CNC Machine

Volume II

<u>Team:</u>

XX Student names have
XX been removed to
XX protect them from
XX abuse and harassment
XX ------------------------

Advisor: **Anthony Quick**

Client: **A. Quick CNC**

Date: **December 9, 2010**

Table of Contents

1.0 Problem Definition Supporting Documents

1.1 Annotated Bibliography

1.1.1 Competitor Machines

Box-style Machines: Blueprints for the MomusDesign benchtop CNC machine are sold by an inventor; the machine is intended for hobbyist use.

Gantry-style Machines: K2CNC provides several US-made aluminum CNC machines, including moving- and fixed-table machines from small to medium sizes. Probotix sells the FireBall V90 machine for a base price of $599. Next Wave Automation provides the CNC Shark and CNC Shark Pro machines in the $2,000 to $4,000 range.

http://www.ajquick.com/cncdesign.pdf
http://www.k2cnc.com/2009/09_CNC_Router_All.asp
http://www.probotix.com/FireBall_v90_cnc_router_kit/
http://www.nextwaveautomation.com/CNCShark_Pro.aspx
http://www.nextwaveautomation.com/CNCShark.aspx

Homemade CNC Machines: Cerebral Meltdown has extensive references to all kinds of homemade CNC machines – over 80 builds – from all over the world. The site also has the author's machine, tutorials on how to make gears and parabolas, a homemade leadscrew nut, and extensive information on drawing-to-code conversions and CNC software use. There is a post on the Polish forum, cnc.info, with images of a fly sculpture assembled from pieces cut on a CNC machine. The CNC 4 Free site has solutions for cheap or free alternatives related to CNC machines for hobbyists and small businessmen. Build Your CNC has a free, well-documented build plan, accessories for sale, articles on CNC-related topics, and more. CNC Guitar shows one individual's project of building guitars with his CNC machine. Solsyva has plans for several do-it-yourself machines for sale.

http://www.cerebralmeltdown.com
http://www.cnc.info.pl/topics68/mucha-vt14889.htm
http://www.cnc4free.org/
http://buildyourcnc.com/default.aspx
http://www.cncguitar.org:7171/router.htm
http://www.solsylva.com/

1.1.2 Lead Screws

The two Amazon links show prices, sizes, and other information on lead screws for sale. Wikipedia's page on lead screws talks about types, characteristics, pros and cons, alternatives, and mechanics.

http://www.amazon.com/THK-Screw-Shaft-Diameter-Length/dp/B00137GIV4
http://www.amazon.com/THK-Diameter-Length-Flange-Capacity/dp/B0015HOHTC
http://en.wikipedia.org/wiki/Leadscrew

1.1.3 Linear Motion

Linear Motion's site has products and information on linear motion components.

http://www.linearmotion.skf.com/en/0/fam-cat950fid189-Rotating_nut_systems.html

1.1.4 Table Surfaces

MDF: Lowe's provides shelving sizes and prices on their website. Sheet sizes and prices from Westwind Hardwood supplier are provided on their website. The next link is for a forum discussing how much MDF tends to cost. Several websites contain contact information for lumberyards, including Scherer Brothers, Siweck Lumber, Grove Wholesale Lumber, Hiawatha Lumber, and Spring Lake Lumber. Flakeboard and Georgia-Pacific each provide a MSDS.

http://www.lowes.com/pl__4294815774+4294862675_4294937087_

http://www.westwindhardwood.com/price_sheet_goods.php

http://www.sawmillcreek.org/showthread.php?t=122228

http://www.schererbros.com/products/building_materials/index.php

http://www.siweklumber.com/contact_us.php

http://www.grovewholesale.com/

http://www.hiawathalumber.com

http://www.springlakeparklumber.com

http://www.flakeboard.com/msds/Flakeboard_MDF_MSDS.pdf

http://www.gp.com/build/DocumentViewer.aspx?repository=BP&elementid=4503

MDO/HDO: This page gives information on medium-density overlay (MDO) and high-density overlay (HDO) plywoods.

http://www.canply.org/english/products/overlaidplywood.htm

Slatwall: Price by quantity for paint grade slatwall and detailed features and shipping information are given from Atlanta Slatwall. JC Whitney lists general information for heavy duty slatwall. Global Industrial has dimensions, specs, shipping info, etc. for slatwall sold in quantities of four. Midwest Slatwall provides dimensions and price per quantity. Display Warehouse has basic dimension and price information. Garment Racks & Store Fixtures has dimensions, features, and price per quantity. In order to create slatwall from a solid sheet of material, Porter Cable provides a T-slot wall groover.

http://www.spacewall.com/atlanta_slatwall.htm

http://www.jcwhitney.com/heavy-duty-wall-storage-systems/p2019430.jcwx?TID=8014524FT2&zmam=15972153&zmas=21&zmac=129&zmap=28697G#prodDetailTabPanel

http://www.globalindustrial.com/p/storage/bulk-rack/display-wall/48x96-slatwall-panel-without-inserts?utm_source=google_pr&utm_medium=cpc&utm_campaign=Display-Wall-Storage-google_pr&infoParam.campaignId=T9F

http://www.storefix.com/midwest-slatwall-prices.html

http://www.displaywarehouse.com/productinfo.asp?item=7804&deptcode1=501

http://www.garment-racks-store-fixtures.com/slatwall.html http://www.google.com/products/catalog?hl=en&client=safari&rls=en&q=slotwall&um=1&ie=UTF-8&cid=7804676864090740837&ei=95K_TNXAAsX_nAfLnM2JDg&sa=X&oi=product_catalog_result&ct=result&resnum=5&ved=0CEoQ8wIwBA#ps-sellers

T-slot & Miter Channel: Woodpeck has several pages' worth of information on Incra T-slot, T-track nuts and aluminum miter channel, including sizes, dimensions, and pricing. Incra's website has several pages of information on their T-slot and miter channel features, sizes, and applications. Toolking and Woodcraft have Incra miter channel dimensions and prices. Grizzly and Woodstock International (brand) have information on dimensions, sizes, and prices for aluminum T-slot track. Amazon has Shop Fox T-slot track for sale and includes sizes, dimensions, and prices. Toolsip.com has prices and sizes for aluminum T-track/accessories. Toolsandmore.com has aluminum T-track dimensions and prices. T-track USA has several pages' worth of information on T-track including dimensions, sizes, features and prices.

http://www.woodpeck.com
http://www.incra.com
http://www.toolking.com/incra-miterchannel32-32-inch-t-slot-miter-channel?CAWELAID=430271255
http://grizzly.com/products/H0878
http://www.woodstockint.com/accessories_index.aspx
http://www.amazon.com
http://toolsip.com/bench-clamps/8.html
http://toolsandmore.us/big-horn-19801-aluminum-t-track.aspx

1.1.5 Large Scale Design

Quicksilver Industries manufactures large-scale CNC machines suitable for the aerospace, industrial, wind energy and marine industries.

http://www.compositemfg.com/GantryRobots.htm

1.1.6 Software

The Mach Support site provides information on Mach3 and LazyCam (file importer) software. The Vetric site has Cut2D and Cut3D software. Mach3 and Cut2D software are Gcode CNC controller packages. Autodesk provides design software and add-on package downloads and support.

http://www.machsupport.com/
http://www.vectric.com/WebSite/Vectric/cut2D/c2d_index.htm
http://students.autodesk.com/

1.1.7 Other

Videos:

This video shows the CNC Solidworks and MasterCam software used to cut a guitar.

http://www.youtube.com/watch?v=z3-P606PO0U

Routers: Reef Central's forum page referenced here explains the difference between trim and plunge routers.

http://www.reefcentral.com/forums/showthread.php?t=1089276

The Numerical Control Wikipedia page provides extensive background information on the history of CNC machines. The Woodgears site tests a triple mortise and tenon joint against a dowel joint. The Virtual Machine Shop at kanabco.com outlines the step-by-step construction of a bill of materials. Vimeo has a video of a torsion box designed by David J. Marks and constructed with excruciating detail. CNC Router Source's page "Builder's Guide" has many links to online charts and calculators useful for finding linear and angular speeds, accuracy and force information, and for calculating lead screw criteria. Thomasnet.com is a search engine; this page shows CNC machining products in Minnesota. A search for "CNC machining" in Minnesota under Company Names included CNC Routerworks in Minneapolis.

http://en.wikipedia.org/wiki/Numerical_control
http://woodgears.ca/joint_strength/index.html
http://jjjtrain.kanabco.com/vms/eng_BOM/eng_bom_00.html
http://vimeo.com/5082731
http://www.cncroutersource.com/calculators-and-charts.html
http://www.thomasnet.com/minnesota/cnc-machining-45330503-1.html
http://www.cncrouterworks.com/contact.htm

1.2 Patent Search

Because our machine does not have an innovative purpose or design, there is not likely to be anything that is patentable on it. Construction methods, such as threaded fasteners, tapped holes, and holding the machine ends together with threaded rod are all common knowledge and are not patentable. The aim of our machine was not to innovate, but to produce a superior machine at a competitive price.

As an example, we examined US patent # 5,384,993. This is a tie down for building structures, and uses the same principal of structural threaded rod in tension that we utilize in our machine. However, the application is very different and we can assume that our machine does not infringe on this patent.

US005384993A

United States Patent [19]

Phillips

[11] **Patent Number: 5,384,993**

[45] **Date of Patent: Jan. 31, 1995**

[54] **TIE DOWN FOR BUILDING STRUCTURES**

[76] Inventor: **Belton R. Phillips**, Rte. 1, Box 1876, Fred King Rd., Hartwell, Ga. 30643

[21] Appl. No.: **152,425**

[22] Filed: **Nov. 15, 1993**

[51] **Int. Cl.**[6] **E04H 9/14**; E02D 27/50

[52] **U.S. Cl.** **52/92.2**; 52/223.6; 52/293.3; 52/DIG. 11; 52/295

[58] **Field of Search** .... 52/295, 293.3, 698, 52/149, DIG. 11, 223.4–223.7, 23, 92.2; 248/499, 400

[56] **References Cited**

U.S. PATENT DOCUMENTS

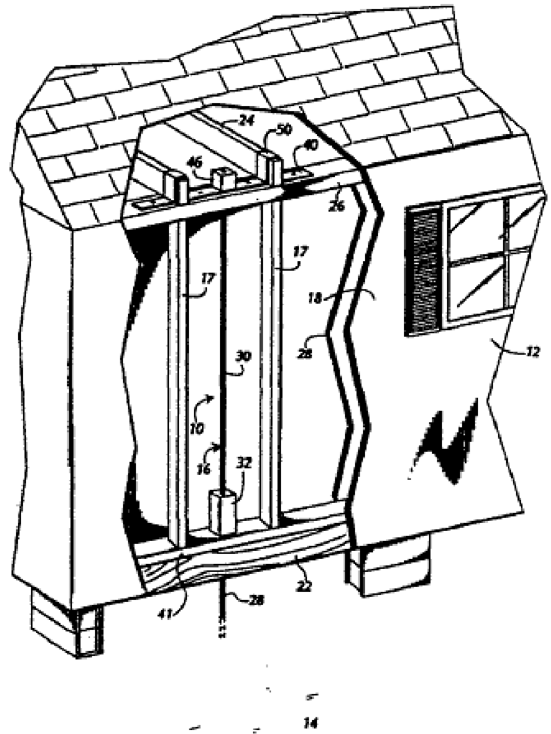
269,018	12/1882	Crowell et al.	52/23
573,452	12/1896	Delahunt	52/92.2
777,441	12/1904	Small	52/23
1,864,403	6/1932	Bradley	403/213
2,165,500	7/1939	Muirhead	52/293.3 X
3,054,151	9/1962	Shankland	52/23
3,335,531	8/1967	Grimelli et al.	52/DIG. 11 X
3,724,151	4/1973	Kaywood et al.	52/295
3,726,054	4/1973	Anderson et al.	52/148
3,802,138	4/1974	McCarler	52/DIG. 11 X
3,828,491	8/1974	Koon et al.	52/DIG. 11 X
3,852,931	12/1974	Morse et al.	52/293.3
3,894,365	7/1975	Abbott	52/23
3,937,436	2/1976	Stewart	248/499
3,943,670	3/1976	Miller	52/23
4,018,015	4/1977	Swanson	52/DIG. 11
4,068,426	1/1978	Warren	52/DIG. 11 X
4,272,933	6/1981	Lopes	52/149
4,321,776	3/1982	Delight	52/295 X
4,688,362	8/1987	Pedersen et al.	52/223.7
5,007,218	4/1991	Bengston et al.	52/295 X

Primary Examiner—Carl D. Friedman
Assistant Examiner—Robert J. Canfield
Attorney, Agent, or Firm—Hopkins & Thomas

[57] **ABSTRACT**

An apparatus for tying down and anchoring a building structure such as a mobile home (**12**). The apparatus comprises an elongated threaded rod assembly (**16**) which is anchored at its lower end (**34**) to a concrete base (**14**) and extends upwardly, first through the floor joist (**22**) and then up to the roof structure where it is connected to the rafters (**48**). The elongated rod assembly (**16**) includes a hold-down block (**32**) that connects upper threaded rod (**30**) and lower threaded road (**28**) together in an end-to-end relationship. The hold-down block (**32**) applies a downward force firmly holding the floor joist (**22**). The upper threaded rod **30** extends upwardly through a frame board (**26**) and an elongated bracket (**40**). An internally threaded lock-block (**46**) is screwed onto the end of the upper threaded rod (**30**) extending past the frame board (**26**) and bracket (**40**), firmly holding the roof structure.

13 Claims, 4 Drawing Sheets



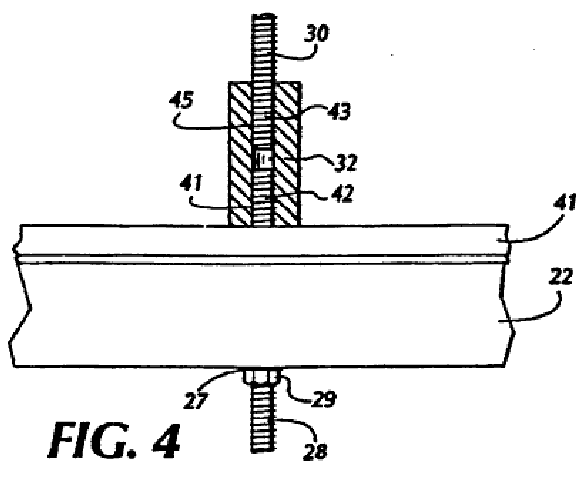


FIG. 4

One respect in which our machine could be perceived as innovative is the exchangeable tool feature on the z-axis. Although it is not the same method we used, we found another patent relevant to this feature, US patent # 5,240,360.

US005240360A

United States Patent [19]

Esser

[11] **Patent Number: 5,240,360**

[45] **Date of Patent: Aug. 31, 1993**

[54] **MACHINE TOOL WITH EXCHANGEABLE MACHINING HEADS**

[76] Inventor: **Karl-Josef Esser,** Pauenstrasse 89, D-4050 Mönchengladbach 5, Fed. Rep. of Germany

[21] Appl. No.: **849,884**

[22] Filed: **Mar. 12, 1992**

[30] **Foreign Application Priority Data**

Mar. 13, 1991 [DE] Fed. Rep. of Germany 4108038

[51] **Int. Cl.**[5] **B23C 1/06**

[52] **U.S. Cl.** **409/230;** 408/238; 409/231

[58] **Field of Search** .... 483/13; 29/57; 409/230, 409/232, 233, 234, 231; 408/239 A, 239 R, 238

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,757,637 9/1973 Eich 409/233
4,548,532 10/1985 Watanabe et al. 409/233
4,599,023 7/1986 Poincenot 409/233

FOREIGN PATENT DOCUMENTS

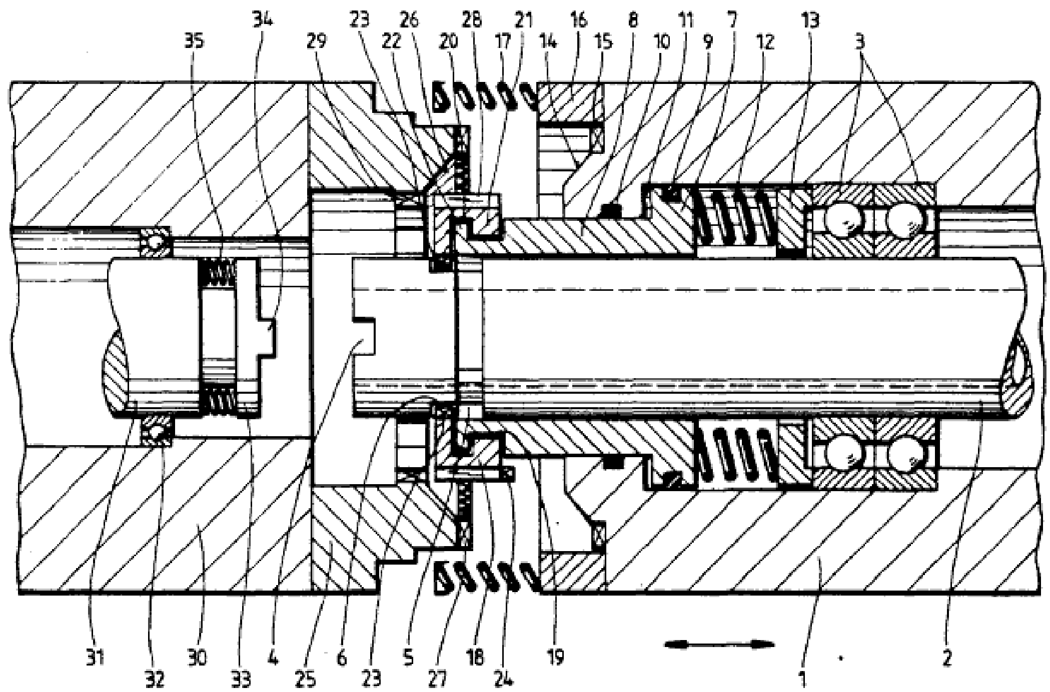
2212875 2/1974 Fed. Rep. of Germany .
2230144 8/1979 Fed. Rep. of Germany .

Primary Examiner—William Briggs
Attorney, Agent, or Firm—Michael G. Marinangeli; Thomas Gallagher

[57] **ABSTRACT**

Machine tool with a driving spindle held in a carrier, an exchangeable machining head that can be coupled with the carrier and a tool spindle in the machining head that can be coupled with the driving spindle and adjustment and locking means on the carrier for locking the machining head onto the carrier. The machining head can be withdrawn from a magazine for machining heads by means of said adjustment and locking means and it can be coupled with and locked onto the machine tool and, after releasing, it can be brought into any desired angular position relative to the machine tool and locked again.

13 Claims, 5 Drawing Sheets



In addition to not having any patentable innovations on our design, we also did not find any related to our design or construction process. Future research could look into patenting a reliable and user-friendly alignment method based on our blocks and standoffs, but the method would need to be refined further than our trial and error execution.

1.3 User Need Research

The starting point of our project was to define the needs of our customer, and the market niche we are trying to fill. This process was jump-started by our sponsor, who identified the need for a low-cost, durable, and accurate tabletop CNC milling machine. We identified our potential customers as hobbyists, small businesses, schools, and anyone else who needs affordable, small-scale milling. Some examples of real projects that should be possible with our machine are shown below:

[1]

[1] http://www.holteyplanes.com/blog/2009/07/20/window-to-my-workshop-9/

[2]

[2] http://www.divxklip.eu/tags/hobby

Because our sponsor and several members of our group are hobbyists with home machining experience, we relied on their input to quickly identify customer needs and proceed with the design process. Some of the initial needs we identified were a high traverse speed, low cost, tabletop size, ease of assembly, robust work piece clamping mechanism, and a good cable management system. We also needed to determine the hardness of material our machine would be capable of milling, and eventually decided in the interest of cost we would not expect to mill materials harder than thin sheets of light aluminum. This should leave us capable of milling all sorts of woods, plastics, foams/resins, and fiberboard materials. Another option we identified as a customer need is the need for a modular cutting head attachment, making it quick and easy to switch milling tools. After some discussion, these were refined into our PDS and assigned a relative importance.

1.4 Concept Alternatives

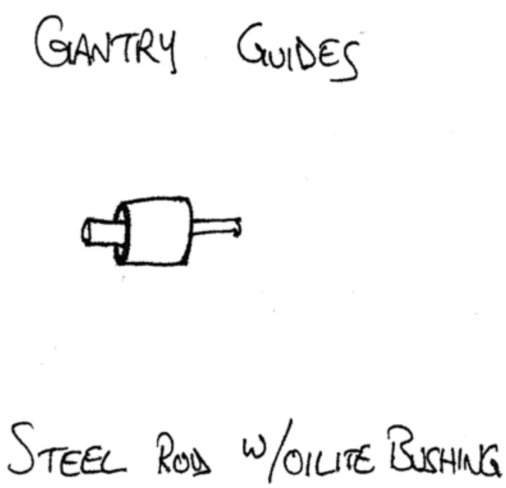
Oftentimes there are many solutions to a particular problem. In the case of the CNC machine the PDS clearly defined the problem but this doesn't mean that the solution was entirely clear. The major concepts which spawned debate were categorized and voted upon. These included linear motion, drive mechanisms, accessories, frame support, overall structure and work surface.

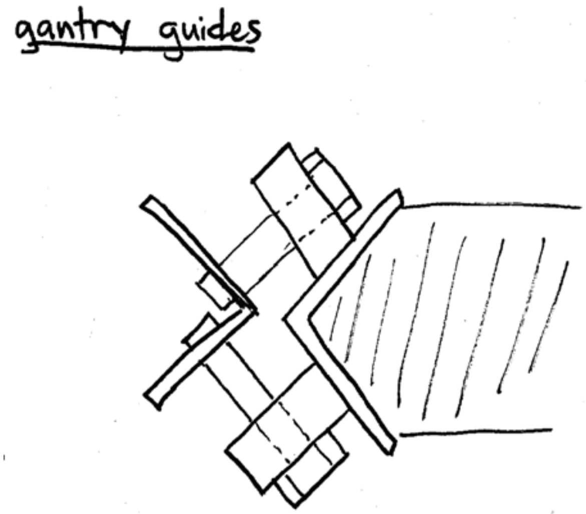
1.4.1 Linear Motion

The operation of the CNC machine requires the cutter to be moved from point to point. For convenience, each point is defined within a three axis coordinate system. The movement of the cutter from point to point is accomplished through linear travel along each of these three axes. The method of movement, however, was up to debate. Two of the alternatives were gantry guides and guide rails with bushings. The guide rails are round shafts of hardened steel, the Oilite bushings are an oil impregnated powder metal bushing. 15% of the weight of the bushing is the oil that has been impregnated by using hot oil and a vacuum system under pressure. This system results in low friction linear motion.

One of the alternatives was angle iron with skate bearings. Two skate bearings are bolted onto each of the outside ends of a piece of angle that is about as long as the gantry arm (approximately 6 inches long). A length of angle is attached along the entire x-axis of the machine to the table surface's edge. Once the gantry arm has been installed, the bearings are constrained laterally so that they will not veer away from the table, and they are supported vertically by contact with the top and bottom bearings against the angle on the table surface.

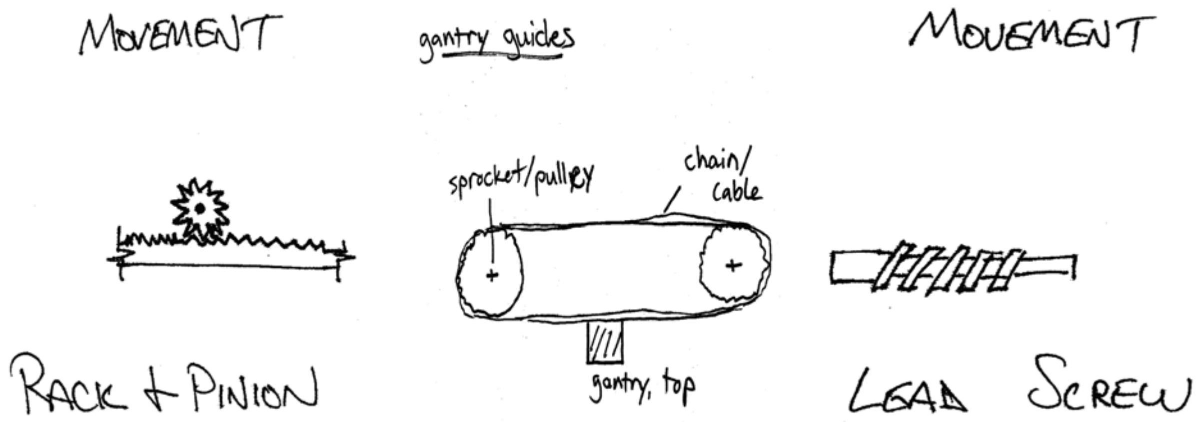
Oilite bushings were chosen as the better solution because of accuracy and reduced assembly.





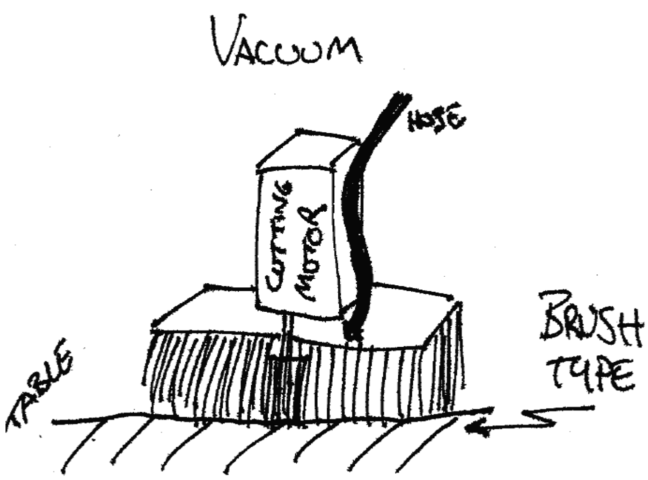
1.4.2 Drive Mechanism

Each of the three axes is equipped with a motor in order to move the cutter from point to point. Just how the motor accomplishes this needed to be decided. Some of the alternative methods were a rack and pinion, a sprocket and chain or a lead screw design. In the rack and pinion design the motor would be mounted directly to a gear. The motor would then turn the gear and produce motion across a rack. The rack and pinion design would have resulted in a very high traverse speed but would have sacrificed precision. In the sprocket and chain design the motor would turn a sprocket which in turn would move a chain. The sprocket and chain design was similar to the rack and pinion in that it would be fast but less accurate. In the lead screw design the motor would be connected to a lead screw which would be fitted to turn freely. As the screw would turn it would force an anti-backlash nut to travel across it. Ultimately we decided the lead screw would provide the most accurate linear motion and would be more than fast enough for our application.

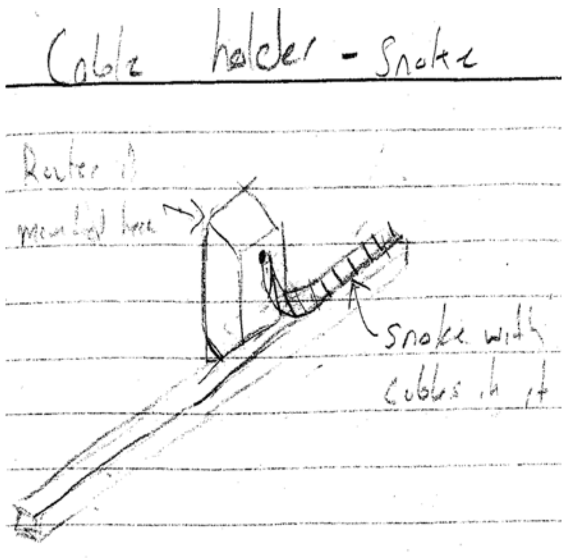


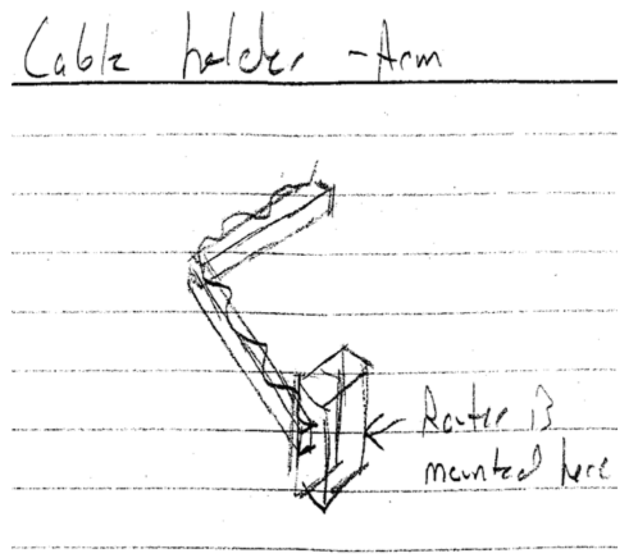
1.4.3 Accessories

As an additional option, our sponsor asked us to generate a list of accessory parts which could be sold separately and attached to the machine. One such concept which was considered was a vacuum attachment which could attach near the router and suck up saw dust as it is created. We decided the vacuum accessory was not required for the first prototype and that the machine could still be modified later in order to accommodate it.



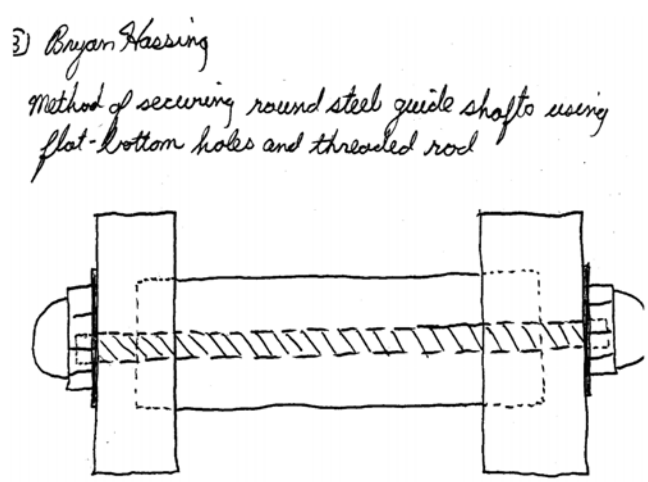
An addition accessory option which was considered was some form of cable management. Each motor is connected, by wire, to the power supply and command computer. These wires must be managed or else they could get in the way.

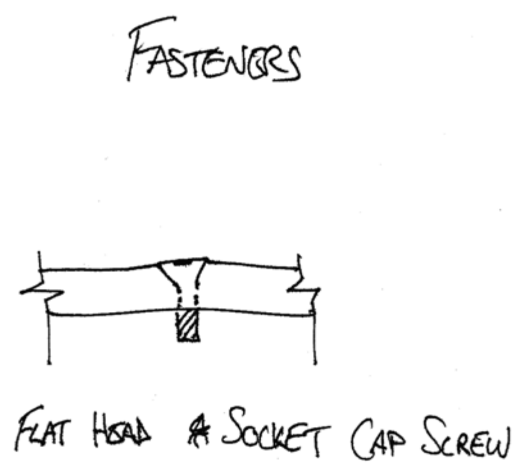


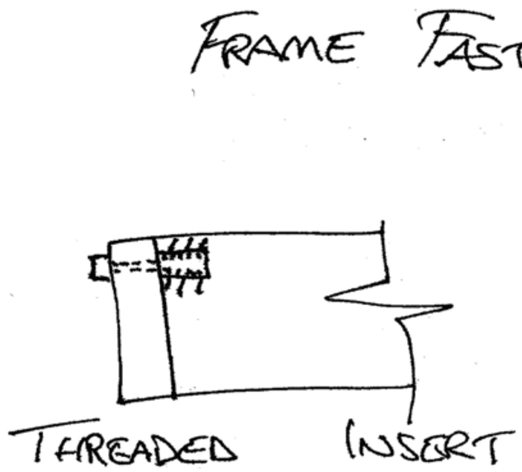


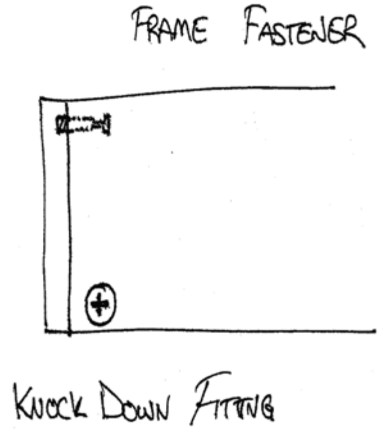
1.4.4 Frame Support

The frame of the CNC machine has to be fastened together somehow, but there are many ways to accomplish this. Some alternative solutions included all thread, glue, screws, threaded inserts, dovetail joints, dado joints, rabbit joints and frame fasteners. Our design incorporates threaded rod, threaded inserts and countersunk screws.



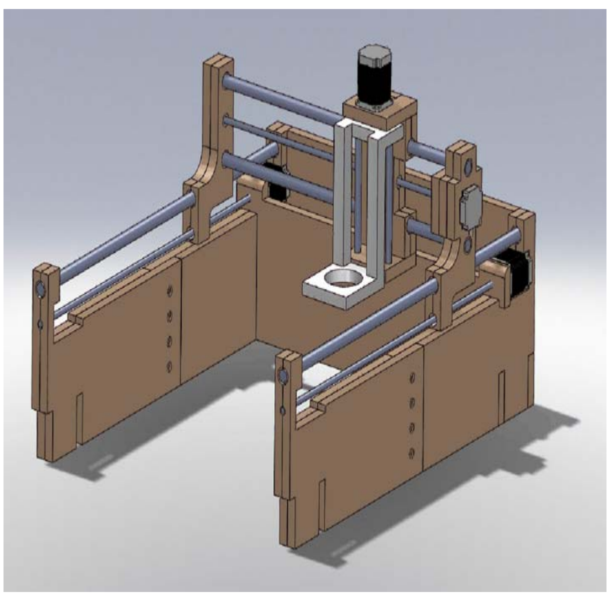


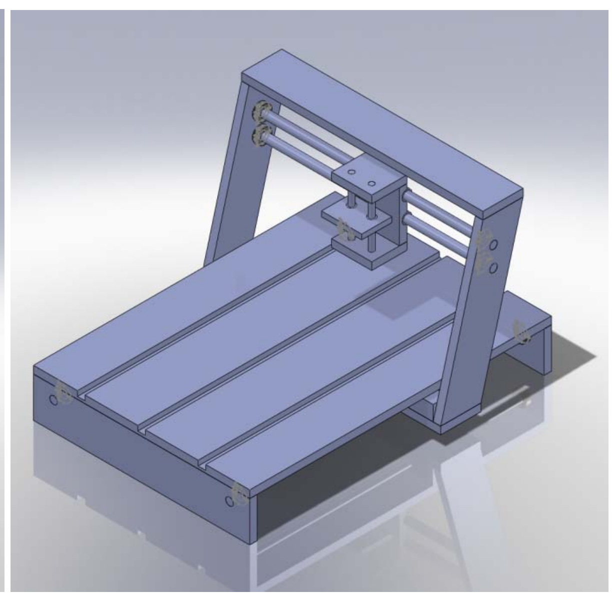




1.4.5 Structure

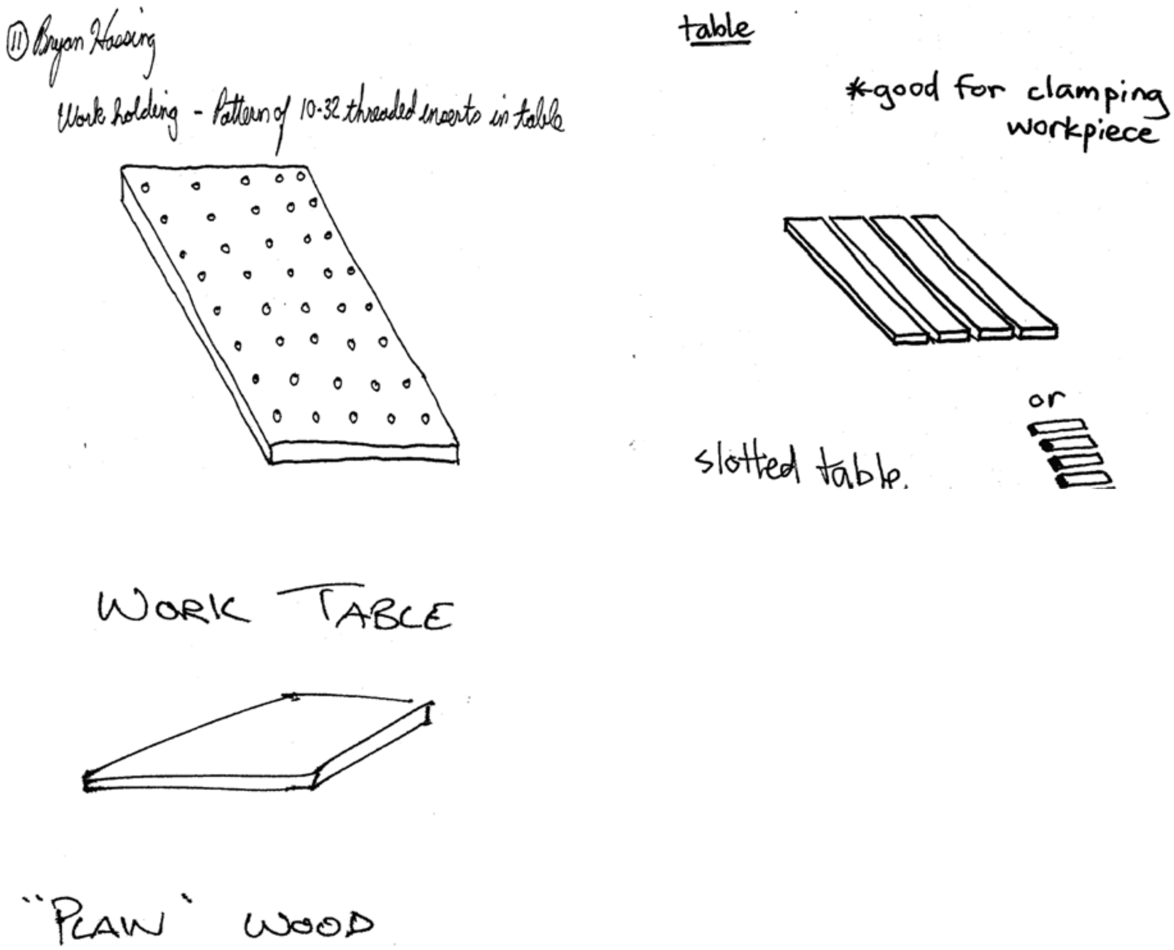
Even the overall structure of the CNC machine was not initially clear. Two competing ideas, which we referred to as the “gantry” design and the “box” design were heavily debated. The debate went far enough that we actually created CAD models of both designs. We referred to the design on the left as a “box” design and the design on the right as a “gantry” design. The “box” design required two lead screws and four motors, which would have resulted in a faster traverse speed but also a much costlier design. The “gantry” design was determined to be both cost effective and more than sufficient functionally. The design from here was not finished, however, and continued to undergo modifications.





1.4.6 Work Surface

The work surface of the CNC machine is an important aspect and thus required consideration. A few of the alternative concepts included slotted wood, drilled holes or a smooth table. Ultimately the smooth table was chosen for our design based on cost and ease of manufacturability.



1.5 Concept Selection

A concept-selection process was exercised for several major attributes of the design. Following establishment of a well-defined product design specification, dozens of concepts were generated for items such as overall machine architecture, linear guidance, drive motor placement, table configuration and work holding, Z-axis carriage arrangement, gantry arm configuration, and spindle holding.

Multi-voting was used to select three to six of the strongest concepts for each component used in the final design.

The multi-voting procedure began with the generation of concept sketches on paper index cards. Redundant concepts were eliminated and the index cards sorted by component. Component concepts were generally presented at the same level of detail on the index cards. Team members reviewed the index cards and initialed their choice of concept. The most popular selections were forwarded to the next round of voting. Rejected index cards were reviewed periodically to ensure promising concepts were not overlooked. The project advisor was present during the final round of voting.

The final step in concept selection was performed using a selection matrix. A selection matrix was used to identify the most desirable concept for each component. The selection matrix shown below as Table 1 indicates the relative degree to which individual concepts satisfied the product design specifications.

Table 1: Concept Selection Matrix

	Cost	Ease of manufacture	Ease of assembly	Meets requirements	Student Rating	Company Rating
Table surface (Notecards 1-5)						
Slab MDF	10	8	9	2	6	5
Slatwood	6	10	9	3	3	8
MDF with T-slot extrusions	4	6	9	9	7	7
Strips of wood	8	8	7	8	6	5
MDF with threaded fasteners	6	7	7	9	5	5
MDF with holes	8	7	8	8	3	6
Aluminum extrusion	1	9	7	10	7	10
Slab of plastic	2	8	9	3	1	1
Bearing mounting (Notecards 6-10)						
Pressure fit in block	10	9	9	8	9	8
Encased in multipiece block	7	6	5	8	3	2
Clamped on sides	7	7	5	8	5	7
Clamped on ends	7	7	5	8	3	3
Glued	9	8	9	7	4	8
Off-the-shelf mounting block	2	10	9	10	7	10
Gantry/Machine style (Notecards 11-26)						
Standard gantry	8	7	6	8	5	5
Offset gantry side arms	8	7	6	9	7	8
Cantilever arm	5	6	6	9	4	3
Box style (enclosed)	9	9	7	9	7	8
Suspended	7	7	7	9	6	3
Moveable table	4	5	4	3	2	1
Polar arm	3	5	5	2	1	1
Rail/Linear motion (Notecards 27-38)						
Round shaft	8	10	7	9	9	10
Linear guide	1	10	7	10	10	10
Drawer slides	4	10	7	4	5	2
Angle aluminum with bearings	5	5	4	8	5	4
Dovetailed ways	4	5	10	4	1	2
Boxed ways	4	6	10	3	2	1
Drive mechanisms (Notecards 27-38)						
Acme leadscrews	6	10	8	9	8	9
Ballscrews	1	10	3	10	10	10
Pulley/belt	8	10	5	8	5	7
Pulley/chain/sprocket	6	10	5	6	3	3
Rack and pinion	8	10	7	7	4	3
Magnetic actuator	1	10	9	8	3	0
Accessories (Notecards 39-44)						
Vacuum attachment	9	8	9	NA	8	10
Cable management	8	7	7	NA	10	10
Lathe attachment	5	6	5	NA	6	2
Structural components (Notecards 45-60)						
PVC tubing	9	8	7	5	5	5
Rectangular tubing	7	7	7	7	9	5
Rail with threaded ends	5	10	8	7	8	5
Aluminum extrusion	4	7	8	9	9	9
Box	9	6	7	9	7	7
Structural table	7	5	5	8	6	4
Material (No notecards)						
Rubber	4	6	NA	NA	1	2
LDPE	5	10	NA	NA	1	2
HDPE	5	10	NA	NA	5	5
Polypropylene	6	10	NA	NA	5	5
Nylon	6	10	NA	NA	1	1
MDF (wood composite)	10	7	NA	NA	8	8
Oak wood (along grain)	6	8	NA	NA	4	4
Pine wood (along grain)	8	9	NA	NA	2	2
Magnesium metal (Mg)	4	2	NA	NA	0	0
Aluminum alloy	7	7	NA	NA	9	10
Brass and bronze	3	2	NA	NA	6	10
Titanium (Ti)	1	1	NA	NA	4	0
Copper (Cu)	2	2	NA	NA	1	0
Steel	7	5	NA	NA	10	10

2.0 Design Description Supporting Documents

2.1 Manufacturing Plan

2.1.1 Manufacturing Overview

Our final machine design consists primarily of slab MDF and off-the-shelf components. Because part of our scope was that the machine could reproduce most non off-the-shelf components, all MDF parts were designed with ease of manufacture in mind. All parts other than the tabletop surface could be machined on a CNC of similar caliber to ours. Alternately, all parts could also be milled with common woodworking tools. This was the rout we selected for producing our prototype machine, as we did not have a functional CNC machine available to us at the time.

2.1.1.1 Parts Manufacturing Procedure

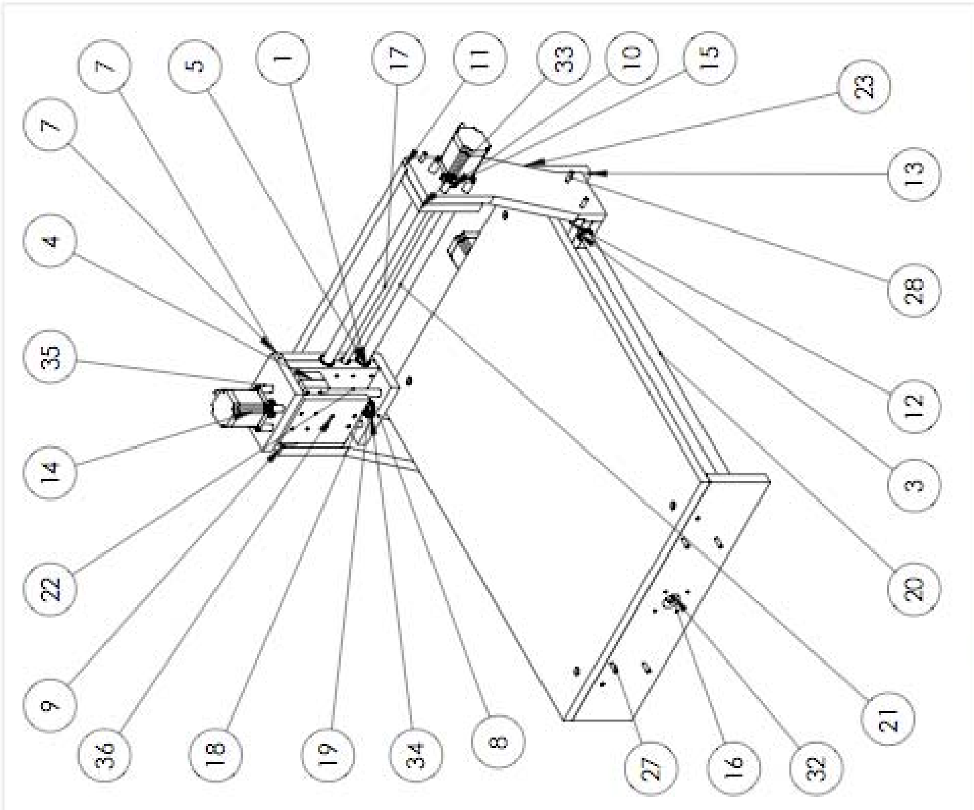
1) Cut all blanks out of ¾" sheet MDF, available at most lumber yards. This was done on a table saw.
2) Cut all necessary dado slots, using a table saw and a dado blade. Alternately, you could use a regular blade and make multiple passes.
3) Mill all curved channels using an appropriately sized half-round router bit.
4) Drill all through holes using a drill press.
5) Mill out all recessed holes (not through) using a flat end router bit.

All MDF pieces should be ready for assembly at this point. Nuts, bolts, washers, and screws are off-the-shelf components, as are the lead screws, shafts, bushings, treaded rod, aluminum extrusion, and PVC pipes.

6) Cut aluminum extrusions and PVC pipes to length using a table saw or chop saw.
7) Cut all threaded rod and lead screws to length using a hacksaw or chop saw.

Once all of the components have been manufactured, the machine can be assembled.

2.1.2 Part Drawings



DWG. NO.	Description	QTY.
1	X & Y Axis Bushings	8
2	Z-Axis Bushing	4
3	X-Axis Shaft Block	4
4	Z-Axis Shaft Block	2
5	Y-Axis Shaft Block 1 of 2	1
6	Y-Axis Shaft Block 2 of 2	1
7	Z-Carriage Top Plate	1
8	Z-Carriage Bottom Plate	1
9	Left Gantry Arm	1
10	Right Gantry Arm	1
11	Top Gantry Support	1
12	Bottom Gantry Support	1
13	End Member	2
14	Nema 23 Motor	3
15	Coupler	3
16	X-Axis Lead Screw (3/8"-10 2 Start)	1
17	Y-Axis Lead Screw (3/8"-10 2 Start)	1
18	Z-Axis Lead Screw (3/8"-12 1 Start)	1
19	3/8" ID Shaft Collar	5
20	X-Axis Guide Rail	2
21	Y-Axis Guide Rail	2
22	Z-Axis Guide Rail	2
23	Sacrificial Table	1
24	Corner Bracket	4
25	PVC Tubing	2
26	Aluminum Extrusion	3
27	X-Axis Threaded Rod (1/4"-20)	4
28	Y-Axis Threaded Rod (1/4"-20)	4
29	X-Axis Lead Screw Block	2
30	3/8"-10 2 Start Anti-Backlash Nut	2
31	3/8"-12 1 Start Anti-Backlash Nut	1
32	X-Axis Bearing Block	2
33	Y-Axis Bearing Block	2
34	3/8" ID Bearing	5
35	Motor Stand-Off Spacers	12
36	Aluminum Mounting Plate	1

Part Name:

CNC Machine - Full Assembly

Notes:

MATERIAL

FINISH

SHEET 1 OF 1

SCALE: 1:16

DWG. SIZE A

DWG. NO. 0

REV A

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/64 BEND ± 1/32 ANGULAR: MACH ± .5° TWO PLACE DECIMAL ± .01 THREE PLACE DECIMAL ± .005 FOUR PLACE DECIMAL ± .0025 INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994