in the two tracks along the x-axis. The “I” seen in the right side view engages with the x-axis track, while the two “I”s in the front view engage with the bottom of the y-axis track. Much of the material removed, as shown in the front view, is to allow for pillow block bearings to be installed on the underside of the y-axis stage to permit motion in the y-direction with a lead screw setup.

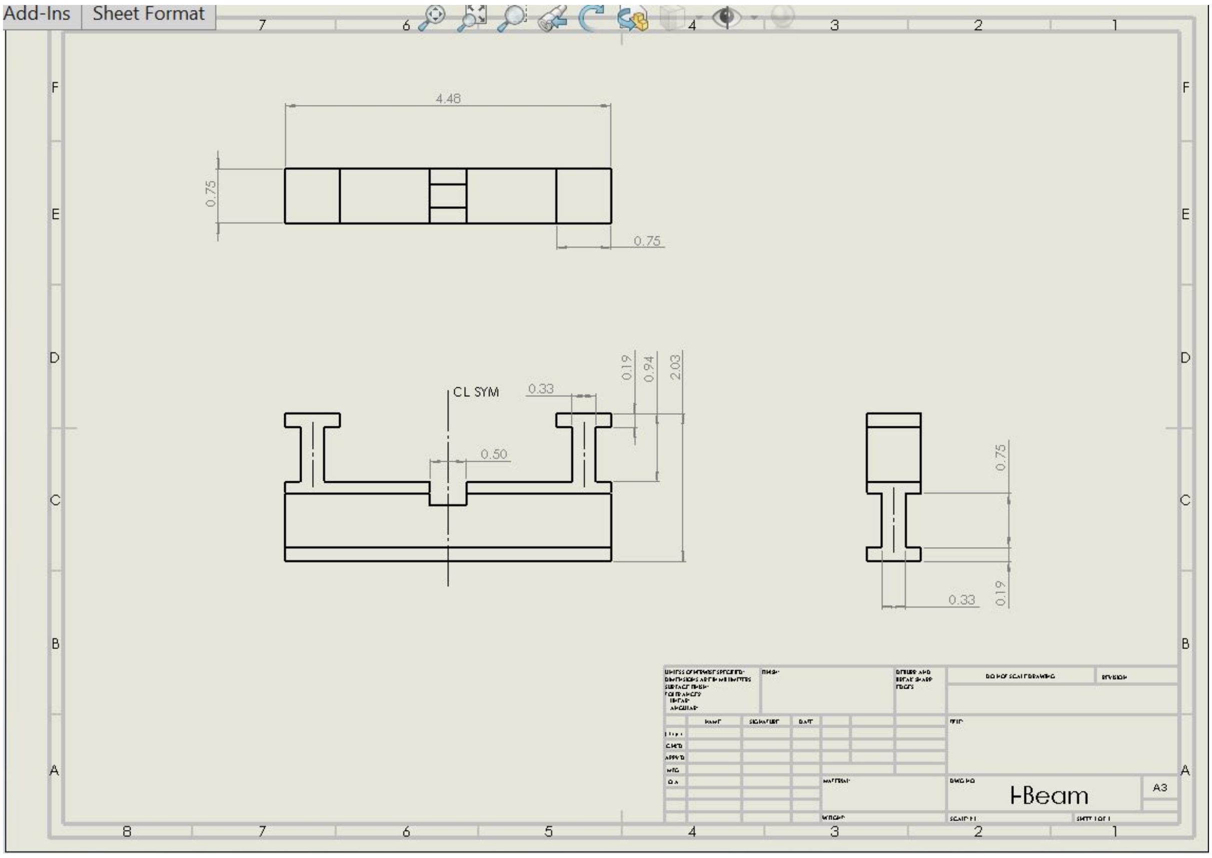


Fig. 23 - Preliminary Design I-Beam Detail Drawing

A hand crank will be used to translate the stage on its axes. The following drawing details the fabrication of the body of the hand crank. A standard ¼-20 bolt will be threaded into the body as a handle for cranking.

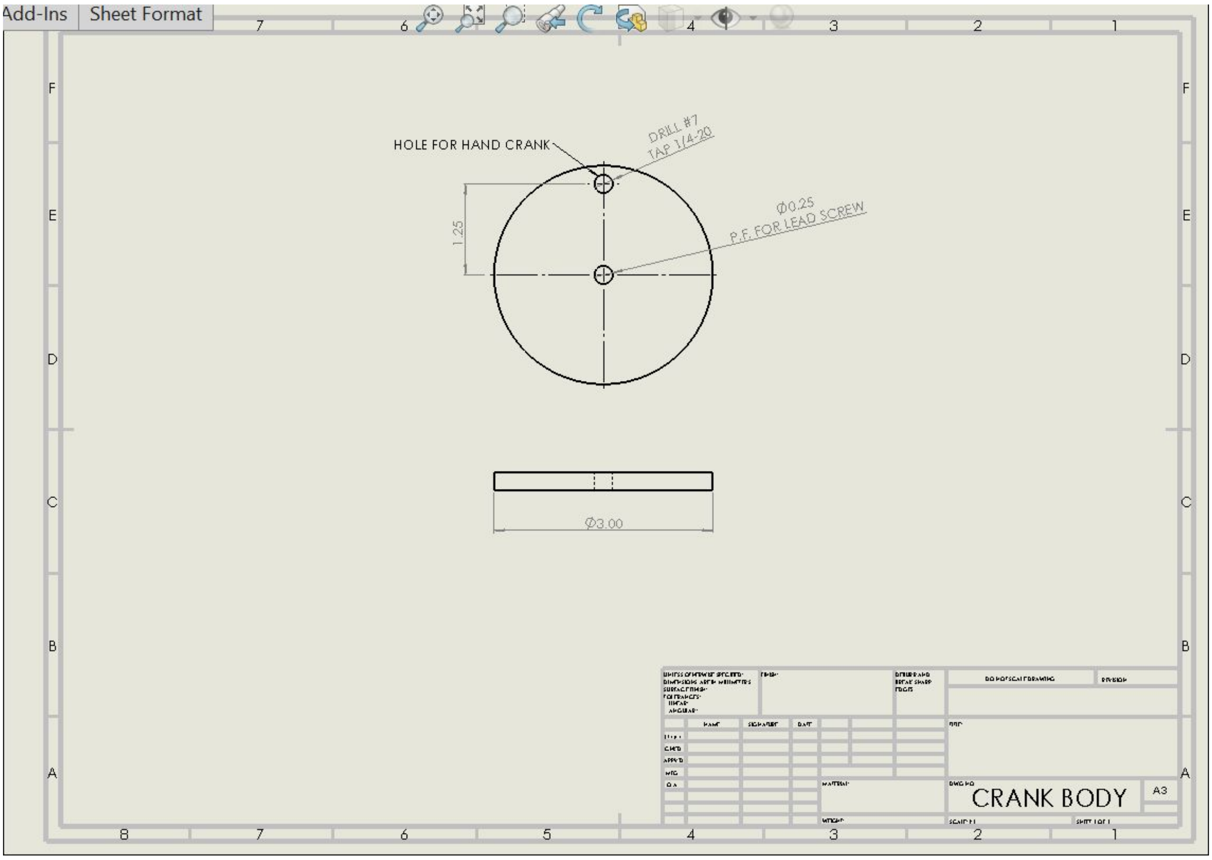


Fig. 24 - Preliminary Design Crank Body Detail Drawing

Since the team's design The image below shows points of interest in the design of our mill/drill/lathe tool. Each point of interest will be described in detail for assembly.

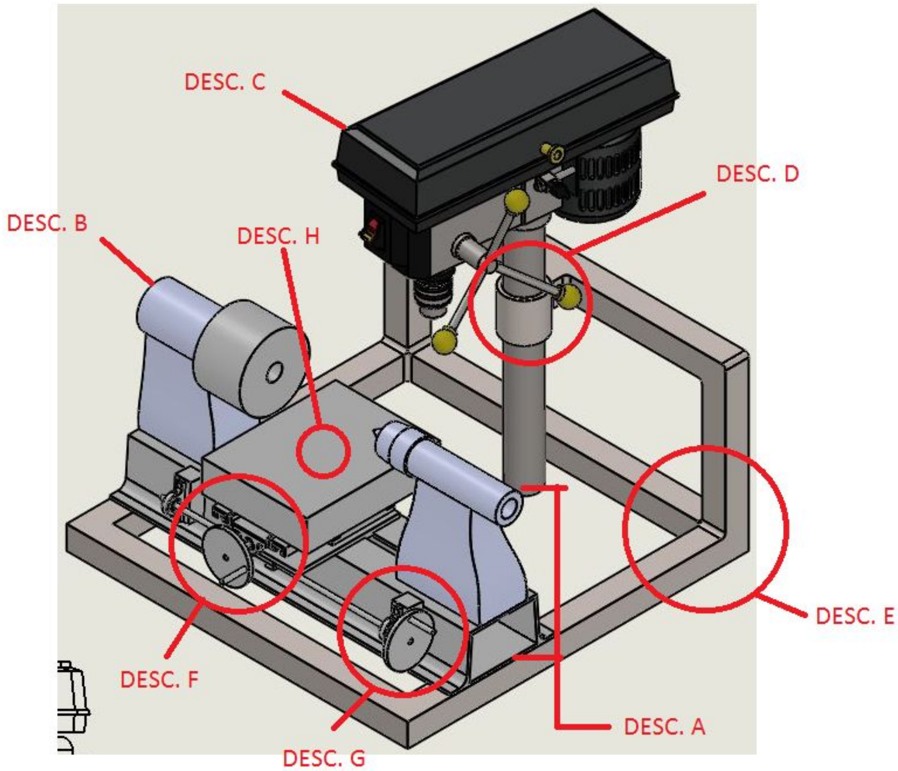


Fig. 25 - Revised Preliminary Embodiment Assembly with Description Callouts

Table 6 - Revised Preliminary Embodiment Callout Descriptions

DESC. A	The track and tailstock of the wood lathe are salvaged and used for the assembly of the new tool.
DESC. B	The headstock may also be saved. The chuck and replacement pulley wheels are sourced commercially.
DESC. C	A commercial small drill press can be modified with a new bearing insert to be used as a milling motor.
DESC. D	Modifying the mounting of the drill press allows for a smaller form factor. This also permits the removal of the motor when not in use, and allows the user to maintain a calibrated z-axis motion using components from the original drill press.
DESC. E	Modification of the drill press and mounting all of the linear motion and lathe components requires a welded aluminum frame to tie everything together.
DESC. F	An inverted t-slot linear motion device permits a smaller form factor for motion in the x and y directions. For reference, this is only a slightly modified variant of the design style most commercial mills follow today. A nut element mounted on the x-stage above the center of the latheway causes the y-stage to translate when the crank is turned. The t-slot rides along the I-Beams shown in a drawing earlier in this section. This design keeps the crank travelling with the y-axis of the stage, which means there will never be any interference between those two components.
DESC. G	Pillow block bearings may be offset from the side of the latheway to act as the guides for the x-axis lead screw. Again, a simple hand crank may be used to translate the stage.
DESC. H	The stage is shown with the size envelope of an installed vise. This vise may be used for milling/drilling purposes. The vise may be removed so that a tool post for cutting parts on the lathe may be installed atop the stage.

4.4 Design Rationale

As detailed above, the team sought to use as many commercial items as possible without much modification. This is because the team believes that the “maker” personality believes much more in repurposing existing items than producing a complete build from scratch. This mindset not only eliminates time spent fabricating parts from stock to construct a mill/drill/lathe, but also the significantly reduces the complexity of the build.

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 Engineering Analysis Contract

MEMS 411 / JME 4110
MECHANICAL ENGINEERING DESIGN PROJECT

ASSIGNMENT 5: Engineering analysis task agreement (2%)

ANALYSIS TASKS AGREEMENT

PROJECT: Combo Mill/Drill/Lathe
INSTRUCTOR: Mark Jakiela
NAMES: Ephraim Abrams, Menasha Abrams, Kevin Le, Brian Mayfield, Ashley Newton, Pete Patton, Thomas Poon, Trevor Potter, Alex Rich, Richard Russell, Parker Stovall

The following engineering analysis tasks will be performed:

Mill/Drill	Lathe	Movement and Transport
"Before" Analysis The ability of the welded frame to support the weight and cutting forces of the modified drill press. "After" Analysis Identify possible points of failure from repeated use due to vibrations that may not be identifiable from a Solidworks analysis. Consider solutions to these issues.	"Before" Analysis The maximum tension in the drive belt of the lathe motor will be determined to ensure the purchase of a strong enough drive belt. This will be done by calculating maximum torque supplied by the motor, assuming a maximum horsepower and output speed (rpm) and a minimum pulley size. "After" Analysis The chosen drive belt will be tested at the maximum output to verify that it will be suitable to operate our prototype. This will be done by setting up the motor with the lathe chuck to gradually run the drive belt at its maximum rating.	"Before" Analysis The ability of the stage components to withstand part and tool weights, as well as cutting forces, will be analyzed using Solidworks. "After" Analysis The "before" analysis will be verified. In addition, the transportation system (wheels and mounting structure), will be analyzed for soundness and stability.

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

All members of each group will be present during that group's testing to provide input. One will lead the analysis, a second will verify the analysis, and the third/fourth will discuss results and if further tests should be performed.

Instructor signature: *Verbally authorized 8/6/18*; Print instructor name: Mark Jakiela

Fig. 26 - Engineering Analysis Contract

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Motivation

Mill/Drill Analysis

During the development of converting a standard drill press to withstand the lateral forces of a mill, the structural integrity of the mounting system becomes of question. We decided to analyze the amount of deflection seen by the mounting pole due to material selection and mounting design. This deflection determines the accuracy of the machine as well as safety aspects.

In order to determine the deflection of the mounting pole due to the mounting design, the force exerted by lateral milling in a standard material needed to be determined. Using ASME material specification handbooks and standard practice machining it was determined that a 25lb lateral force would be sufficient loading to simulate milling material. Using standard young's modulus values for aluminum and steel, we used Solidworks simulation software to perform FEA analysis on the design. This allowed helpful insight on mounting design specifications as well as material selection.

Lathe Analysis

We will be analyzing the tension that will be carried in the drive belt of our lathe. Since our lathe is belt driven by an electric motor, it is important to find a belt that can transfer the necessary power. Completing our analysis will ensure that we get a belt which will be sufficient to drive our lathe without any risk of it breaking. The pre-analysis will also ensure we do not waste money on a belt that is too weak, or on a more expensive belt that is much stronger than necessary.

Movement and Transport Analysis

The ability of the linear motion system to withstand weights and cutting forces is imperative to the tool's use. While it may not cause immediate failure, the group would also like to ensure a long fatigue life of the tool. Lastly, failures of the linear motion system could be a safety concern. For instance, if the tool post broke off during regular lathe use, and the tool were to be sent in an unknown, dangerous direction.

5.2.2 Summary of Analysis

Mill/Drill Analysis

In order to determine the deflection of the mounting pole due to the mounting design, the force exerted by lateral milling in a standard material needed to be determined. Using ASME material specification handbooks and standard practice machining it was determined that a 25lb lateral force would be sufficient loading to simulate milling material. Using standard young's modulus values for aluminum and steel, we used Solidworks simulation software to perform FEA analysis on the design. This allowed helpful insight on mounting design specifications as well as material selection.

Using Solidworks simulation on a single location clamp mount and an aluminum mounting pole, approximately 0.0035" deflection was observed (See Figure 27). This large amount of deflection would not be suitable for our application.

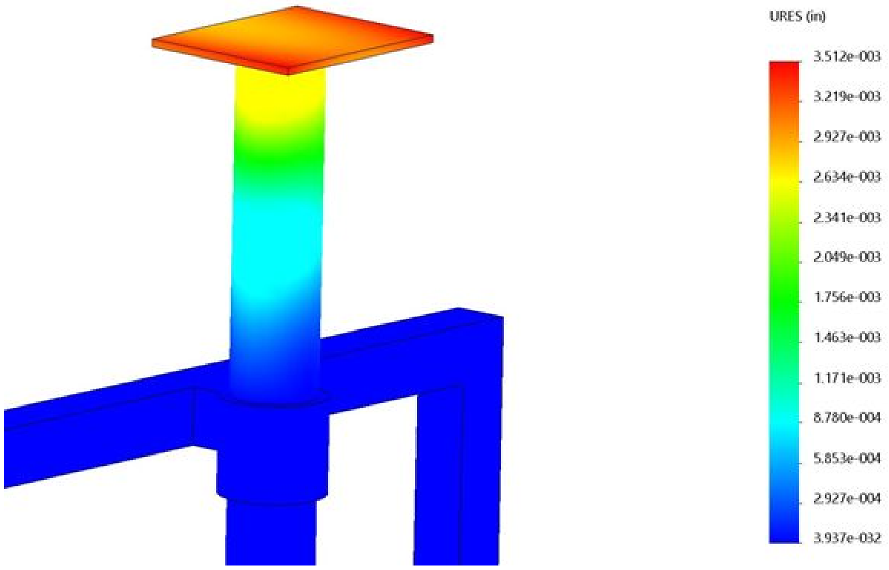


Fig. 27 - Aluminum, Single Mount Simulation Data

The same 25lb lateral force and single location clamp mount was simulated this time with a steel mounting pole. Again, a large amount of deflection was observed, approximately 0.0011" (See Figure 28). Although the observed performance was better than that of the aluminum, this was still not adequate for our application.

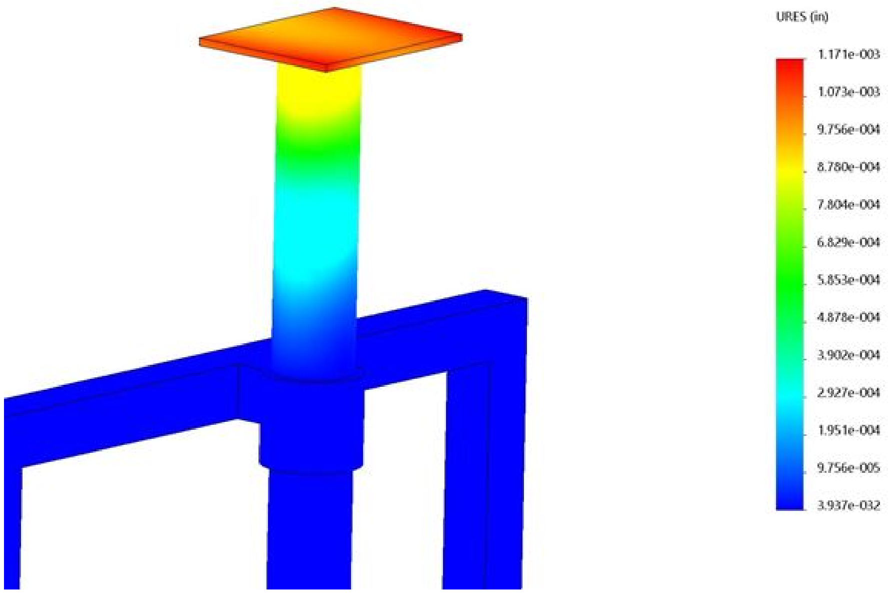


Fig. 28 - Steel, Single Mount Simulation Data

In order to reduce the deflection to a reasonable amount, we simulated a single location clamp mount with an additional guide slot on the lower portion of the frame. Using the two locations to reduce deflection along with a steel mounting pole, the simulated deflection was approximately 0.0001" (See Figure 29). This design shows to be an adequate design for our application.

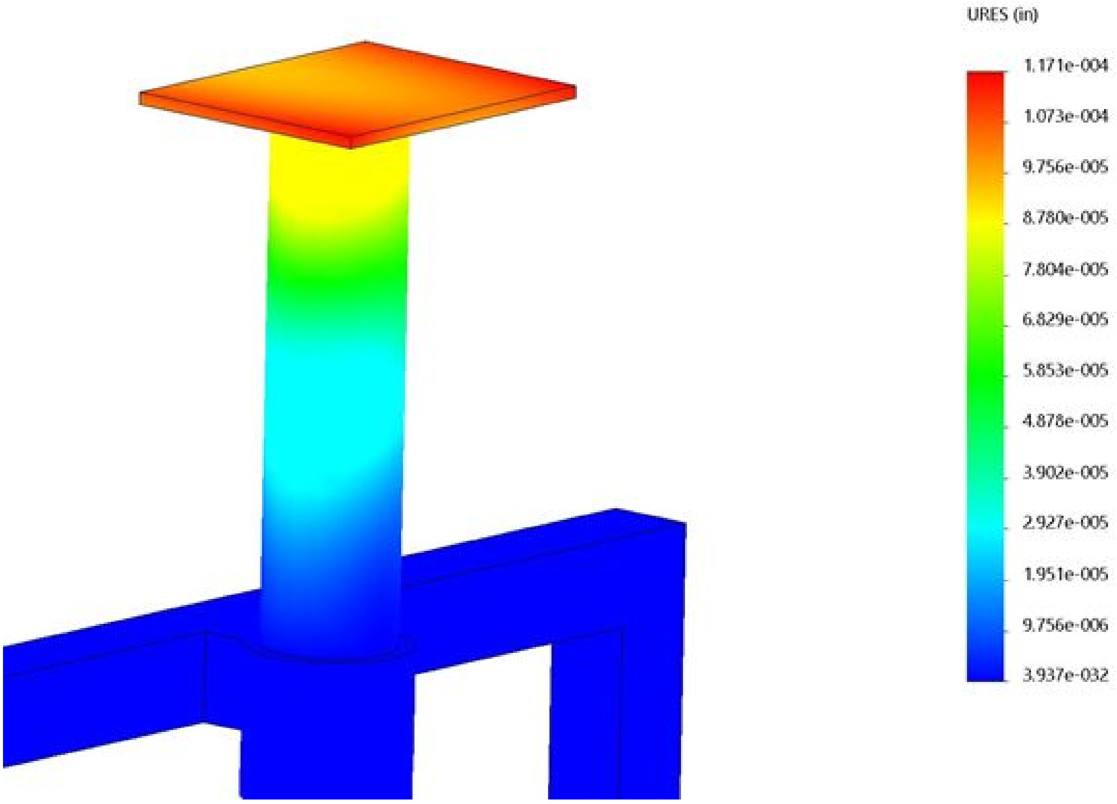


Fig. 29 - Steel, Double Mount Simulation Data

Lathe Analysis

Using the equations for power and torque, we can determine the necessary tension (force) in the drive belt.

Power equation: $P = \tau\omega$

Torque Equation: $\tau = Fr$

P – motor power (ft-lb/s, convert from HP)

τ – motor torque (ft-lb)

ω – rotational velocity of the motor shaft (rad/s, convert from rpm)

r – radius of the shaft (ft, convert from inches)

F – belt tension (lb)

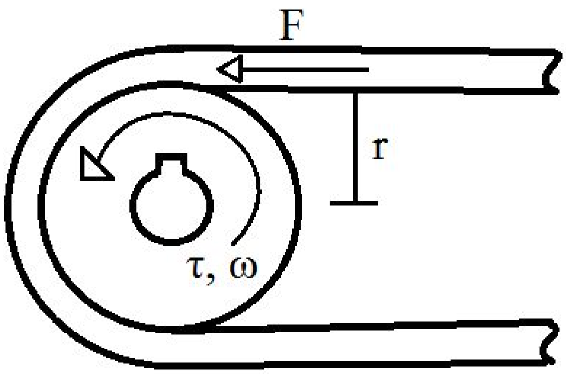


Fig. 30 - Pulley Torque Calculations Figure

Movement and Transport Analysis

Simple FEA analysis using Solidworks is to be performed on the integrated concept model. By applying material properties to each of the movement components, the group is able to replicate a completed build. Solidworks will then calculate stress, strain, and displacement of the bodies. The figure below shows the model before analysis.

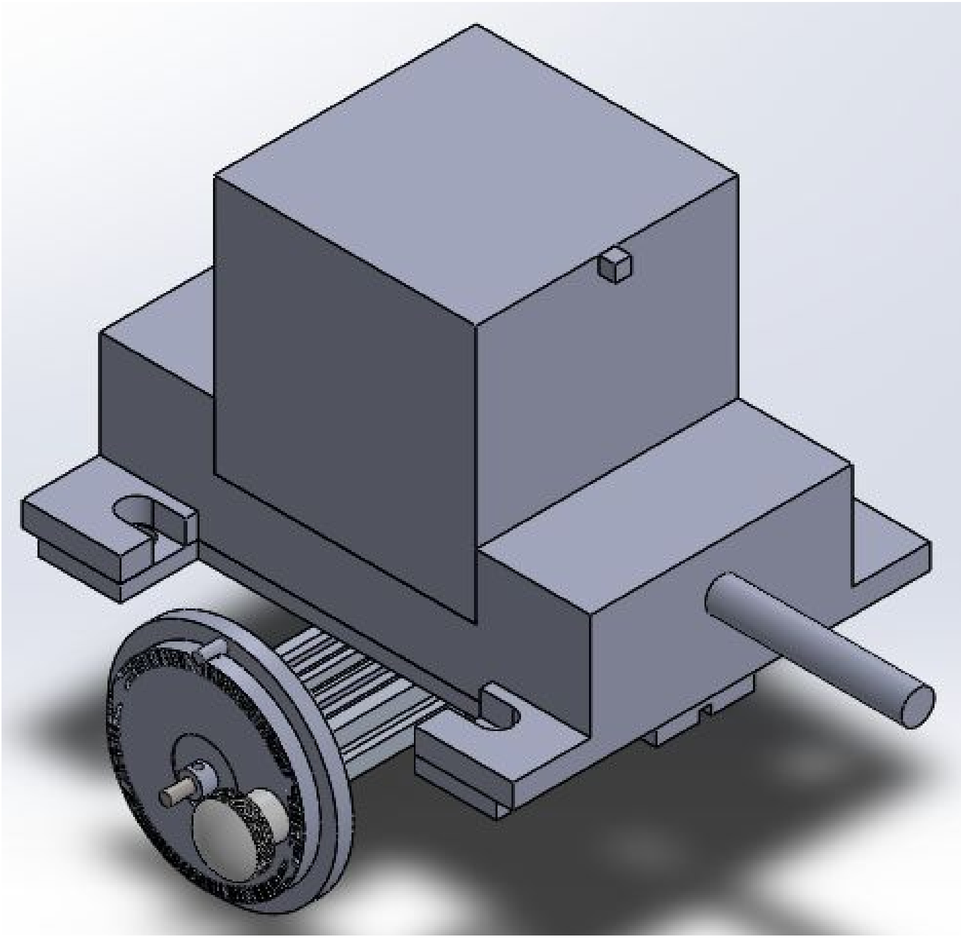


Fig. 31 - Movement and Transport FEA Analysis Model

5.2.3 Methodology

Mill/Drill Analysis

Using a magnetic dial indicator, we were able to measure this deflection on the prototype after it was assembled. The initial measurements taken were skewed due to an improper weld on the base, however, after correcting this weld the results were very close to that of the simulation. The measured results were roughly 0.001" of movement. Although this is closer to the steel with single mount simulation, the majority of this deflection was caused by changing the base from steel to aluminum due to weight restrictions. Ultimately, the simulation data helped determine that a single mount system was not suitable for the application and positively impacted our results.

Lathe Analysis

The largest motor we would conceivably have is a 1 HP, 1800 rpm, with a 5/8" diameter shaft. A small V-belt pulley that would fit on this shaft has an outside diameter of 1¾". We used these values and the equations provided previously to calculate the maximum conceivable tension in our belt.

Movement and Transport Analysis

A combined weight of the linear motion components was applied across the top surface of a "work part" to simulate actual weight forces in the system. The combined weight was 40 pounds. In addition a 25 pound force was applied laterally at the top of the "work part" to simulate a milling cutter making contact with the part. The simulation setup is shown in the figure below.

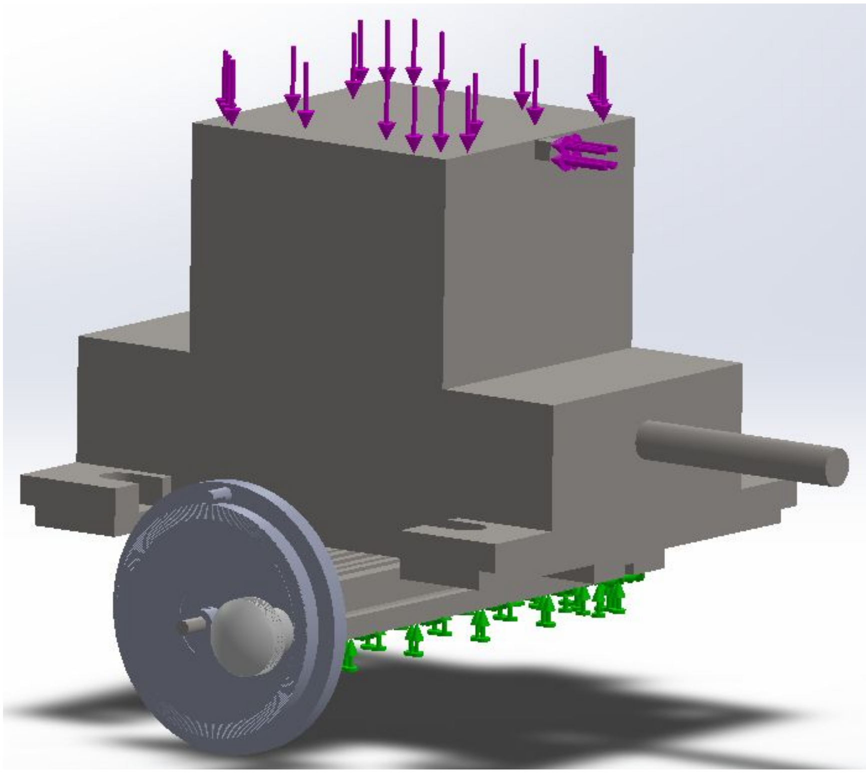


Fig. 32 - Movement and Transport FEA Analysis Loading

5.2.4 Results

Mill/Drill Analysis

The Mill/Drill group did not report any results from testing.

Lathe Analysis

The calculated value of the tension our drive belt must sustain is 20.0 lb. Comparing with belt tensioning guides found on the web, this calculation is in the right range, though intuitively it seems like a low value.

We ended up using a belt from salvage, and simply tested its ability to operate our lathe. We found that it was able to rotate our shaft.

Movement and Transport Analysis

The Solidworks analysis determined that the linear motion system would be capable of sustaining the weight and cutting forces. The solution of the Solidworks analysis is shown below. As shown, a majority of the tool experiences minimal stresses.

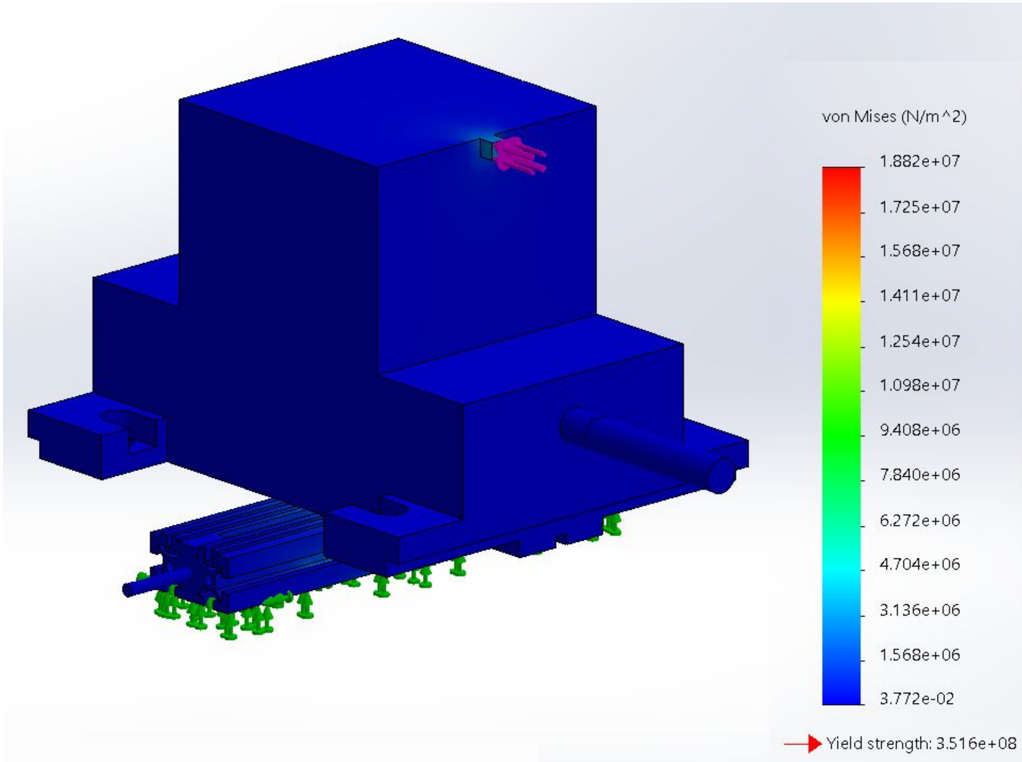


Fig. 33 - Movement and Transport FEA Analysis Stress Results

5.2.5 Significance

Mill/Drill Analysis

These results effectively change the initial design concept that we created. We changed the material selection from aluminum to steel as well as, added an additional support at the bottom of the frame. The deflection results make sense and showed that our initial design intent would have caused large amounts of inaccuracy in the precision of the mill. Changing the material and mounting design will increase the rigidity of our mill and ensure the accuracy of our mill.

Lathe Analysis

This analysis affects our design in that we will ensure the belt we buy is properly rated. We will also include a factor of safety of 1.5, so the belt we buy will be rated for 30 lbs. The diagram of the belt used in the prototype will be shown in the final CAD model.

Movement and Transport Analysis

As shown in the results, the weight and cutting forces have almost no impact on the structure of the linear motion device. This means that our design should have no issues once constructed. In addition, the tool should be able to machine even larger parts, and not have any issues. Lastly, since the stresses sustained are so low, the fatigue life should also be very lengthy.

6 Risk Assessment

6.1 Risk Identification

Cost

Students and DIY-ers are always looking for ways to cut costs. Hence the reasoning for DIY.

Operator Safety

Operating any machine or power tool comes with inherent risks for bodily harm.

Power Outage

Power outages can significantly damage electronics, and in some cases may even start fires.

6.2 Risk Analysis

Cost

Cost can be monitored by sourcing used or hand-fabricated parts.

Operator Safety

Safety features to guard an operator from bodily harm are easy to install, such as a plexiglass shield to prevent chips from flying back onto the operator.

Power Outage

Integrating failsafes such as fuses can quickly eliminate risk of damage from power outages.

6.3 Risk Prioritization

As with any task, safety is of the utmost importance. Therefore Operator Safety should take first priority. Second, since power outages may cause property damage, this the the next most significant risk. Lastly, although DIY-ers are always concerned about keeping costs of projects low, the risk of investment does not outweigh the two previous risks. Specifically, monetary damages will be significantly less if the tool costs more to produce than expected versus the operator having medical bills from an injury.

7 Codes and Standards

7.1 Identification

ISO 26303:2012(E) 6.1 GENERAL constrained us to follow an engineering process of design for this prototype and machine. We followed an initial process according to this standard being:

1) Agreements which includes the test plan and procedure. This means that we had to plan according for each piece and run through a procedure that would fulfill this standard.
2) Warm up Procedure: which constrains us to warm up the machine and make sure everything was up to running temperature and safety meaning no noises or exposed wires or unsecure machinery.
3) Adjustment- adjusting the machine to be within a specific tolerance range
4) Analysis- measurement of results
5) Measurement of parts and results capability for each machinery specified part
6) Production- production of parts

7.2 Justification

7.2.1 Agreements

Agreements - states the machine and the applied machining process are evaluated with as few interfering influences as possible.

This ISO standard 6.2 agreement was influenced into our design because we tried to simplify our design as best as possible to keep the number of interfering variables to a minimum. This meant that we designed machinery that could detach to move out of the way to keep the parts from interfering with one another or creating a safety hazard while parts are being machined.

ISO 26303:2012(E) 6.2

7.2.2 Warm-up Procedure

Warm up Procedure - states that the running machine should have a short-term test that allows us to test the operating temperature; if the machine is not performing at a thermal equilibrium it should not be operated.

This is significant in our design rationale for the motor attached to the lathe and mill because during the build we constrained and proved that our motor was at running temperature before we tried any cutting. This short-term capability ensured that our motor was in temperature equilibrium and assured us under a load this would not overheat or burn up the motor prematurely.

ISO 26303:2012(E) 6.3

7.2.3 Adjustment

Adjustment - serves the purpose of adjusting the process to achieve a target value of a characteristic.

This ISO standard 6.4 constrained our design process to adjust as we needed to along the design process and analysis to achieve our precision or movement as necessary. Our target values were essential such as a functional x,y and z movement as well as a 2 inch z plunge given by the drill press. We could test pieces to make sure we at a fully targetable speed as well as making sure our instruments could allow the material size. This ultimately minimizes deflection if our part may be secured and supported properly as well as remain precise. This ISO standard allows us to make the minimal or maximum changes necessary such as adjusting a bit or how a machine is positioned. We realized we needed to adjust the motor and frame to get a fully functional track for vertical and horizontal movement. We were also able to constrain and adjust the drill height and plunge to achieve precision and accuracy within the z direction. As traditional aware occurs; new parts and new updates will need to be accounted for. While this may not be in the initial budget, this will need to be adjusted for down the road such as belts, new motors, drill bits and possible lead screw adjustments to keep the movement oiled and moving linearly.

ISO 26303:2012(E) 6.4

7.2.4 Production

Production - constrains the final production pieces made without stopping to achieve a final part without flaw. If the method or change in timing occurs the part that is being manufactured is not accurate and distorts the final image.

This constrained and made us account for vibrational distortion such as if the mill or lathe created inaccuracy due to vibration or if weight of the drill was going to cause the frame to deflect or tip. We want to manufacture a part, from start to finish with having control over the part and the process.

ISO 26303:2012(E) 6.5

7.2.5 Measurement

Measurement - justifies our precision tolerances for each machine, set by professor Jakiela. For this project we tried to constrain and be within the precision specified for the particular part at hand. We want to ensure our part being machined is at room temperature too to ensure that the precision is not affected. We had to ensure that our test material was smooth on the surface to avoid a false representation of the measurement. We can apply this standard to our project because our measured uncertainty should be less or equal to 10% of our given tolerance.

ISO 26303:2012(E) 6.6

7.2.6 Thermal Influences

Thermal Influences - justifies that the working accuracy of the machine is dependent on static, geometric, dynamic and thermal characteristics. This constrains our design to take into account any internal and external heat sources, this means we had to account to any heat transfer to a cutting bit or to the surroundings that may create a safety hazard or potential machinery shortage. In our design thermal influences constrained the tool offset, lubrication/dry measurement of our material, tool wear given a bit that may deflect due to heat as well as clearance, maintenance and axes positioning systems. Thermal influences also influenced the environment of our design because of vibration caused by attached machines as well as any external heat sources.

ISO 26303:2012(E) 7.2

7.3 Design Constraints

7.3.1 Functional

The design must fit the needs of the customer: a compact, portable mill/drill lathe tool that can be made at home or with limited access to a machine shop.

7.3.2 Safety

The design should incorporate safety devices to stop the motors and any cutting devices.

7.3.3 Quality

There is minimal constraints for quality in this design, since it is mostly the repurposing of existing materials. Just maintain tight tolerances on any machined or modified components so that the final product will maintain a high accuracy.

7.3.4 Manufacturing

After fabrication of any parts, the design should be easily assembled with basic tools that should be accessible to the “maker” persona.

7.3.5 Timing

The tool should have a cleanup time of less than 10 minutes and a setup/teardown time of less than 20 minutes.

7.3.6 Economic

The design should cost no more than $800.

7.3.7 Ergonomic

All switches, levers, handles should be easily accessible by a user in the case that the tool is placed on a workbench against a wall.

7.3.8 Ecological

The design should not produce any immediate or long-term health/environmental hazards. This constraint reinforces the need for safety features to protect the user from flying chips.

7.3.9 Aesthetic

The design does not have to be particularly pleasing to the eye. However, simplistic designs tend to be more aesthetically pleasing.

7.3.10 Life Cycle

This design should have a life cycle of 1.5 years or greater to allow a student to utilize the tool during their final, most hands-on semesters on an engineering degree track.

7.3.11 Legal

The released design should have an included safety briefing about the tool’s use. The briefing should also include notices that, since the design may be self-assembled by consumers, errors in the assembly process and then use of the tool in an improper state may result in serious injury or even death.

8 Working Prototype

8.1 Working Prototype Photos

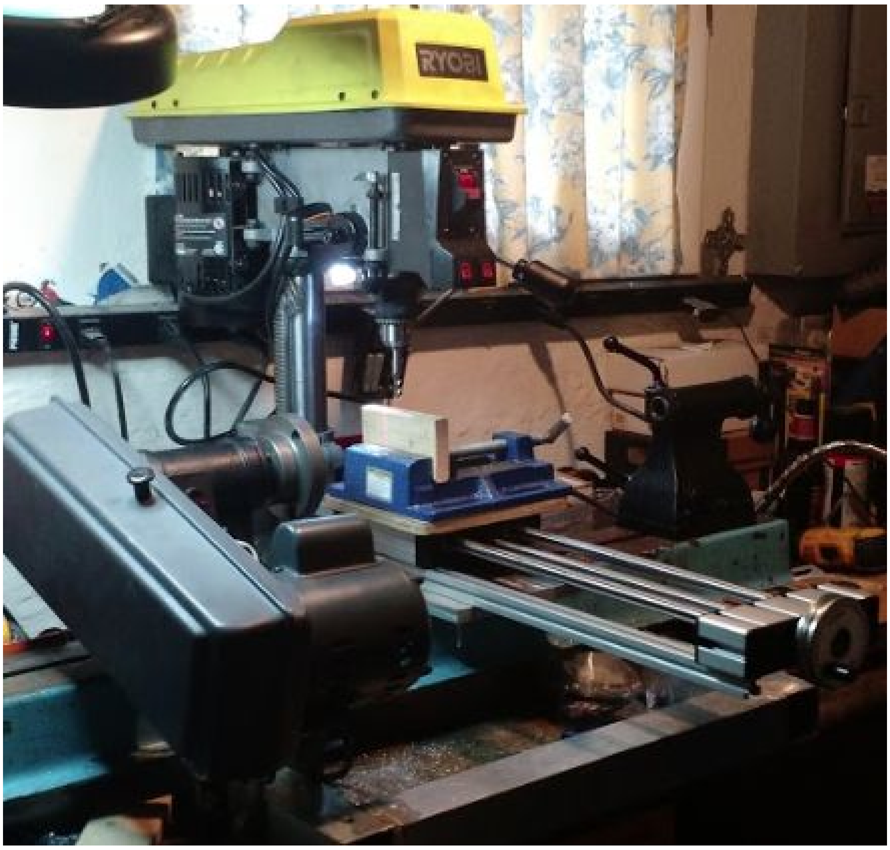


Fig. 34 - Prototype Photo #1

8.2 Working Prototype Video

A longer, well documented video is available at the following link:
https://drive.google.com/file/d/1xKPpBw70Ku8BEtfgGdpXtohiMQiXqY5N/view?usp=sharing

A brief overview and presentation of the project is available at the following link:
https://youtu.be/P0uTjRpynrQ

8.3 Prototype Components

Fig.35 - Drill press

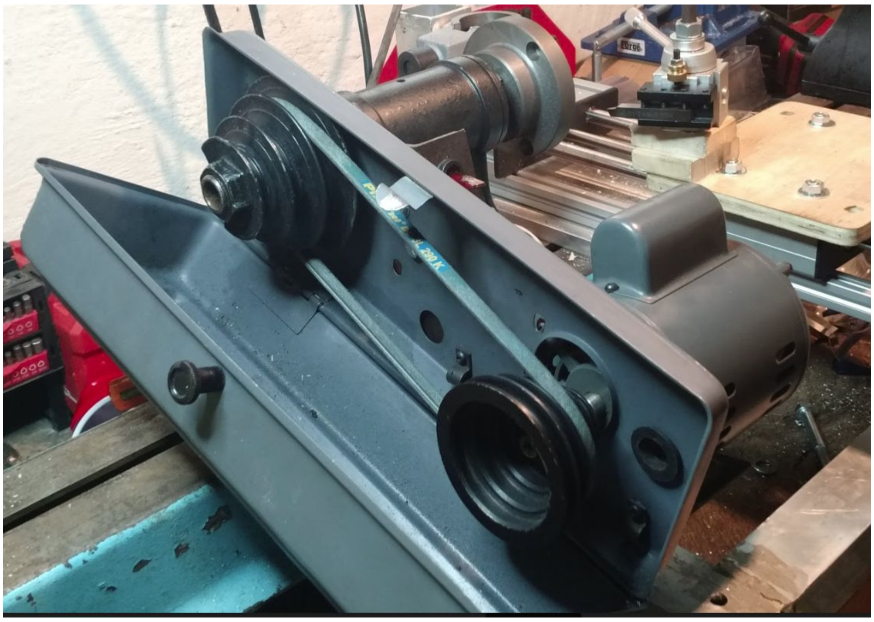


Fig. 36 - Lathe Motor and Headstock

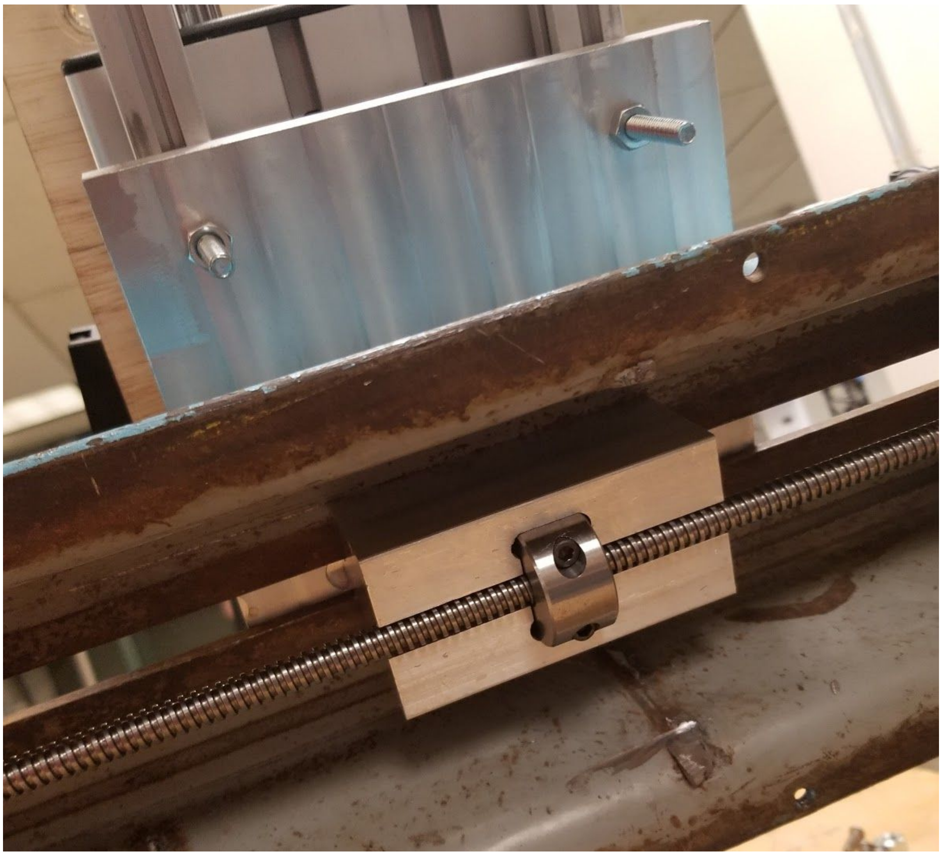


Fig. 37 - Underside of Base

Fig. 38 - Cross-slide

9 Design Documentation

9.1 Final Drawings and Documentation

9.1.1 Engineering Drawings

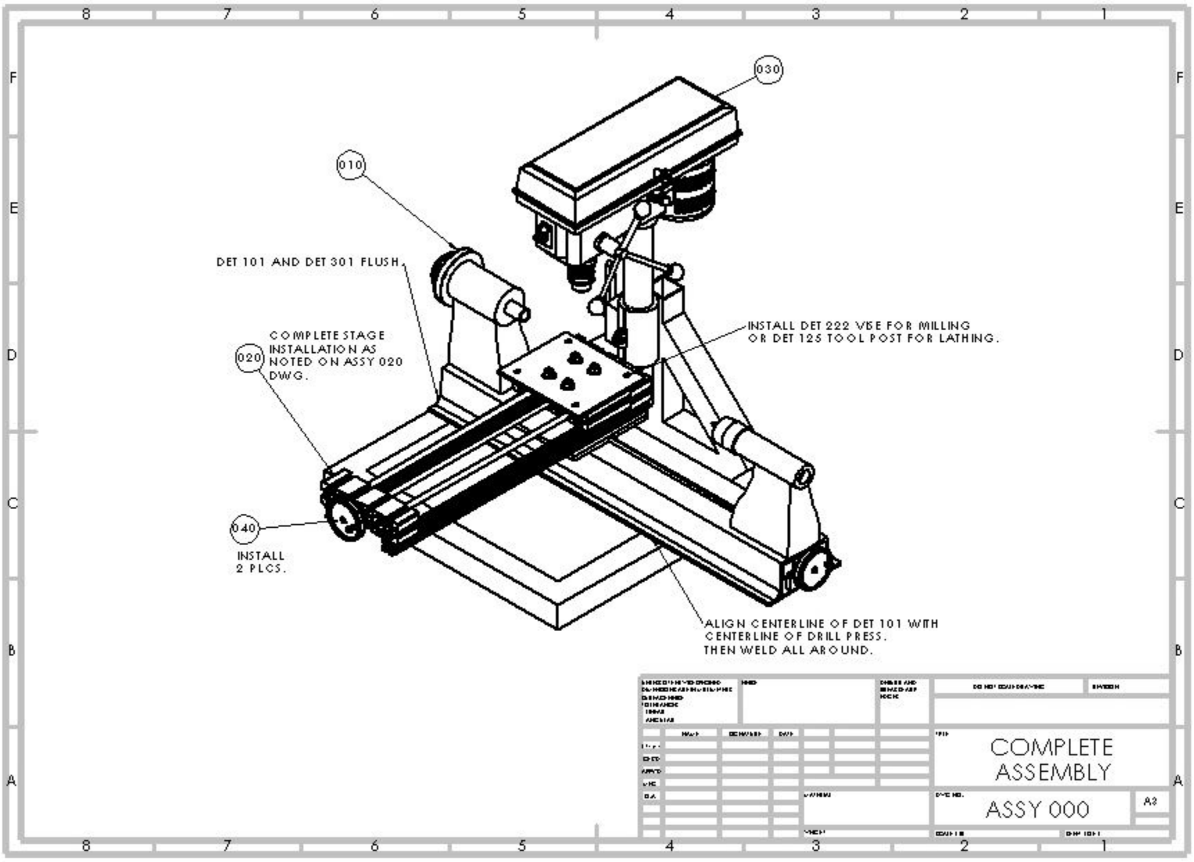
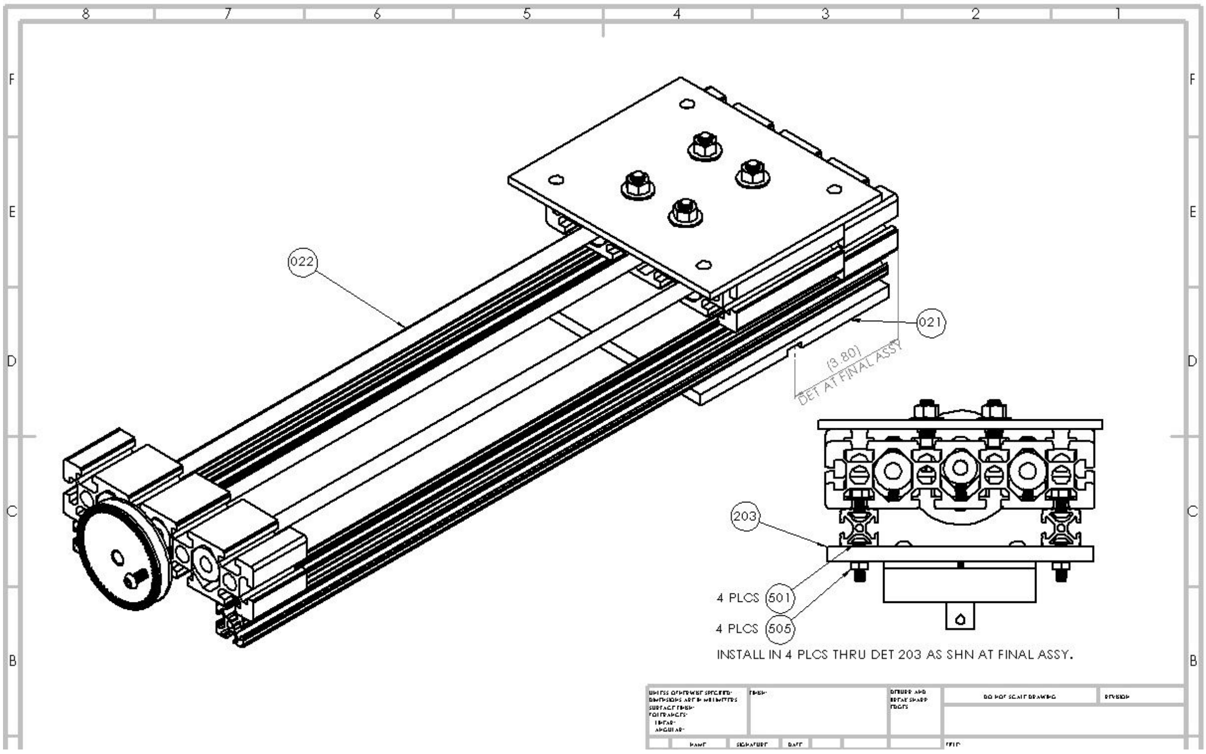
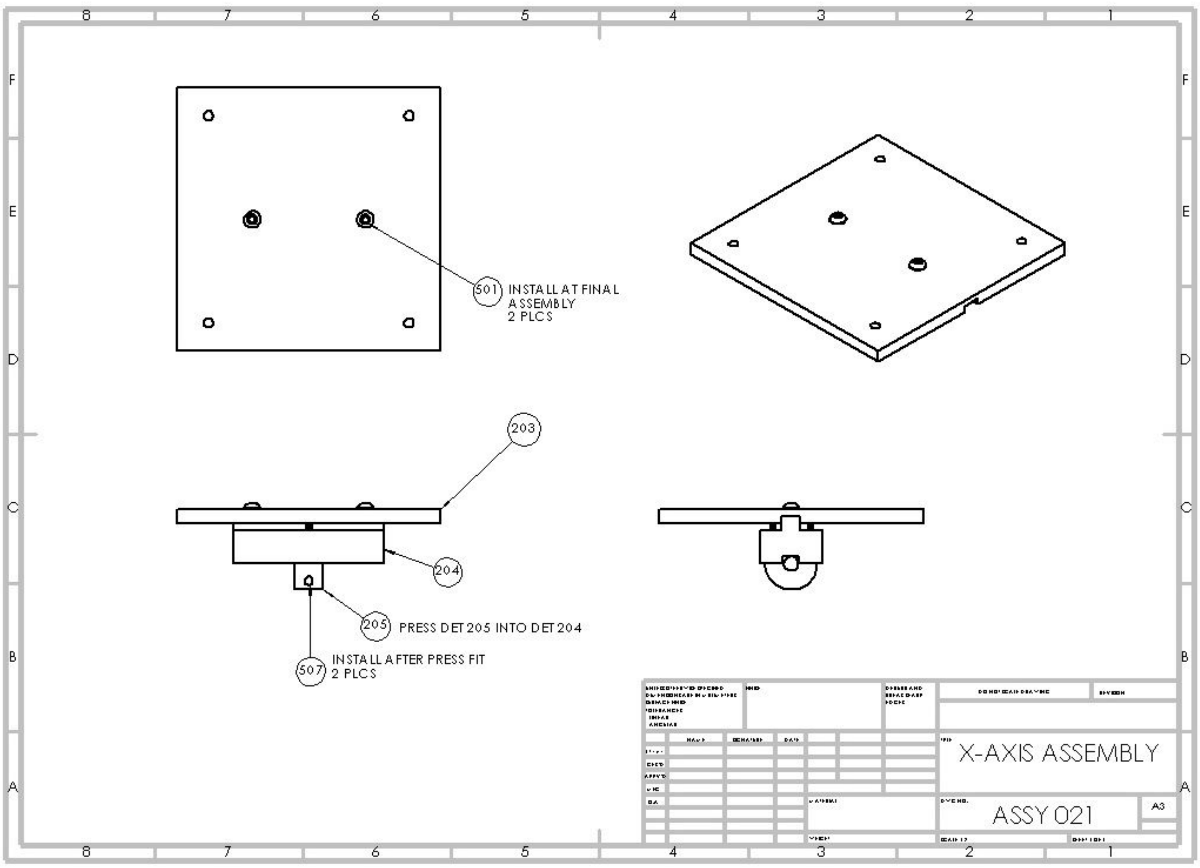
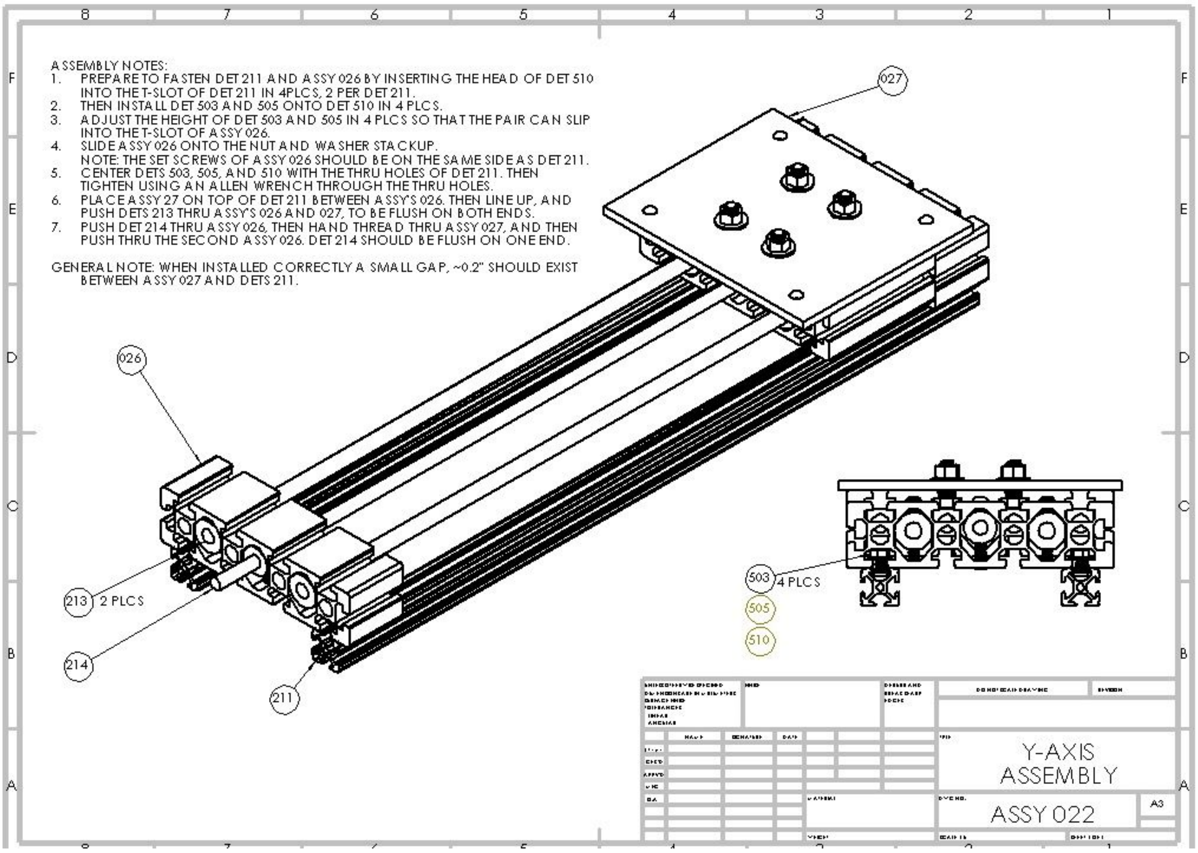
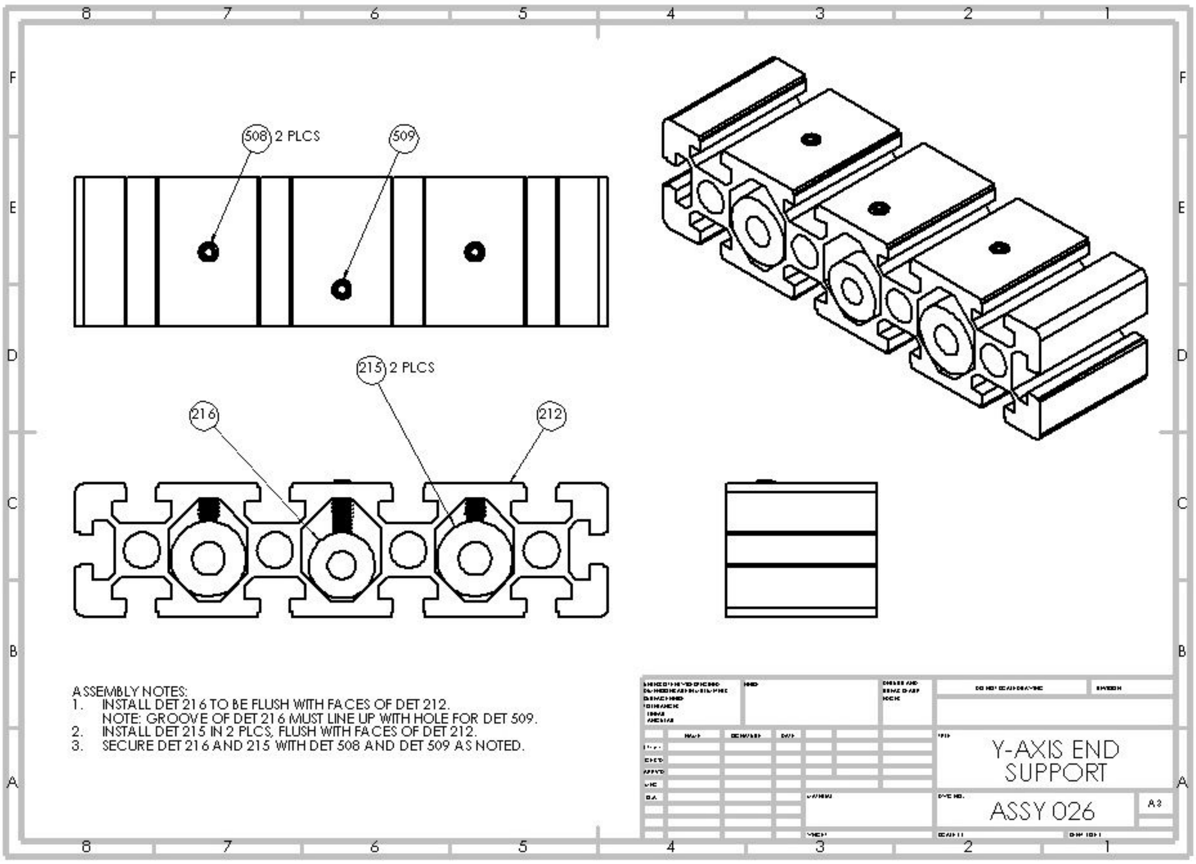


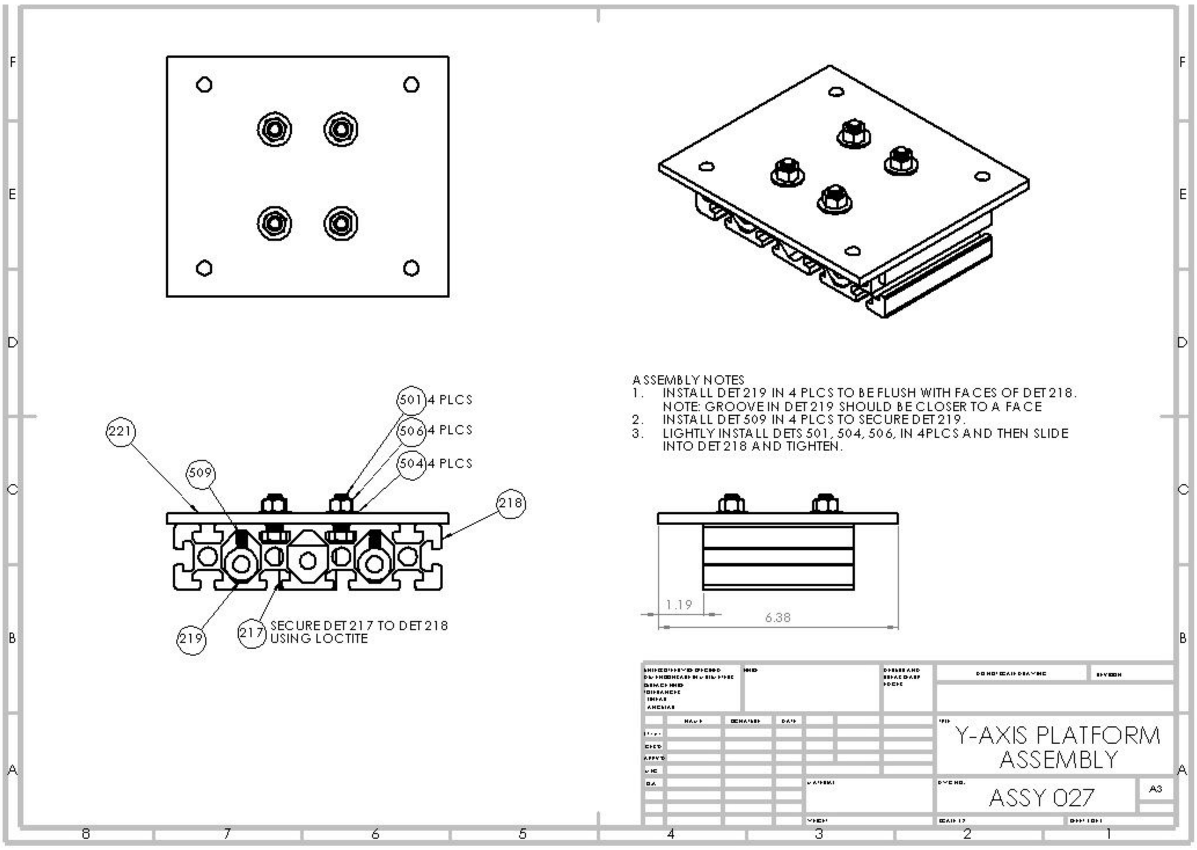
Fig. 39 - Final Assembly Drawing

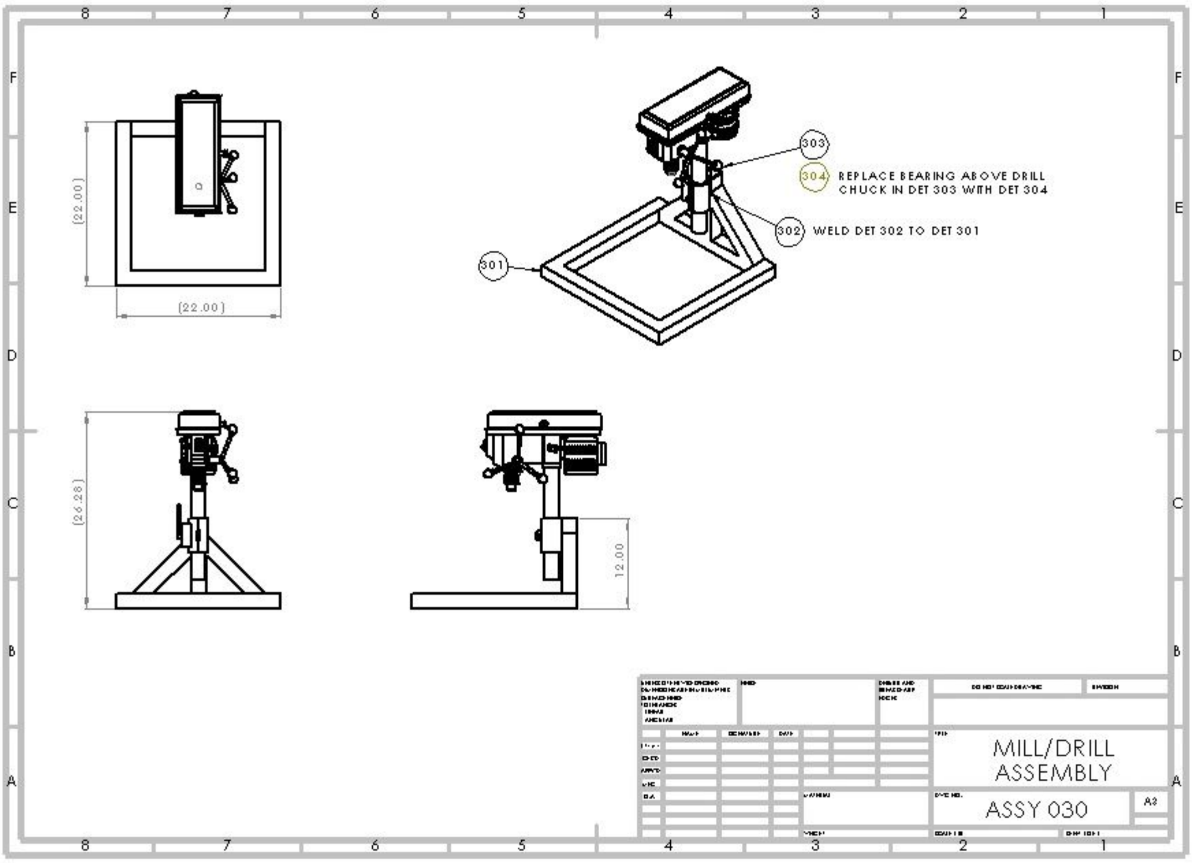

022
021
(3.80)
DET AT FINAL ASSY
203
4 PLCS 501
4 PLCS 505
INSTALL IN 4 PLCS THRU DET 203 AS SHN AT FINAL ASSY.

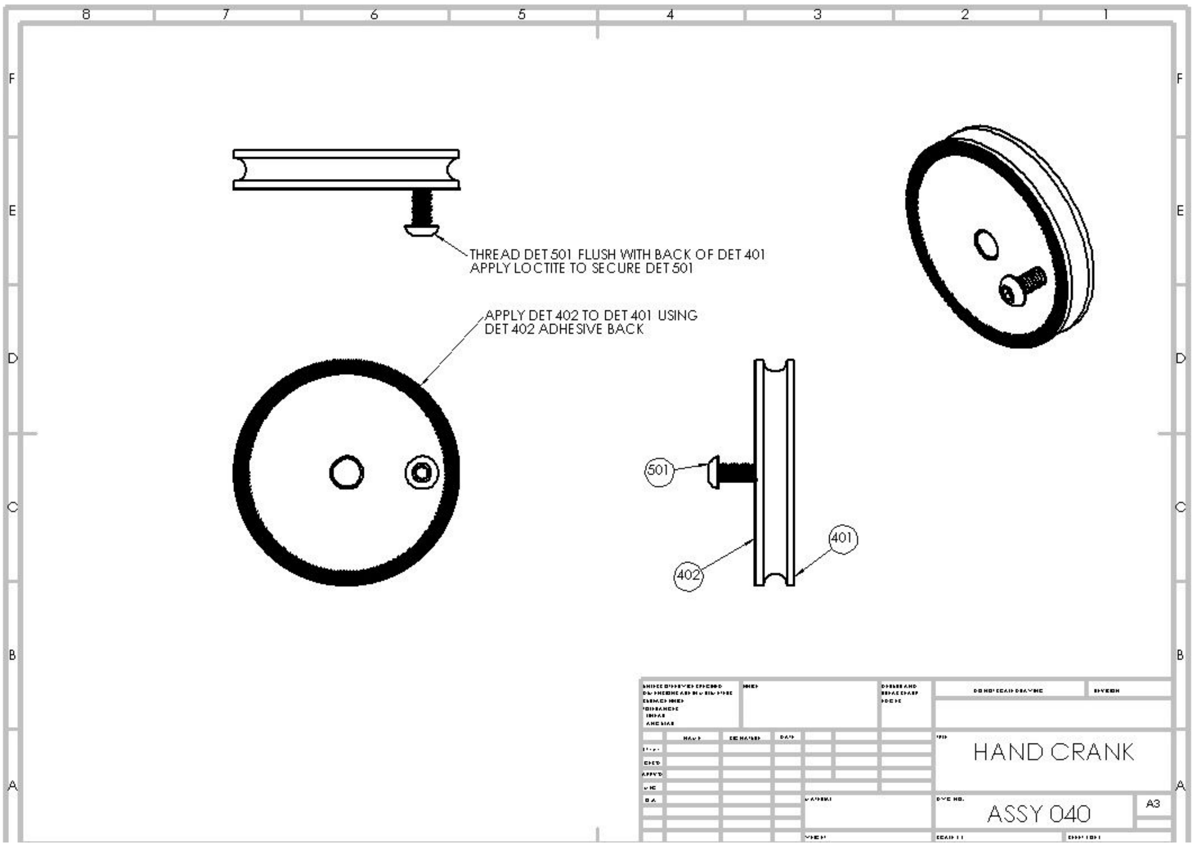

501 INSTALL AT FINAL ASSEMBLY 2 PLCS
203
204
205 PRESS DET 205 INTO DET 204
507 INSTALL AFTER PRESS FIT 2 PLCS
X-AXIS ASSEMBLY
ASSY 021
A3

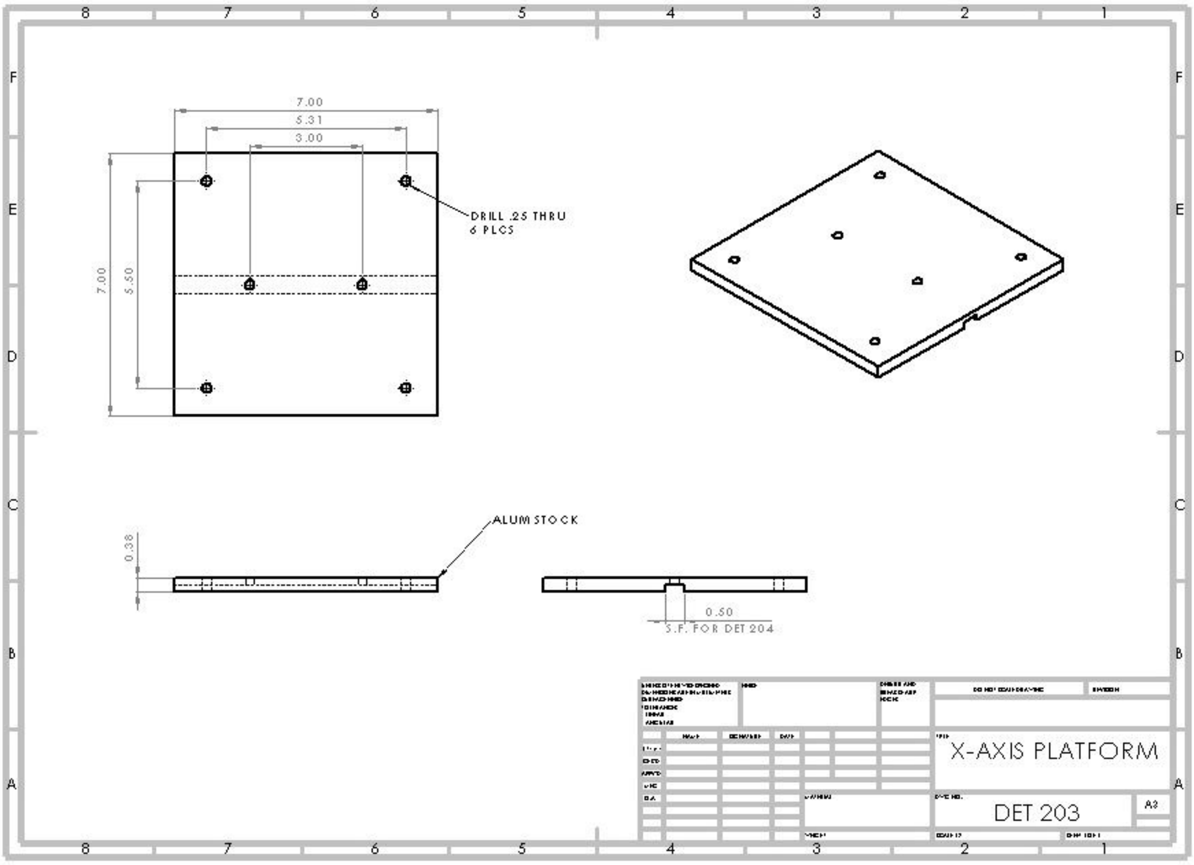

ASSEMBLY NOTES:
1. PREPARE TO FASTEN DET 211 AND ASSY 026 BY INSERTING THE HEAD OF DET 510 INTO THE T-SLOT OF DET 211 IN 4PLCS, 2 PER DET 211.
2. THEN INSTALL DET 503 AND 505 ONTO DET 510 IN 4 PLCS.
3. ADJUST THE HEIGHT OF DET 503 AND 505 IN 4 PLCS SO THAT THE PAIR CAN SLIP INTO THE T-SLOT OF ASSY 026.
4. SLIDE ASSY 026 ONTO THE NUT AND WASHER STACKUP.
NOTE: THE SET SCREWS OF ASSY 026 SHOULD BE ON THE SAME SIDE AS DET 211.
5. CENTER DETS 503, 505, AND 510 WITH THE THRU HOLES OF DET 211. THEN TIGHTEN USING AN ALLEN WRENCH THROUGH THE THRU HOLES.
6. PLACE ASSY 27 ON TOP OF DET 211 BETWEEN ASSY'S 026. THEN LINE UP, AND PUSH DETS 213 THRU ASSY'S 026 AND 027, TO BE FLUSH ON BOTH ENDS.
7. PUSH DET 214 THRU ASSY 026, THEN HAND THREAD THRU ASSY 027, AND THEN PUSH THRU THE SECOND ASSY 026. DET 214 SHOULD BE FLUSH ON ONE END.
GENERAL NOTE: WHEN INSTALLED CORRECTLY A SMALL GAP, ~0.2" SHOULD EXIST BETWEEN ASSY 027 AND DETS 211.
027
026
213 2 PLCS
214
211
503 4 PLCS
505
510
Y-AXIS ASSEMBLY
ASSY 022
A3

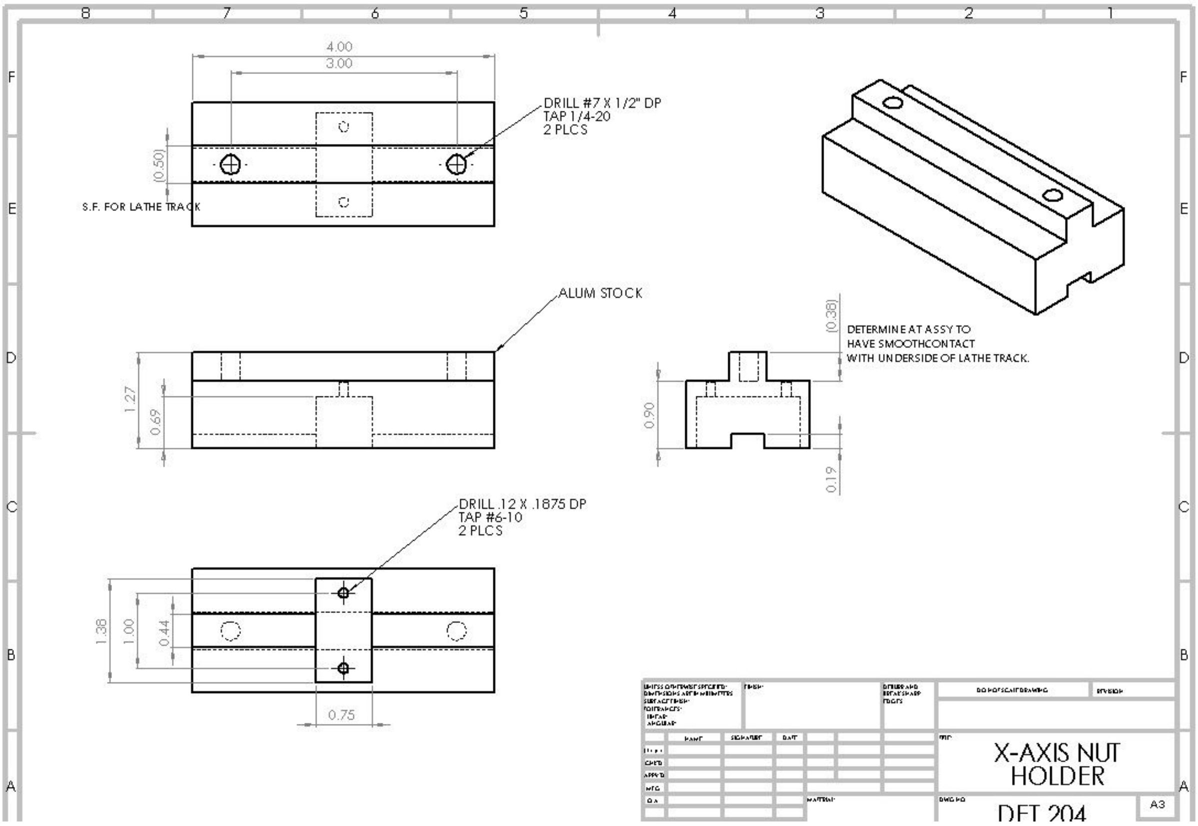

508 2 PLCS
509
215 2 PLCS
216
212
ASSEMBLY NOTES:
1. INSTALL DET 216 TO BE FLUSH WITH FACES OF DET 212.
NOTE: GROOVE OF DET 216 MUST LINE UP WITH HOLE FOR DET 509.
2. INSTALL DET 215 IN 2 PLCS, FLUSH WITH FACES OF DET 212.
3. SECURE DET 216 AND 215 WITH DET 508 AND DET 509 AS NOTED.
Y-AXIS END SUPPORT
ASSY 026
A3

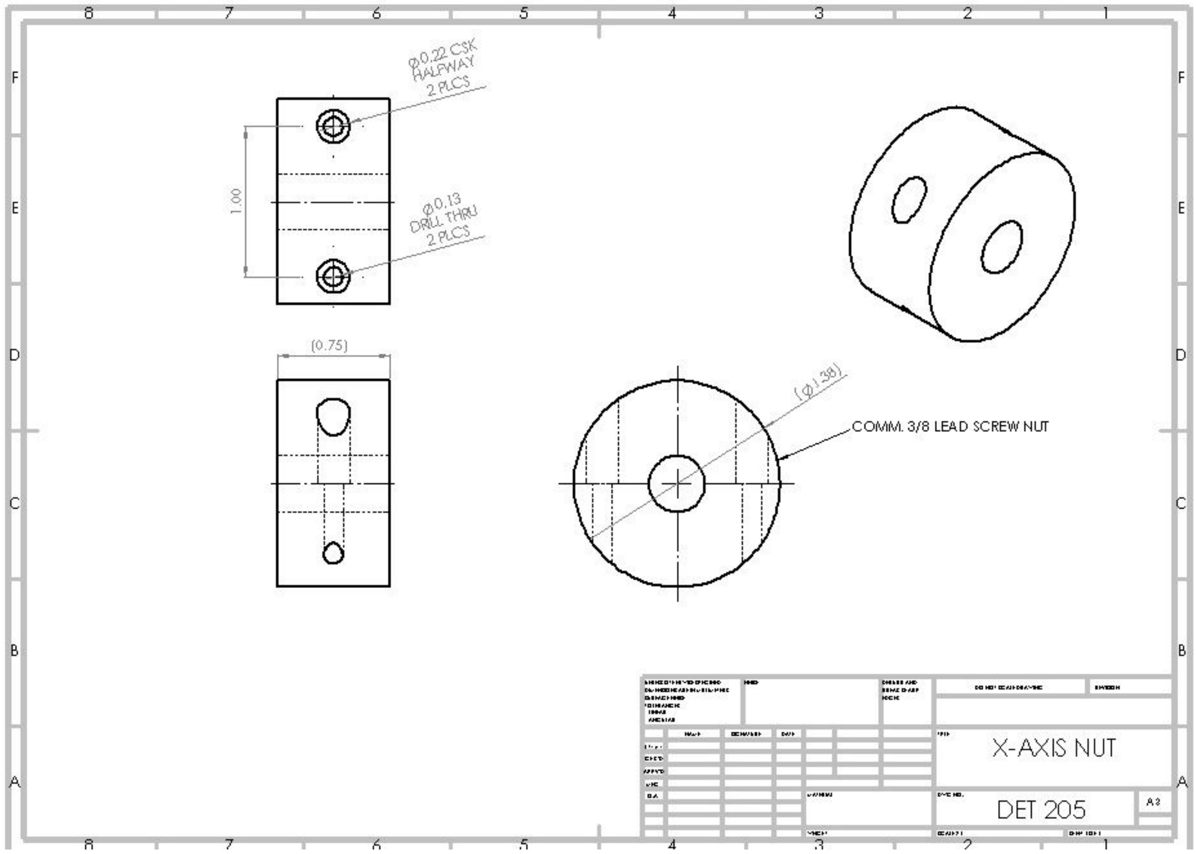

ASSEMBLY NOTES
1. INSTALL DET 219 IN 4 PLCS TO BE FLUSH WITH FACES OF DET 218.
NOTE: GROOVE IN DET 219 SHOULD BE CLOSER TO A FACE
2. INSTALL DET 509 IN 4 PLCS TO SECURE DET 219.
3. LIGHTLY INSTALL DETS 501, 504, 506, IN 4PLCS AND THEN SLIDE INTO DET 218 AND TIGHTEN.
501 4 PLCS
506 4 PLCS
504 4 PLCS
221
509
218
219
217 SECURE DET 217 TO DET 218 USING LOCTITE
1.19
6.38
Y-AXIS PLATFORM ASSEMBLY
ASSY 027
A3

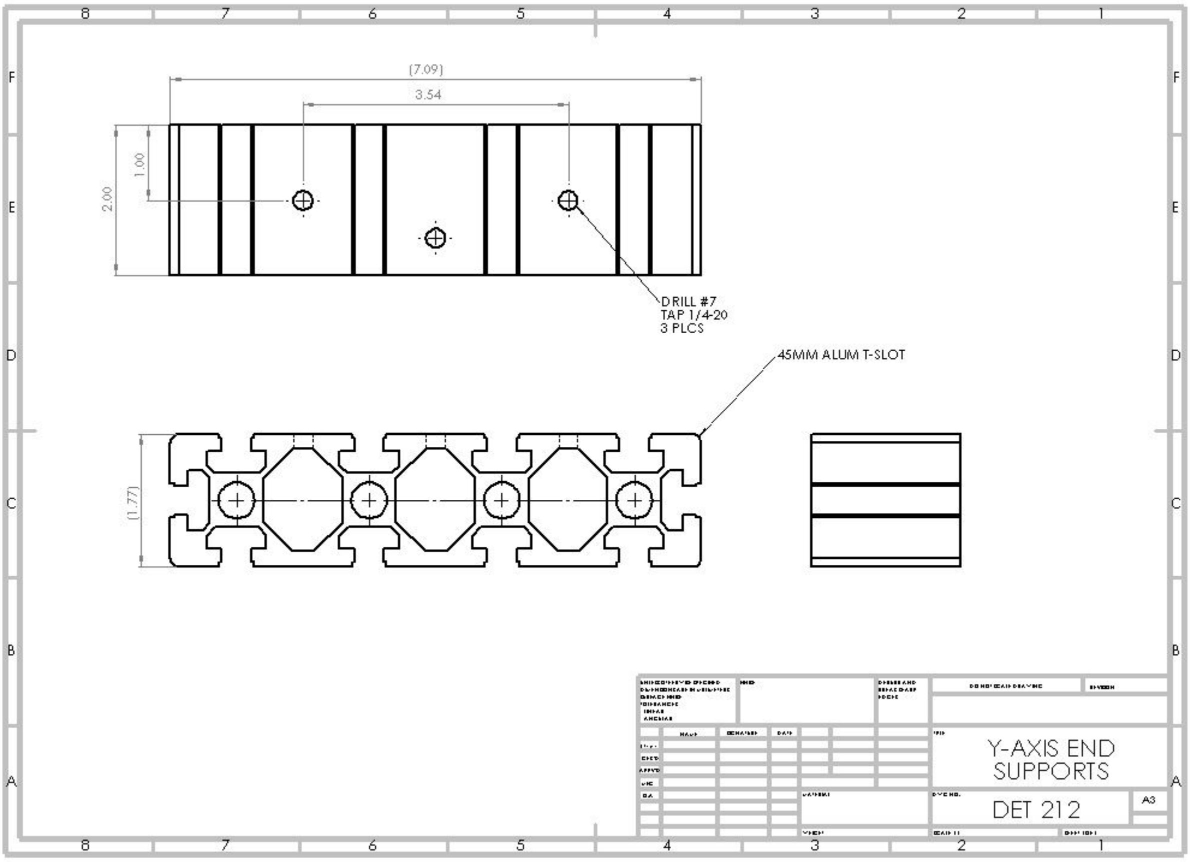

303
304 REPLACE BEARING ABOVE DRILL CHUCK IN DET 303 WITH DET 304
302 WELD DET 302 TO DET 301
301
(22.00)
(22.00)
(26.28)
12.00
MILL/DRILL ASSEMBLY
ASSY 030
A3

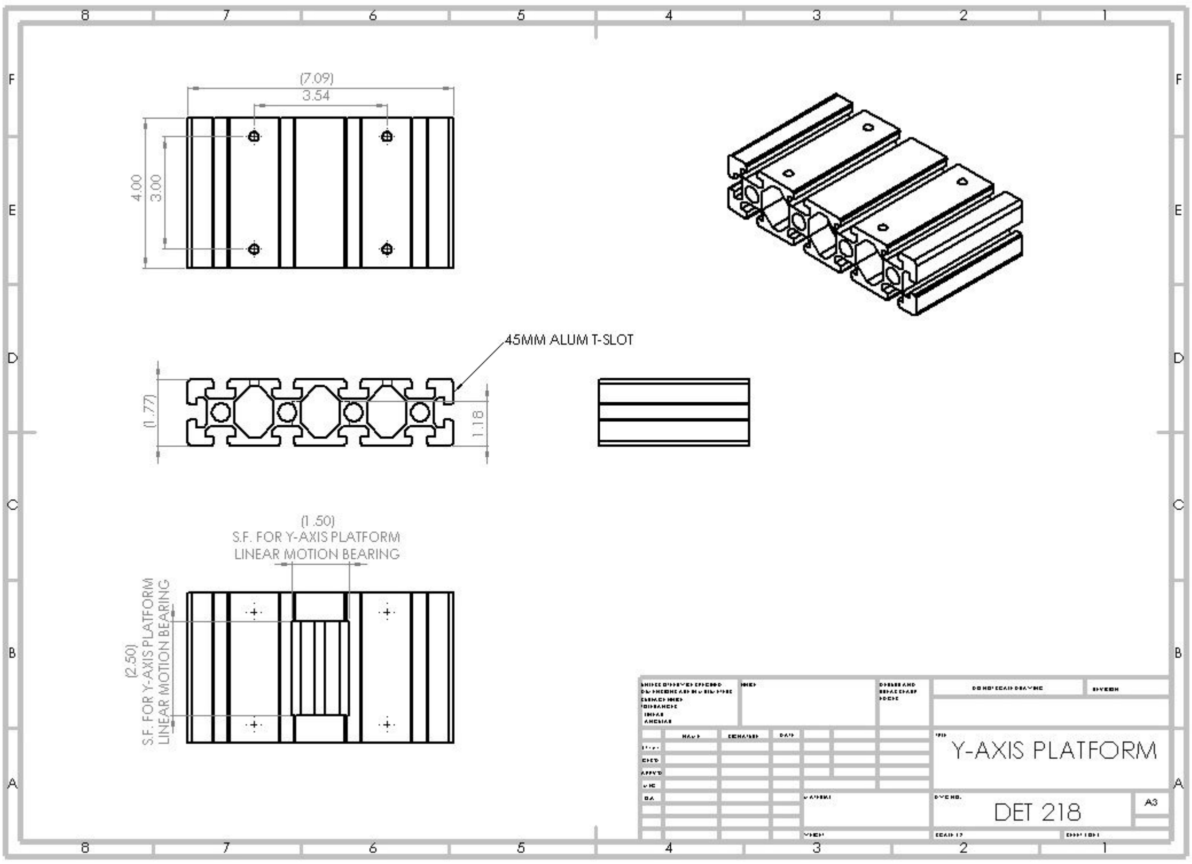

THREAD DET 501 FLUSH WITH BACK OF DET 401
APPLY LOCTITE TO SECURE DET 501
APPLY DET 402 TO DET 401 USING
DET 402 ADHESIVE BACK
501
401
402
HAND CRANK
ASSY 040
A3

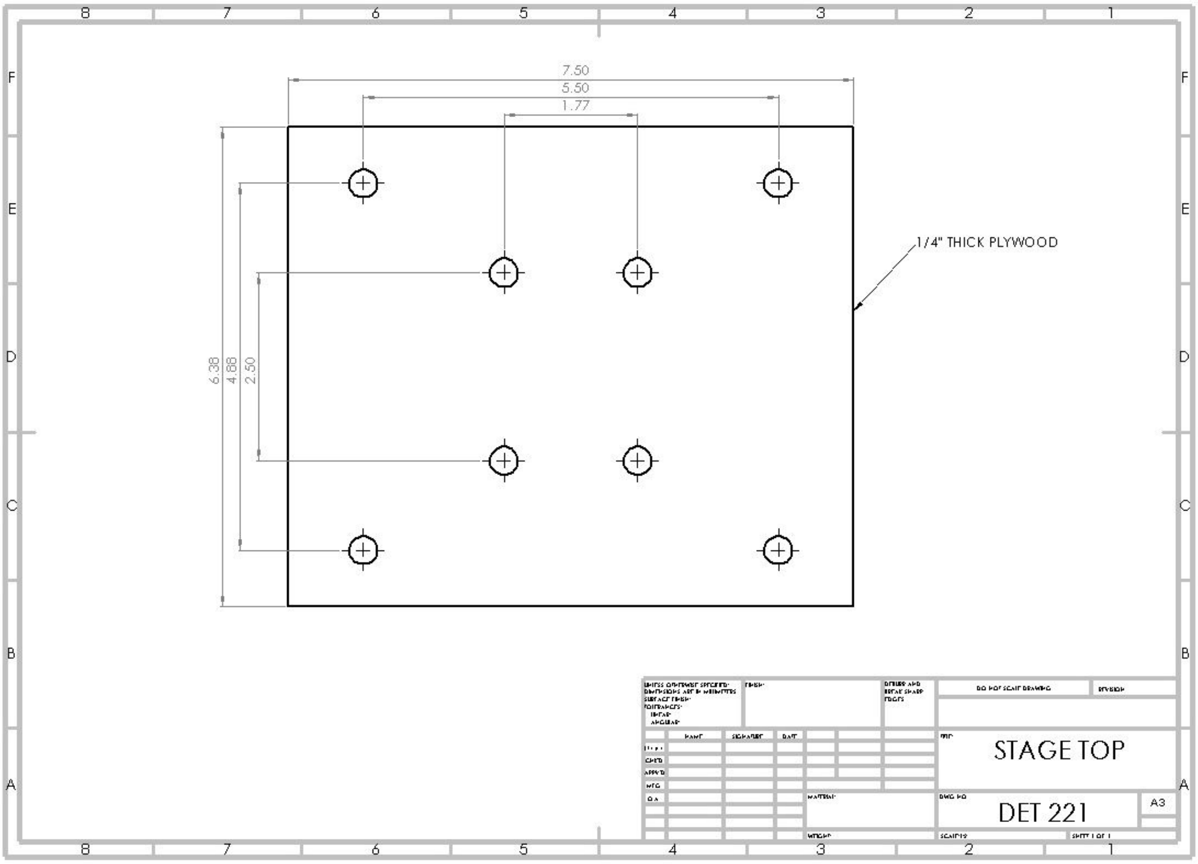

7.00
5.31
3.00
7.00
5.50
DRILL .25 THRU
6 PLCS
ALUM STOCK
0.38
0.50
S.F. FOR DET 204
X-AXIS PLATFORM
DET 203
A3

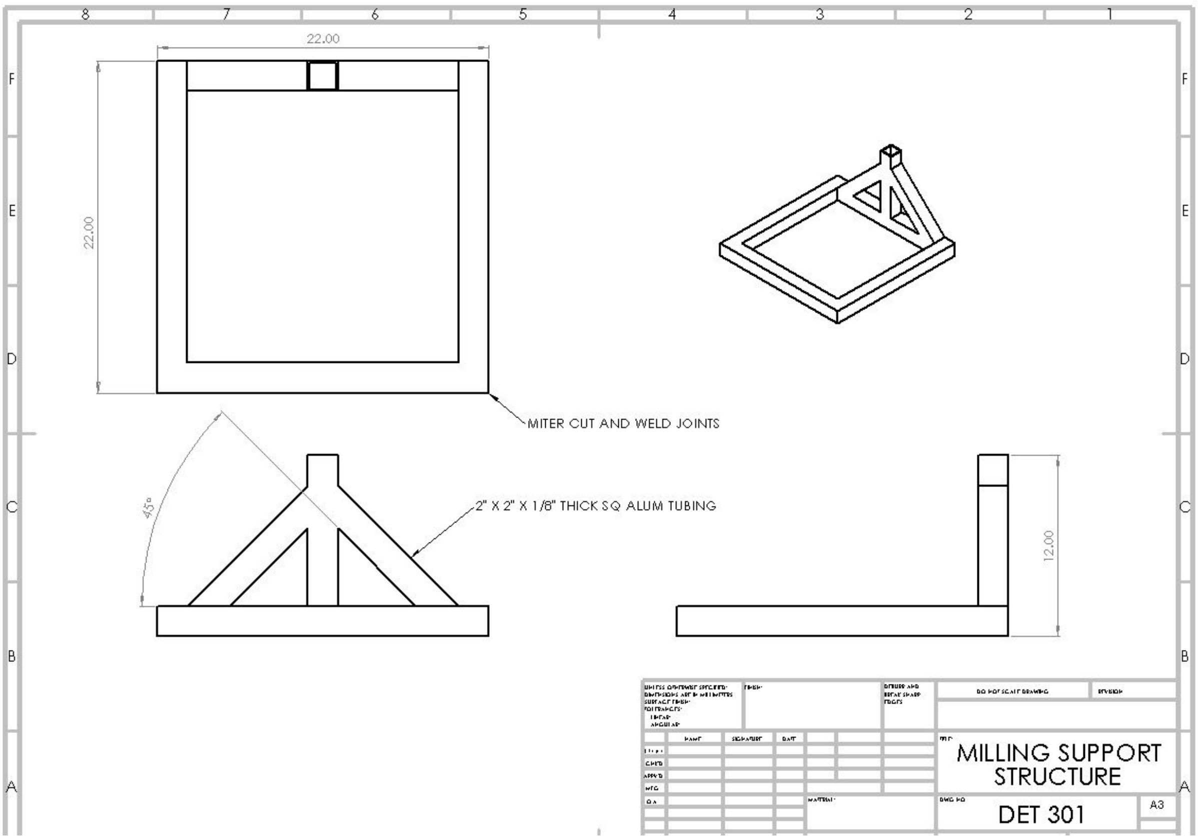

4.00
3.00
DRILL #7 X 1/2" DP
TAP 1/4-20
2 PLCS
(0.50)
S.F. FOR LATHE TRACK
ALUM STOCK
1.27
0.69
(0.38)
DETERMINE AT ASSY TO
HAVE SMOOTHCONTACT
WITH UNDERSIDE OF LATHE TRACK.
0.90
0.19
DRILL .12 X .1875 DP
TAP #6-10
2 PLCS
1.38
1.00
0.44
0.75
X-AXIS NUT
HOLDER
DET 204
A3

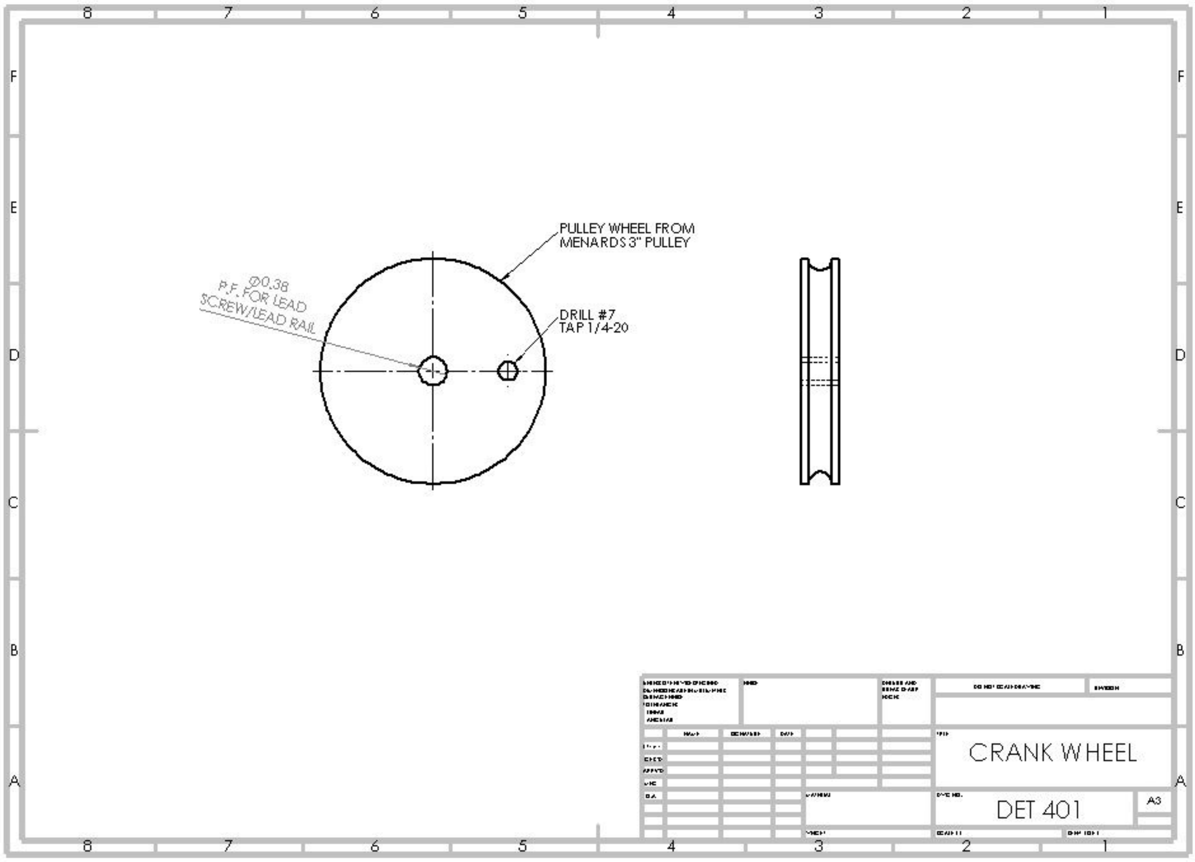

Ø0.22 CSK
HALFWAY
2 PLCS
1.00
Ø0.13
DRILL THRU
2 PLCS
(0.75)
(Ø1.38)
COMM. 3/8 LEAD SCREW NUT
X-AXIS NUT
DET 205
A3


(7.09)
3.54
1.00
2.00
DRILL #7
TAP 1/4-20
3 PLCS
45MM ALUM T-SLOT
(1.77)
Y-AXIS END SUPPORTS
DET 212
A3


(7.09)
3.54
4.00
3.00
45MM ALUM T-SLOT
(1.77)
1.18
(1.50)
S.F. FOR Y-AXIS PLATFORM
LINEAR MOTION BEARING
(2.50)
S.F. FOR Y-AXIS PLATFORM
LINEAR MOTION BEARING
Y-AXIS PLATFORM
DET 218
A3


7.50
5.50
1.77
6.38
4.88
2.50
1/4" THICK PLYWOOD
STAGE TOP
DET 221
A3


22.00
22.00
MITER CUT AND WELD JOINTS
45°
2" X 2" X 1/8" THICK SQ ALUM TUBING
12.00
MILLING SUPPORT STRUCTURE
DET 301
A3



9.1.2 Sourcing Instructions

The Parts List and BOM, Appendices A and B respectively, show the items that the team was able to salvage.The final parts list only shows a total cost of around $300. For many of the items the team salvaged, they were waiting to be trashed, or available for use at Washington University in St. Louis. For most items that were fabricated from metal stock, the metal stock could most likely be obtained from a local junk/scrapyard for very low cost. For the lathe components, the team was very fortunate to find an old woodworking lathe at the University. For other students, or DIY-ers, the team suggests searching local junkyards first, then resorting to online sites such as Facebook Marketplace, Ebay, or Amazon, and lastly, purchasing a similar item as new. For the capacity the team was trying to obtain, a brand new lathe of similar capacity should only be around $250-300. While this seems like a significant purchase, it will provide the builder with much fewer headaches, and sped up fabrication time (versons constructing everything from scratch). The team firmly believes that producing a similar design with less scavenged/repurposed parts would still remain under the $700 mark.

9.2 Final Presentation

9.2.1 Summary of Presentation

For turning, milling, and drilling in wood the tool works great. However, some vibration in the tool makes it difficult to maintain accuracy when metalworking. The team believes that this large amount of vibration is due to the wide tolerances of the tool parts. Closer slip fits and tighter press fits would aid in reducing the vibration. Lastly, the team would like to slim down the linear motion devices to produce a more compact design. Unfortunately time constraints had prevented the team from making these modifications the first time around. Overall success for a prototype build!

9.2.2 Link to YouTube Video

https://youtu.be/P0uTjRpynrQ

10 Teardown

10.1 Disassembly Notes

- The drill press can be removed by cranking the it out all of the way and lifting it out of the holder.
- To take apart the stage, remove the bolts on the vice or toolpost - which ever is currently attached to the stage - and then remove the wooden plate by unbolting it. Next, loosen the nut underneath the metal plate under the cross-slide and slide the cross-slide off. Unscrew the metal plate from the nut. Flip the machine on its side so that the location where the drill press was is now on the bottom and loosen the set screws that hold the lead screw in place. Unscrew the lead screw from the nut and remove the nut and lead screw.
- Next, to disassemble the lathe, with the machine still on its side, unhook the belt on the headstock and tilt the machine onto the side where the drill press goes. Loosen the bolts under the headstock and tailstock so that you can slide them off of the base.

11 Appendix A - Parts List

ASSY/DET No.	Stock Size/Description	QTY	Part No.	Source	EACH	TOTAL
101	BASE	1	---	SALVAGE	FREE	$0.00
102	HEADSTOCK	1	---	SALVAGE	FREE	$0.00
103	TAILSTOCK	1	---	SALVAGE	FREE	$0.00
104	LATHE CHUCK	1	M1057	Optics Planet	$82.79	$82.79
105	LIVE CENTER	1	MT2	Amazon	$17.99	$17.99
106	BEARING OFFSET BLOCK	3	---	SALVAGE	FREE	$0.00
121	AC MOTOR	1	---	SALVAGE	FREE	$0.00
122	ADJUSTABLE SPEED V BELT PULLEY	1	---	SALVAGE	FREE	$0.00
123	V-BELT PULLEY	1	---	SALVAGE	FREE	$0.00
124	BELT	1	---	SALVAGE	FREE	$0.00
125	TOOL POST	1	120034	EBAY	$30.80	$30.80
201	X-AXIS BEARING	3	3813T1	MCMASTER	$6.10	$18.30
202	X-AXIS LEAD SCREW	1	98935A807	MCMASTER	$8.57	$8.57
203	X-AXIS PLATFORM	1	---	SALVAGE	FREE	$0.00
204	X-AXIS NUT HOLDER	1	---	SALVAGE	FREE	$0.00
205	X-AXIS NUT	1	---	SALVAGE	FREE	$0.00
211	Y-AXIS BASE	1	---	SALVAGE	FREE	$0.00
212	Y-AXIS END SUPPORTS	2	---	SALVAGE	FREE	$0.00
213	Y-AXIS LINEAR RAIL	2	---	SALVAGE	FREE	$0.00
214	Y-AXIS LEAD RAIL	1	---	SALVAGE	FREE	$0.00
215	Y-AXIS JOURNAL BEARINGS	4	---	SALVAGE	FREE	$0.00
216	Y-AXIS BALL BEARINGS	2	---	SALVAGE	FREE	$0.00
217	Y-AXIS LINEAR MOTION BEARING	1	---	SALVAGE	FREE	$0.00
218	Y-AXIS PLATFORM	1	---	SALVAGE	FREE	$0.00
219	Y-AXIS PLATFORM LINEAR BEARING	4	---	SALVAGE	FREE	$0.00
221	STAGE TOP	1	---	SALVAGE	FREE	$0.00
222	VISE	1	30999	HARBOR FREIGHT	$17.99	$17.99
301	MILLING SUPPORT STRUCTURE	1	STOCK	LOWES	$15.99	$15.99
302	ADAPTED DRILL PRESS CLAMP	1	---	HARBOR FREIGHT	FREE	$0.00
303	DRILL PRESS	1	---	HARBOR FREIGHT	$64.99	$64.99
304	BEARING	2	30202	NEWEGG	$7.97	$15.94
401	CRANK WHEEL	2	---	MENARDS	$7.49	$14.98
402	DIAL	2	20045A52	MCMASTER		$0.00
501	1/4-20 X 1.00 BUTTON HEAD HEX DRIVE SCREW	4	---	SALVAGE	FREE	$0.00
502	3/8-16 X 1.75 HEX HEAD SCREW	4	PANSTOCK	HOME DEPOT	$0.20	$0.80
503	1/4 WASHER	8	---	SALVAGE	FREE	$0.00
504	3/8 WASHER	4	PANSTOCK	HOME DEPOT	$0.12	$0.48
505	1/4-20 NUT	14	---	SALVAGE	FREE	$0.00
506	3/8-16 NUT	8	PANSTOCK	HOME DEPOT	$0.16	$1.28
507	5-40 X 1.13 SOCKET HEAD CAP SCREW	2	---	SALVAGE	FREE	$0.00
508	1/4-20 X .50 SET SCREW	4	---	SALVAGE	FREE	$0.00
509	1/4-20 X .75 SET SCREW	6	---	SALVAGE	FREE	$0.00
510	1/4-20 X .50 BUTTON HEAD HEX DRIVE SCREW	4	---	SALVAGE	FREE	$0.00
511	3/8-15 X 1.00 HEX HEAD SCREW	4	PANSTOCK	HOME DEPOT	$0.20	$0.80
512	3/8 SHAFT COLLAR	2	6432K14	MCMASTER	$1.13	$2.26
					TOTAL:	$293.96

12 Appendix B - Bill of Materials

ASSY/DET No.	QTY	Stock Size/Description	Material	Availability	Source	Remarks
000	---	Complete Assembly	Noted	Noted	Noted	None
010	---	Lathe Assembly	Noted	Noted	Noted	None
020	---	Stage Assembly	Noted	Noted	Noted	None
021	---	Stage - X-Axis Assembly	Noted	Noted	Noted	None
022	---	Stage - Y-Axis Assembly	Noted	Noted	Noted	None
026	---	Stage - Y-Axis End Support Assembly	Noted	Noted	Noted	None
027	---	Stage - Y-Axis Platform Assembly	Noted	Noted	Noted	None
030	---	Mill and Drill Assembly	Noted	Noted	Noted	None
040	---	Hand Crank Assembly	Noted	Noted	Noted	None
101	1	BASE	STL	COMM	---	SALVAGE
102	1	HEADSTOCK	STL	COMM	---	SALVAGE
103	1	TAILSTOCK	STL	COMM	---	SALVAGE
104	1	LATHE CHUCK	STL	COMM	VARIOUS	PURCHASE
105	1	LIVE CENTER	STL	COMM	VARIOUS	PURCHASE
106	3	BEARING OFFSET BLOCK	STL	STOCK	VARIOUS	FABRICATE
121	1	AC MOTOR	---	COMM	---	SALVAGE
122	1	ADJUSTABLE SPEED V BELT PULLEY	ZINC	COMM	---	SALVAGE
123	1	V-BELT PULLEY	ZINC	COMM	---	SALVAGE
124	1	BELT	RUBBER	COMM	---	SALVAGE
125	1	TOOL POST	STL	COMM	VARIOUS	PURCHASE
201	3	X-AXIS BEARING	STL	COMM	MCMASTER	PURCHASE
202	1	X-AXIS LEAD SCREW	STL	COMM	MCMASTER	PURCHASE
203	1	X-AXIS PLATFORM	ALUM	STOCK	VARIOUS	SALVAGE
204	1	X-AXIS NUT HOLDER	ALUM	STOCK	VARIOUS	FABRICATE
205	1	X-AXIS NUT	STL	COMM	VARIOUS	MODIFY
211	1	Y-AXIS BASE	ALUM	COMM	VARIOUS	SALVAGE
212	2	Y-AXIS END SUPPORTS	ALUM	COMM	VARIOUS	MODIFY
213	2	Y-AXIS LINEAR RAIL	STL	COMM	MCMASTER	SALVAGE
214	1	Y-AXIS LEAD RAIL	STL	COMM	MCMASTER	SALVAGE
215	4	Y-AXIS JOURNAL BEARINGS	STL	COMM	VARIOUS	SALVAGE
216	2	Y-AXIS BALL BEARINGS	STL	COMM	VARIOUS	SALVAGE
217	1	Y-AXIS LINEAR MOTION BEARING	STL	COMM	VARIOUS	SALVAGE
218	1	Y-AXIS PLATFORM	ALUM	STOCK	VARIOUS	MODIFY
219	4	Y-AXIS PLATFORM LINEAR BEARING	STL	COMM	VARIOUS	SALVAGE
221	1	STAGE TOP	WOOD	STOCK	VARIOUS	FABRICATE
222	1	VISE	STL	COMM	HARBOR FREIGHT	PURCHASE
301	1	MILLING SUPPORT STRUCTURE	ALUM	STOCK	VARIOUS	FABRICATE
302	1	ADAPTED DRILL PRESS CLAMP	STL	COMM	HARBOR FREIGHT	MODIFY
303	1	DRILL PRESS	---	COMM	HARBOR FREIGHT	MODIFY
304	1	BEARING	STL	COMM	MCMASTER	PURCHASE
401	2	CRANK WHEEL	STL	COMM	MENARDS	MODIFY
402	2	DIAL	PLASTIC	COMM	MCMASTER	PURCHASE
501	4	1/4-20 X 1.00 BUTTON HEAD HEX DRIVE SCREW	STL	COMM	VARIOUS	PURCHASE
502	4	3/8-16 X 1.75 HEX HEAD SCREW	STL	COMM	VARIOUS	PURCHASE
503	8	1/4 WASHER	STL	COMM	VARIOUS	PURCHASE
504	4	3/8 WASHER	STL	COMM	VARIOUS	PURCHASE
505	14	1/4-20 NUT	STL	COMM	VARIOUS	PURCHASE
506	8	3/8-16 NUT	STL	COMM	VARIOUS	PURCHASE
507	2	5-40 X 1.13 SOCKET HEAD CAP SCREW	STL	COMM	VARIOUS	PURCHASE
508	4	1/4-20 X .50 SET SCREW	STL	COMM	VARIOUS	PURCHASE
509	6	1/4-20 X .75 SET SCREW	STL	COMM	VARIOUS	PURCHASE
510	4	1/4-20 X .50 BUTTON HEAD HEX DRIVE SCREW	STL	COMM	VARIOUS	PURCHASE
511	4	3/8-15 X 1.00 HEX HEAD SCREW	STL	COMM	VARIOUS	PURCHASE
512	2	3/8 SHAFT COLLAR	STL	COMM	VARIOUS	PURCHASE

13 Appendix C - Complete List of Engineering Drawings

A complete copy of all of the details of the final design my be found at the following link. This includes fabricated parts, purchased parts, drawings, assemblies, and more:

https://drive.google.com/file/d/19N5D3HGbS_Y2Itfg7sgv30nd3WLTF80z/view?usp=sharing

14 Appendix D - Project Management and Collaboration

14.1 PRELIMINARY: Team organization

1. How did you decide to subdivide the project into subsystems?

We divided the group into subsystems by deciding what would be the most proficient. We wanted to give each group enough of the project that they could work on their own part without depending on another group to much to move on. We decided on creating three subsystems, the first was the Mill/Drill group that was incharge of the frame and mounting the mill/drill. The second was the lathe group, which was tasked with construction the lathe and mounting on the frame. Lastly, we had the XYZ/Portability team. They were tasked with designing the base for the frame that gave us our XYZ movement. They were also tasked with finding a way to make this object portable.

2. How did you allocate people into groups for each subsystems?

We allocated people into groups mostly randomly.

3. Each group should write a design brief for their subsystem.

Done.

4. Before doing the Background and literature search, did the team discuss and agree on interfaces between subsystems?

We did briefly discuss how the individual groups would deal with interfaces between subsystems, but without really getting into the research it was hard to know how much we would have to work with the other groups.

14.2 ASSIGNMENT 2: Background information study (10%)

1. Produce a subsystem project description for each group.
2. List and explain any preliminary design decisions made even before doing the background information study.
3. Do you feel that there are any implied constraints limiting the scope of subsystem designs? Describe them.

14.3 ASSIGNMENT 3: Specification and conceptual design study (15%)

1. Comment on the “design integration step” of this assignment:

This part had its setbacks, but was not as difficult as it could have been. In the initial design phase subsystems talked with each other on how they would be building their parts of the project so we were able to be aware of other teams designs and take them into consideration while doing our own design.

   1. Technically, was integration easy or difficult?

      Overall it was pretty easy, as I stated above we had done a fair amount of talking beforehand so we all had a brief idea of what was going on in each subsystem during the design phase.

   2. How much did the overall list of user needs change?

      Our user needs list did not change.

   3. Was there conflict between groups?

The only conflict between groups was deciding how the Z movement would be achieved, whether it was to be a rack and pinion set up in the frame or if the base would have this movement.

14.4 ASSIGNMENT 4: EMBODIMENT AND FABRICATION PLAN (15%)

1. Explain clearly how the work was subdivided

This was mostly a team assignment, Each group was incharge of producing their own part of the overall team document. Within the groups each person was tasked with finding a part or parts so that in the end all necessary pieces were accounted for. This part of the project was less about telling people what to do and more about who stepped up to the plate and got the work done. This is not the best method as some people do no work while others sholder the majority of it

1. How will everyone still "do" each homework?
   Each homework from here on out will be done almost on a volunteer basis. Each group is still responsible for producing their subsystems part of the homework but at this point the people who had time got the work done.
2. How will design integration be done?
   Design integration was handled by one (or a few) people getting all the designs and creating one final integrated drawing. This works best as there's not "too many cooks in the kitchen" and all the initial designs were pretty clear as to what needed to be in the final design for this project to work.

14.5 ASSIGNMENT 5: ENGINEERING ANALYSIS (10%)

1. Now that you can identify every part in the design, list the parts each group is responsible for. Provide justification if needed.

1. Drill press (purchased)
2. Aluminum structure (fabricated)
3. Chuck (purchased)
4. Base (scavenged)
5. Headstock (scavenged)
6. Tailstock (scavenged
7. Toolstock (purchased)
8. Live center (purchased)
9. Lead screw (purchased)
10. Nut (fabricated)
11. Metal plate (Fabricated)
12. Cross-slide (Scavenged)
13. Wooden plate (fabricated)
14. Vice (purchased)
15. Motors (purchased)
16. 4" chuck/backing plate (purchased)
17. cranks/dials (fabricated)

2. Clearly explain any analysis that requires the attention of more than one group.

The analysis that all the groups really need to pay attention to was the strength of the frame and the base. This helped us to understand how much power we could look for in a motor and how much of a cut/hole we would be able to make with our tools.

14.6 ASSIGNMENT 6: CODES AND STANDARDS (5%) THIS ASSIGNMENT CAN BE DONE AT THE "TEAM LEVEL" (I.E. SAME ASSIGNMENT FOR ALL MEMBERS OF THE TEAM).

Done

14.7 ASSIGNMENT 7: WORKING PROTOTYPE (20%)

1. Advise the instructor if you want another week to work on the prototype
2. For deliverable 2, a, b, c, each group should take responsibility for one photograph and its caption. List the group members in the caption.

Done. See in section 8.3

14.8 ASSIGNMENT 8: DOCUMENTATION (10%)

1. Remember that this is the main documentation that would allow someone else to build a version of your design.

Done.

14.9 ASSIGNMENT 9: PUBLICATION (5%)

1. Try to get your report done as soon as possible to allow Lauren Todd time to review it.
2. Remember, your report will get downloaded around the world.

Done.

14.10 ASSIGNMENT 10: TEAR DOWN (0%)

1. You must contact the instructor if you want to keep the prototype.
2. If you don't keep your design, it will be absorbed back into the "morgue."

Done.

14.11 ASSIGNMENT 11: TEAM PERFORMANCE (1% EXTRA CREDIT)

1. Although this is extra credit, it is very important!
2. Also, please do not forget course evaluations.

Done.