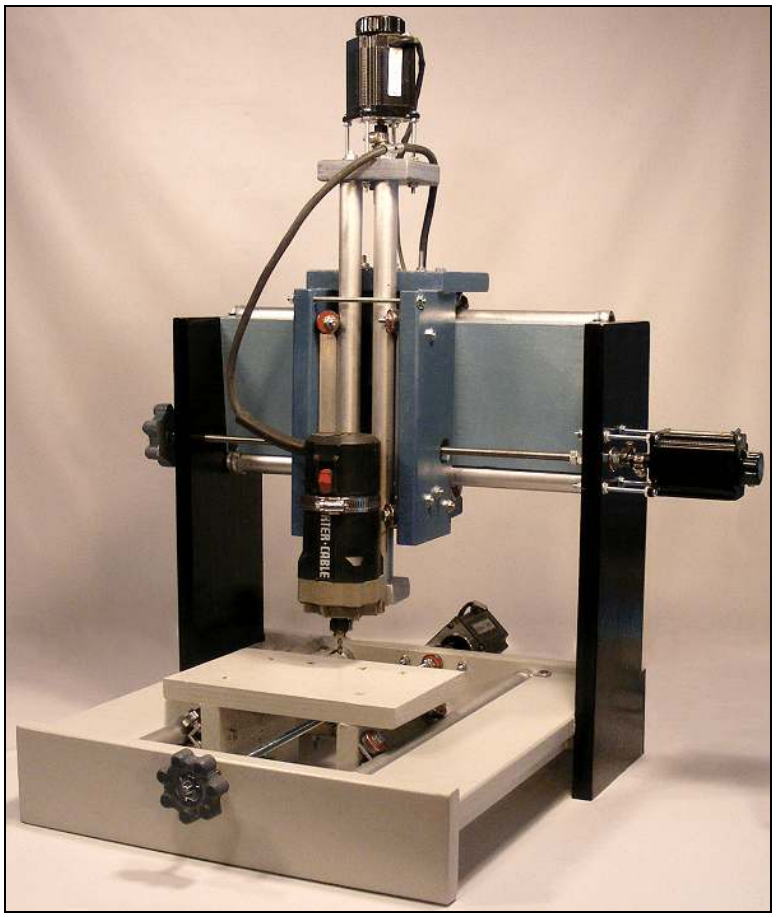
CNC Router Plans

Plans for a 10 x 9 Inch
Fixed Gantry Machine



David Steele

NOTICE: That which makes CNC machines useful also makes them dangerous; they move without direct human control.
A CNC table MUST have an easily accessible Emergency Stop button. The table must be in a safe location where it is inaccessible to children and unauthorized users; these are not toys, even a small machine can inflict serious injury. You, the user of these plans, assume all liability and responsibility for the construction process, and the product you create.
Do not use these plans if these conditions of use are unacceptable to you.

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Cut and Drill Wood

Y Table Frame Axis

X Gantry Axis

Z Carriage Axis

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Introduction

This machine was made to meet the need in this shop for a small, simple and inexpensive machine that could test g-codes for aluminum prototypes.

The cost of the 10x9 was kept low, and the construction time was reduced, by using off the shelf stock with little waste.
The rails are conduit or pipe, the leadscrews can be threaded rod, the leadnuts can be tee nuts, and the bearings are 608 bearings, which are sold as skate bearings.

The fixed gantry design is solid and simple. The machine's rigidity is maintained by keeping the machine small, by using solid wood rather than MDF, and by tensioning all bearings against their rails.

The machine is designed to only require a few tools to build, and its construction is sequenced to be straightforward.

Plans and Building Sequence

These plans are sequenced in the order of the building process.
First is an overview of the three axes and their components.
This is followed by both a simple and a detailed materials list.
Next are directions with templates for cutting and drilling the home center stock.
The directions for assembling the components of each axis follow.
Next are directions for the final assembly of the axes into a completed machine.

When the table is to be upgraded from All Thread to Acme rod, the Acme Upgrade page at the end of the manual should be reviewed before buying materials. The threaded rod, bearing, clamp, hose and tee nut counts will change with the upgrade.

Read, or at least browse, through the plans before beginning work. There are hundreds of captioned photos that describe the building process. Looking over these ahead of time will add clarity.

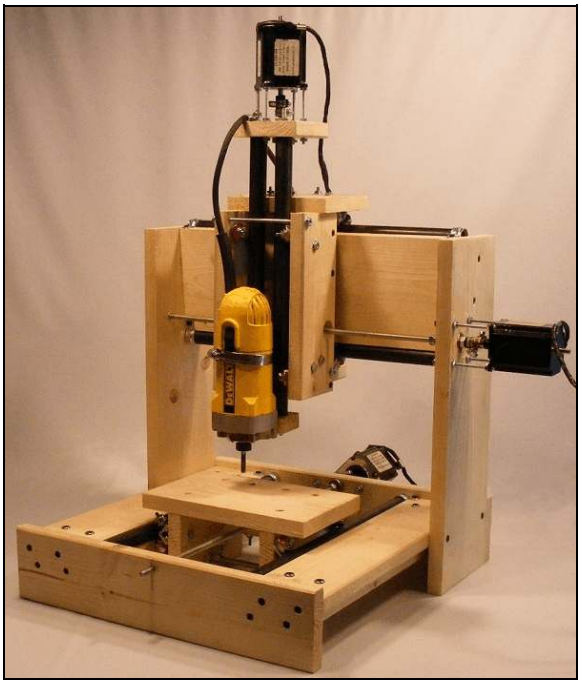
A dedicated work space with quality tools will help to make this an enjoyable project.

Good Luck!

Overview

The machine consists of three axes.
These are the Y table frame and bed, the X gantry, and the Z carriage and rails.

The machine is made of 1x4 and 1x6 boards that are cut to length, drilled and assembled.



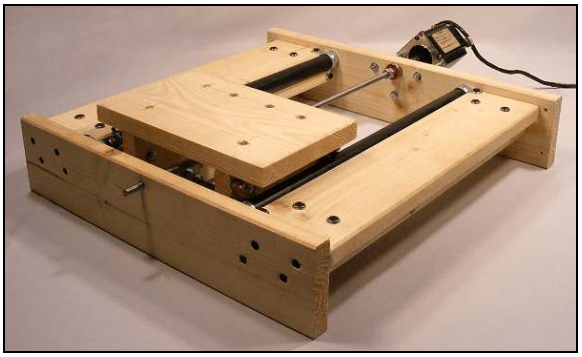
Completed machine.

Table Frame and Bed

The frame is made of standard sized 1x4 stock, and the top of the table bed is cut from a 1x6.

The rails are 1/2 inch ID (Inside Diameter) black iron pipe, galvanized pipe, or rigid electrical conduit. The pipes are held in place with EMT clamps or metal plumber's tape.

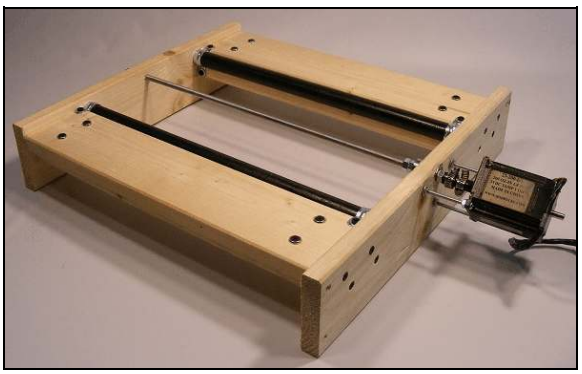
The wooden components are held together with 1-5/8 inch drywall screws and glue.



Y table frame and bed.

The stepper is attached to the table frame with 3 inch long machine screws.

The Y leadscrew spans the front and back 1x4 plates, and is supported near the stepper by a pair of 608 bearings, which are also sold as skate bearings.



Y table frame.

Y Table Bed

The Y table bed is a section of 1x6 that is glued and screwed to two pieces of 1x4.

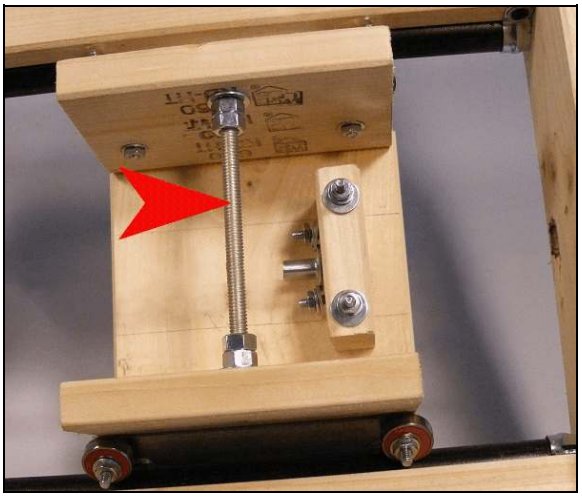
The 1x4s hold the bearing trucks that ride the Y pipe rails.
The trucks are made of 608 bearings that are attached to aluminum angle.

The angle is 1/8 x 3/4 x 3/4 inch, and is sold in home centers.
The angle, like the pipe rails, can be cut by hand with a hacksaw.

A compression rod, middle image, presses the bearings into the rails by pushing the 1x4 legs apart.

The Y leadnut assembly consists of a tee nut that is connected to a wood block that is machine screwed to the Y top.
Oversized connection holes in the components permit adjustments for proper leadscrew to leadnut alignment.

Y table bed.



Y compression rod spans the legs.

Bottom of Y bed showing tee nut.

X Gantry

The gantry beam is made of two 1x6 boards that are screwed and glued together.

Its pipe rail system is the same as the Y table frame's with 1/2 inch pipe that is held with EMT clamps.

The vertical end plates are also made of 1x6 boards. They support the beam, the stepper, and the leadscrew.

The X gantry assembly is screwed and glued to the Y table frame.

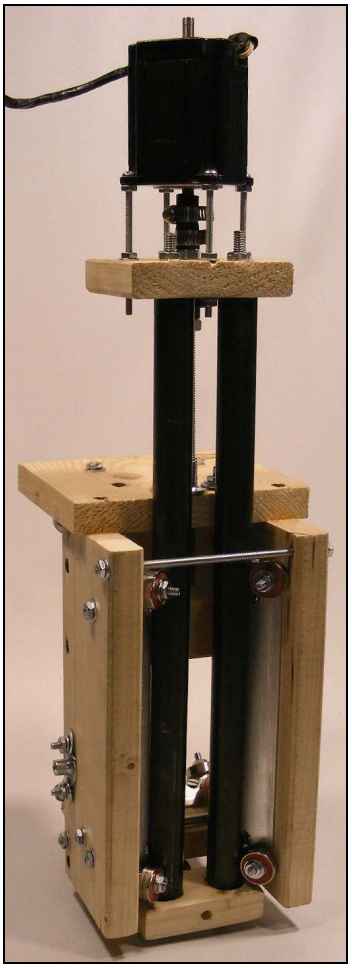
X gantry beam, end plates, leadscrew and stepper.

Gantry beam with pipe rails.

Gantry ends.

Carriage and Z Rails

The carriage is made of 1x4 and 1x6, and the Z rail assembly is made of sections of 1x4 and black iron pipe.



Z carriage and rails.

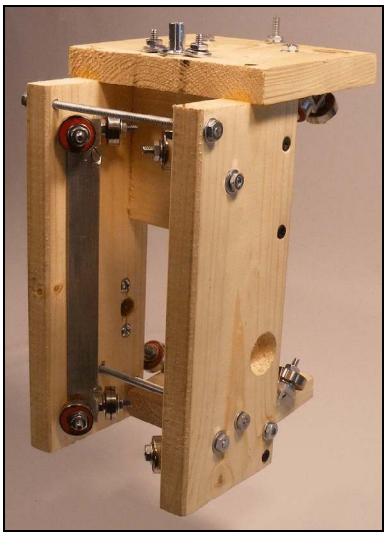
Z Carriage

The Z carriage supports the X and Z bearing trucks.
The bearing trucks are the same as the Y trucks, except the aluminum angles' lengths are different.

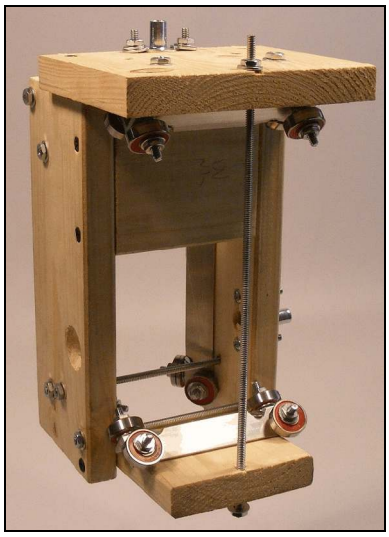
The X bearings are on the back of the carriage, and they ride the gantry rails. The X bearings are tightened against the rails by a tension rod that spans the carriage's top and bottom plates. Middle image below.

The Z bearings are in the front of the carriage, and they support the Z rail assembly.
The sides of the carriage are pulled against the trucks and rails with a pair of tension rods that extend through the two sides.

The X leadnut is attached to the side of the carriage, and the Z leadnut is attached to the top of the carriage.
The leadnut system on these axes is the same as the one used on the Y axis. Machine screws with washers hold tee nuts to the wooden components.



Stepper side of carriage.



Carriage back.

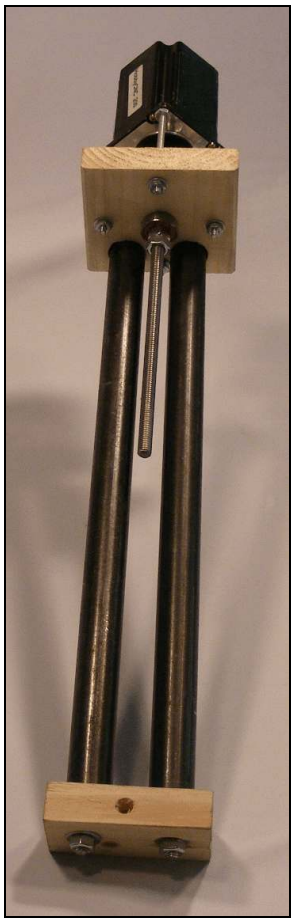
Leadnut side of carriage.

Z Rail Assembly

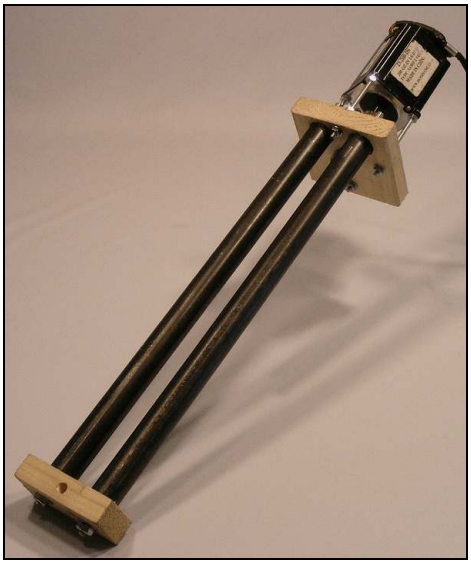
The Z rail assembly holds the Z stepper and the trim router.

The wooden components are cut from 1x4 stock, and the pipe rails, like all the other rails, are 1/2 inch ID (Inside Diameter) black iron pipe or similar.

The assembly is held together with threaded tension rods that pass through the pipe rails and clamp the wooden blocks into place.



Z pipe rails, back.



Z rails with stepper.

Router attached to rails.

The stepper is held to the rail top plate with 3 inch long machine screws. Bearings near the stepper mount hold the leadscrew into place.

The router is tied to the bottom block with a 1/4-20 x 2 inch bolt that threads into the router's base. The threaded hole for this bolt is already machined into the DeWalt and Porter-Cable trim routers for their factory made attachments.

The website's Spindle page gives directions on rotating the trim router's base so it can be attached to the Z axis' bottom block.

The body of the router is tied to the rails with a strap that is made of a band clamp or metal plumbing tape. An aluminum angle anchor prevents the router's strap from pulling through the rails.

Materials, Simple List

Notes		Quantity	Size	Part	Might Buy
		15	5/16-18	Nuts	
		5	5/16-18	Tee Nuts	
		2	5/16	Washers	
		53 inches	5/16-18	Threaded Rod	2 @ 36 inches.
		13	1/4-20	Nuts	
		20	1/4	Washers	
		1	1/4-20 x 3/4	Bolt	
		1	1/4-20 x 1	Bolt	
		1	1/4-20 x 2	Bolt	
		36 inches	1/4-20	Threaded Rod	
		109	#10-24	Nuts	
		126	#10	Washers	
		2	#10-24 x 3/4	Round Head Machine Screw	See notes
		22	#10-24 x 1	Round Head Machine Screw	
		6	#10-24 x 1-1/4	Round Head Machine Screw	
		12	#10-24 x 1-1/2	Flat Head Machine Screw	
		13	#10-24 x 3	Round Head Machine Screw	See notes
		27 inches	#10-24	Threaded Rod	1 @ 36 inches
		72	1-5/8	Drywall Screw	1 pound box
		12	#8	Finish Washers Optional	
		36 inches	1/8 x 3/4 x 3/4	Aluminum Angle	
		94 inches	1/2 inch ID	Black Iron Pipe	10 foot length
		4 inches	1/4 inch ID	Fuel Line	
		6	#4	Hose Clamp	
		1	4 inch diameter	Band Clamp	See note below
		8	1/2 inch	EMT Two Hole Clamps	
		1	Small Bottle	Carpenter’s Wood Glue	
		12 feet	1x4	Wood Board	2 @ 8 feet
		7 feet	1x6	Wood Board	1 @ 8 feet
		1	Tube	Loctite Green Thread Locker	
		30	608 (22x8mm)	Skate Bearings	

Note: One roll of plumbing hanger tape can replace the 1/2 inch EMT clamps and band clamp.

Materials, Detailed List

Notes		Quantity	Size	Part	Might Buy
		15	5/16-18	Nuts	
			3 per leadscrew (9)		
			4 Y compression rod		
			2 for optional knobs		
		5	5/16-18	Tee Nuts	
			3 for leadnuts		
			2 for optional knobs		
		2	5/16	Washers	
			2 Y compression rod		
		53 inches	5/16-18	Threaded Rod	2 @ 36 inches.
			6 inches Y compression rod		
			7 inches Z leadscrew		
			2 @ 20 inches for X and Y leadscrews (40)		
		13	1/4-20	Nuts	
			6 Z rails		
			1 Cable clamp on Z rail		
			4 Router cradle		
			1 Router band anchor		
			1 Router band strap		
		20	1/4	Washers	
			4 Z rails		
			2 Z cable clamp		
			2 on each leadnut support screw (6)		
			2 Y leadnut block		
			1 Router mount on 2 inch bolt		
			2 Router cradle		
			2 Router band strap		
			1 Router aluminum angle anchor		

		1	1/4-20 x 3/4	Bolt for Anchor Angle	
		1	1/4-20 x 1	Bolt for Router Band Strap	
		1	1/4-20 x 2	Bolt for Router Mount	
		36 inches	1/4-20	Threaded Rod	
			2 @ 17-1/4 Z rails (34.5)		
			1.5 cradle		
		109	#10-24	Nuts	
			2/ truck bearing, 24 bearings (48)		
			2/ truck for flat head screws (12)		
			2/ Z tension rod (6)		
			2/ X tension rod (2)		
			2/ leadnut (6)		
			2 for Y leadnut block (2)		
			3/ stepper mounting screw, 11 screws (33)		
		126	#10	Washers	
			2/ truck bearing (48)		
			2/ truck mount, on flat head screws (12)		
			2/ leadnut (6)		
			2 Y leadnut block (2)		
			2/ Z tension rod (6)		
			2 X tension rod (2)		
			2/ EMT clamp (16)		
			2/ stepper screw, 11 screws (22)		
			Y rail support boards. Can be finish washers (8)		
			X gantry beam. Can be finish washers (4)		
		2	#10-24 x 3/4	Round Head Machine Screw	See notes
			2 Required for Z bottom truck bearings All other bearing axles can be 3/4 or 1 inch		
		22	#10-24 x 1	Round Head Machine Screw	
			8 X trucks		
			8 Y trucks		
			6 Z trucks		

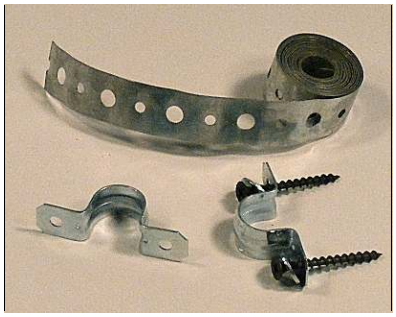
		6	#10-24 x 1-1/4	Round Head Machine Screw	
			2 per leadnut (6)		
		12	#10-24 x 1-1/2	Flat Head Machine Screw	
			2 per each truck (12)		
		13	#10-24 x 3	Round Head Machine Screw	See notes
			3 Y stepper mount		
			4 X stepper mount		
			4 Z stepper mount		
			2 Y leadnut block		
		27 inches	#10-24	Threaded Rod	1 @ 36 inches
			10-1/2 X tension rod		
			2 @ 5-1/2 Z truck tension rods (11)		
			5-1/2 Z bottom tension rod		
		72	1-5/8	Drywall Screw	1 pound box
			8 Y rail support tops		
			16 Y rail support ends		
			8 Attach X gantry to Y frame		
			8 Y Tie EMT clamps to Y rail supports		
			4 Y table bed to table legs		
			6 Tie X gantry beam to X ends		
			4 Tie Gantry beam together		
			8 Tie EMT clamps to gantry		
			4 Tie Z sides to Z back		
			2 Tie Z sides to Z bottom		
			4 Tie Z top to carriage body		
		12	#8	Finish Washers Optional	
			Use with screws that tie rail supports together		
		36 inches	1/8 x 3/4 x 3/4	Aluminum Angle	
			2@ 4-1/8 X trucks (8-1/4)		
			2@ 5-1/2 Y trucks (11)		
			2@ 7-1/2 Z trucks (15)		
			1@ ~1-3/4 Z router band anchor		

		~94 inches	1/2 inch ID	Black Iron Pipe	10 foot length
			4@ 15-7/8 for X and Y pipe rails		
			2@15 for Z rails		
		~4 inches	1/4 inch ID	Fuel Line	
			Tie leadscrews to steppers, 3 @ ~1-1/4 inch each		
		6	#4	Hose Clamp	
			Tie stepper to leadscrew. 2 per leadscrew		
		1	4 inch diameter	Band Clamp	See note below
			Ties trim router to Z rails		
		8	1/2 inch	EMT Clamps	
			2 per X and Y pipe rail. Tie rails to boards		
		1	Small Bottle	Carpenter's Wood Glue	
			Glue wooden components together		
		12 feet	1x4	Wood Board. See wood section	2 @ 8 feet
		7 feet	1x6	Wood Board	1 @ 8 feet
		1	Tube	Loctite Green, Thread Locker	
			Use to lock nuts into place		
		30	608 (22x8mm)	Skate Bearings	
			2 per leadscrew (6)		
			4 for each truck (24)		

Note: One roll of plumbing hanger tape can replace the 1/2 inch EMT clamps and the 4 inch band clamp.

For the router's mounting strap, the hanger tape is easier to use than a four inch band clamp. Near right image.
See page 77 before purchasing a band clamp.

Router band clamp made of plumbing hanger tape.



1/2 inch EMT clamps and plumbing tape.

Purchasing Notes

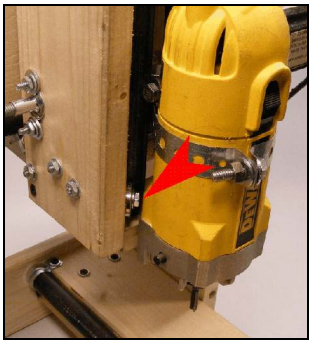
This information addresses alternatives to the sizes and dimensions listed, and gives reasons for the sizes that are used.

Machine Screws

The #10-24 thread size is used everywhere to keep the parts inventory simple. Also, a lot of nuts are required, and buying one size in bulk can lower the overall cost.

All #10 screws can be replaced with #8, but #10 is much better for the bearing axles.

The bearing axles are listed as #10-24 x 1 inch. This length will work well with all of the bearings except for the bottom front Z bearings.
These two bearings are close to the router and require a 3/4 inch axle.
A 1 inch axle will scrape the router.
All of the bearing axles can be 3/4 inch long.
However, the thickness of the bearings, washers, and nuts will vary, and a 3/4 inch long screw may be a little short to easily use. A bearing washer can be left out if needed.


Bottom Z bearings are close to the router body.

The #10-24 x 3 inch screws used to hold the steppers and Y leadnut block can also be #8. #10 will flex less, but the heads of #10 may not fit in the space around the holes in some of the steppers. The #10 head may have to be filed down to fit in the stepper.

Using the smaller diameter #8 screws to hold the leadnuts will require smaller 9/64 inch holes where the screws are threaded into the wood for the leadnut supports. The holes in the plans are sized for #10 and are listed as 5/32 inch.

Flat Head Machine Screws

These are used to hold the aluminum bearing truck angles to the wood.

Screws of 1-1/2 inches are barely long enough. 1-3/4 inch flat head screws may be hard to find locally, and on the Z axis the longer screws will protrude from the sides of the carriage and may be a nuisance.

Flat head #10-24 x 1-1/2 may be locally unavailable; #10-32 will work, but of course will require #10-32 nuts.

#10 Washers

The total of 126 is listed, but they are sold in boxes of 100. Not all listed washers are needed. One per tension rod and one per truck bearing can be removed.

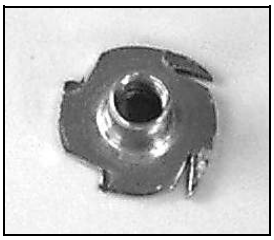
The washers are necessary with the nuts for the flat head screws that support the aluminum truck angles, and washers are very helpful with the stepper mounts.

Using finish washers with the drywall screws on the X gantry and Y rail supports will give a cleaner appearance, and further lessen the #10 washer count by 12 pieces.

5/16-18 Tee Nuts

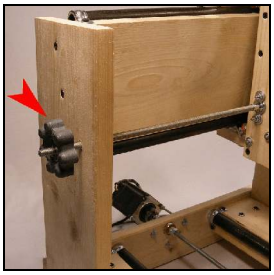
Tee nuts are used as leadnuts, and can be used with the optional leadscrew knobs.

Tined or pronged tee nuts will work instead of the flat flanged ones shown in the construction photos. The tines will have to be bent or removed from the tined nuts so the washers can seat properly against the tee nuts.



Bent and removed tines on tee nut.

Three tee nuts are required as leadnuts. Two others can be inserted into optional homemade knobs that are attached to the ends of the X and Y leadscrews.



Knob on gantry leadscrew.

Knobs

An old volume knob or similar can be attached to the top of the Z stepper to permit easier hand jogging. These knobs can be used with the other two steppers also. This would negate the need for the homemade knobs on the leadscrews.

Knob on Z stepper.

The large diameter of the homemade knobs makes them easier to use than most volume knobs.

The directions with a g-code for the homemade knobs are on the website's Hold Downs page.

Threaded Rod

The #10-24 rod is strong enough for the Z's 5-1/2 inch, and the X's 10-1/2 inch tension rods, but 1/4 inch rod can be used in its place, though the holes in the wood will be tight.

The #10 rod will not work inside the Z rails where 1/4 inch rod is specified in these plans. The tension here is quite high and the smaller rod may twist or strip threads.

5/16-18 rod can be used in place of the 1/4-20 rod inside the Z rails.

5/16-18 is used for the leadscrews because it is easily found, fits well in skate bearings, and does not whip in the lengths used on this machine.

5/16-18 threaded rod is used for the Y compression rod because it is large enough to take the load without buckling.

5/16-18 rod can not easily be used in place of the #10 rod because the clearances are tight.

The 5/16-18 rod can be as short as 18 inches for the Y and X leadscrews, 5-1/4 inches for the Y compression rod, and 5-1/2 inches for the Z leadscrew. These minimum lengths will permit a 4 foot threaded rod to provide all of the 5/16-18 stock. Note that the 18 inch long leadscrews will not be long enough to support the optional knobs.

The rod is usually available from home centers in 3 foot rather than 4 foot lengths, so two 3 foot rods will probably have to be purchased.

Drywall Screws

1-5/8 inch drywall screws and #8 finish washers.

1-5/8 inch coarse thread is a compromise length.

One inch screws will work with the EMT clamps.

The screws that are driven into the end grain of the boards (table frame and gantry ends), and the screws that hold the table bed to the legs, can be over 2 inches long.

1-5/8 inch screws protrude through two 3/4 inch boards (rail supports) but 1-1/4 inch screws are too short for the rail supports. However, the preferred length of 1-1/2 inches may be unavailable locally.

A one pound box of coarse thread 1-5/8 inch drywall screws will work well enough for all of the wood screws in this machine. There will be many screws left over from the pound box.

1/2 Inch Black Iron Pipe

The pipe is sold as gas pipe, black pipe, iron pipe or any combination of those terms.
It is painted black, and is sold in the plumbing section of home centers.

Rigid electrical conduit is very similar and can also be used, as can galvanized plumbing pipe.

The quality and prices of these options will vary; it is worthwhile to comparison shop.

Note that the black paint and the galvanization of the different types of pipes will all wear with use. This has not been an issue. A little sanding or filing can remove minor pits and scratches.

The pipe size is called 1/2 inch. Its inside diameter is a little more than 1/2 inch and its outside diameter is around 7/8 inch.

The plumbing pipe is sold in sections of varying length from a few inches to 10 or more feet.
The machine requires at least 92 inches. Usually the best value at home centers is to buy a 10 foot section, and to cut the pieces to length.

The stores often will cut the pipe for free or for a small fee. It also can be cut with a hacksaw.

The X and Y wooden rail supports are 16 inches long. The pipe should be cut a fraction shorter than 16 inches so the pipe will not keep the end plates from abutting the rail support boards.

The length listed in these plans is 15-7/8 inches. The pipe can be as short as 15-1/2 inches, but longer pipe will give more stock for the EMT clamps to grasp.

The pipe will probably be threaded at each end. The threads can be cut off, which is preferred, but the threaded section can be left on the pipe. The clamps will cover most of the threaded portion of the pipe, so the threads will only be hit by the bearings at the extreme of the axis travel.

The Z axis' carriage is capable of more travel than the height of the gantry permits. With longer rails, the full travel could approach a foot before the pipes flex too much while cutting soft stock. However, to reduce chatter, it is better for the router to work as close as possible to the Z bearings.

On this machine the travel from carriage bottom to the table top is around 4 inches.

Pipes of 14 inches will barely permit this travel.

The four inch travel distance was chosen so the router could extend low enough to trim the edge of the table top while raising high enough to cut 1-1/2 inch stock. The travel also makes it easier to change router bits while stock is attached to the table bed.

It is not a problem for the Z pipes to be longer, and it is possible for all pipes to be the same length of 15-7/8 inches.

However, 15-7/8 inch Z pipes will require threaded rods that are nearly 18 inches long. This would require an entire 3 foot length of rod, which will not leave enough stock for the router cradle.

The router cradle requires 1-1/2 inches of 1/4 inch rod. A full-thread bolt can be used for the cradle in place of the section of threaded rod, but full-thread bolts can be hard to find locally. Therefore, these plans state 15 inches for the Z pipes, so a single 3 foot rod can be used for all 1/4 inch threaded rod stock.

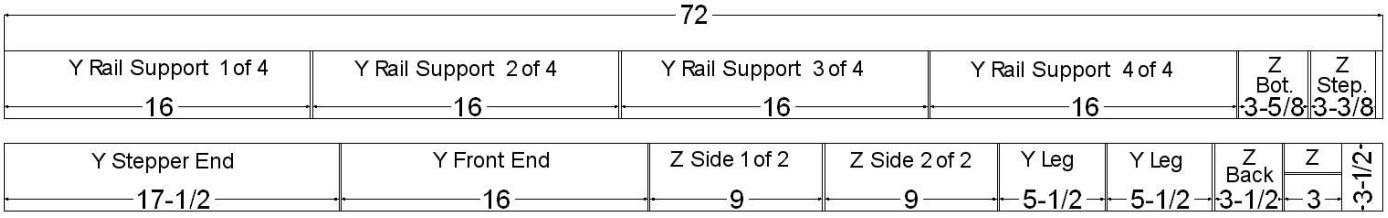
Wood

The machine was designed to use standard 1x4 and 1x6 boards. The boards' actual dimensions are 3/4 x 3-1/2 inches, and 3/4 x 5-1/2 inches.

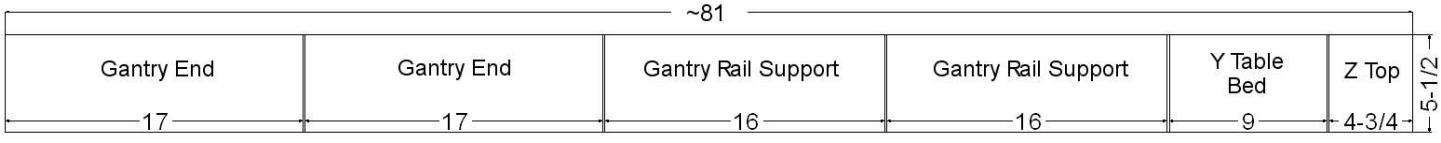
The 1x4 components require 12 feet of stock. As shown below, the pieces can be cut from two 6 foot long boards. Two standard length 1x4 by 8 foot boards will serve well. The extra stock will permit the boards' blemishes to be avoided.

The 1x6 components require 81 inches, less than 7 feet, of stock. Again, a standard sized 1x6 by 8 foot board will serve well.

Both total lengths shown below (72 and 81 inches) allow 1/8 inch kerf between pieces. The kerf is the wood that is removed, turned into sawdust, by the saw blade.



Cuts in 1x4 stock. The wood is 3-1/2 inches wide and 3/4 inch thick.



Cuts in 1x6 stock. The wood is 5-1/2 inches wide and 3/4 inch thick.

1x4 Parts		Actual Size 3/4 x 3-1/2 Inches
✓	Length	Parts Listed by Length
	17-1/2	Y Axis Stepper End
	16	Y Axis Front End
	16	Y Axis Rail Support 1 of 4
	16	Y Axis Rail Support 2 of 4
	16	Y Axis Rail Support 3 of 4
	16	Y Axis Rail Support 4 of 4
	9	Z Axis Side 1 of 2
	9	Z Axis Side 2 of 2
	5-1/2	Y Table Leg 1 of 2
	5-1/2	Y Table Leg 2 of 2
	3-5/8	Z Carriage Bottom
	3-1/2	Z Carriage Back
	3-3/8	Z Stepper Support
	3 See Note Below	Z Router-Rail Support & Y Leadnut Block
1x6 Parts		Actual Size 3/4 x 5-1/2 Inches
	17	X Gantry End 1 of 2
	17	X Gantry End 2 of 2
	16	X Gantry Beam 1 of 2
	16	X Gantry Beam 2 of 2
	9	Y Table Bed
	4-3/4	Z Carriage Top

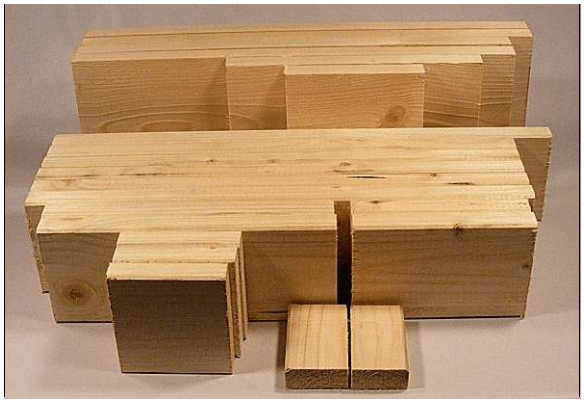
NOTE:
Cut to 3 inches long. Then make one rip cut that leaves two pieces. One piece is 1-1/2 inches and the other is 1-7/8 inches. The lost 1/8 inch is the kerf. (1-1/2 in. + 1-7/8 in. + 1/8 in. = 3-1/2 in.)

A rip cut is a cut that is parallel to, rather than across, the wood's grain.

Wood Cut List

The table on the left is a check list for cutting the stock.

It can ease construction to mark the length of the stock on the pieces as they are cut. Some parts are close to the same length, but the slight differences do matter.



Boards cut to length. Note the 3 inch section of 1x4 is ripped into two pieces.

Threaded Rod and Pipe Lengths

5/16-18 Threaded Rod	
X Leadscrew	20 inches
Y Leadscrew	20 inches
Y Compression Rod	6 inches
Z Leadscrew	7 inches
1/4-20 Threaded Rod	
Z Pipe Tension Rods	2 at 17-1/4 inches
Router Cradle	1-1/2 inch
#10-24 Threaded Rod	
Z Side Tension	3 at 5-1/2 inches
X Tension	10-1/2 inches

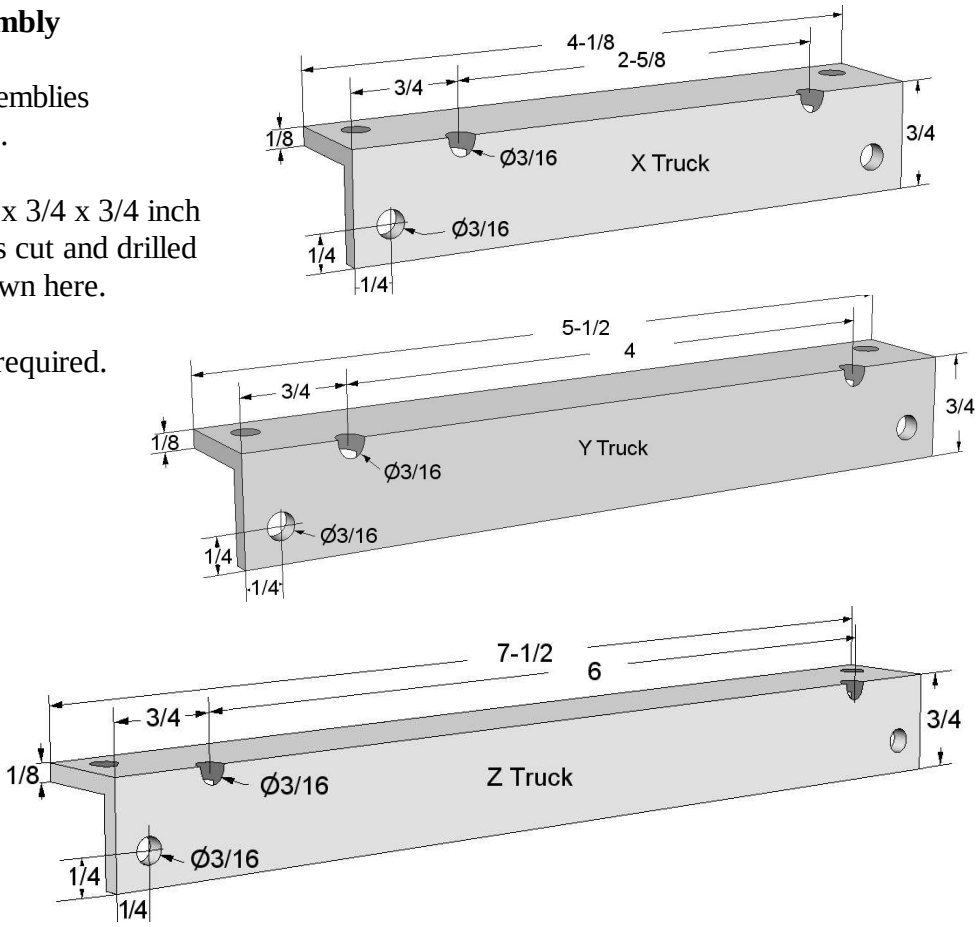
1/2 inch ID Pipe	
X Rails	2 pieces at 15-7/8 inches each
Y Rails	2 pieces at 15-7/8 inches each
Z Rails	2 pieces at 15 inches each

Bearing Truck Assembly

The bearing truck assemblies are similar for all axes.

They are made of 1/8 x 3/4 x 3/4 inch aluminum angle that is cut and drilled to the dimensions shown here.

Two of each size are required.



The stock is cut to length with a hacksaw. A vise helps considerably, but the cutting can be done by holding the metal on the edge of a work surface as shown.

The aluminum angles are cut to length.

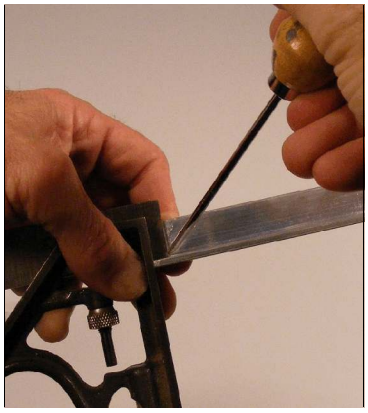
Cut the aluminum with a hacksaw.

The holes that are 1/4 inch from the corners are scribed, punch-marked, and drilled.

It is easier to work on the inside of the angle so it can be laid flat on the work surface for drilling. Far right middle image.

Set the combo square at 1/4 inch, and scribe the 1/4 inch marks from the edges and ends. Right images.


Scribe1/4 inch from the edge.

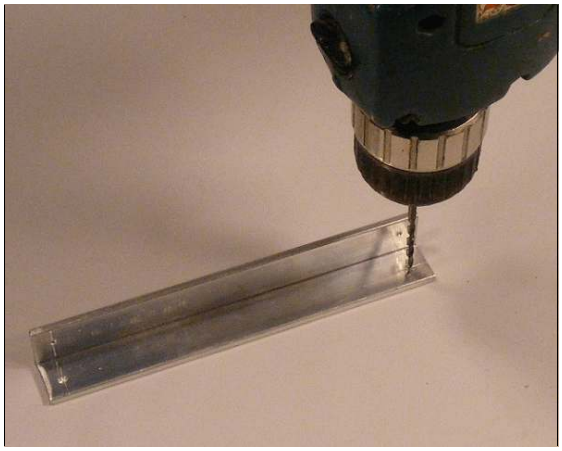

Scribe1/4 inch from the end.

Use a punch to mark where the scribed lines cross, then drill pilot holes. A 7/64 or 1/8 inch bit can be used to drill pilot holes. The pilots will help to keep the 3/16 inch bit from wandering. Images below.

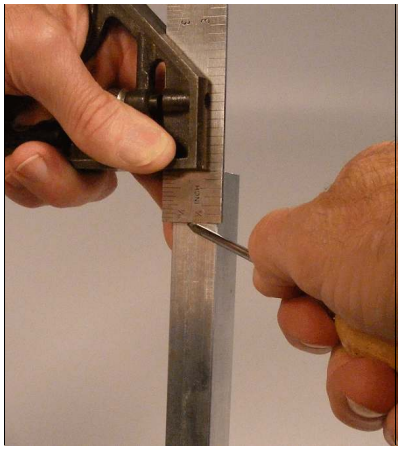
Next, scribe the marks for the holes that are 3/4 inch from the ends of the pieces. Left image below.

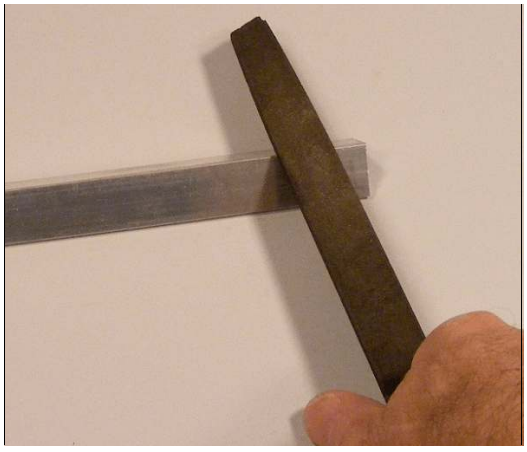
To make punching and drilling these corner holes easier, file or sand flats on the corner of the aluminum at the 3/4 inch marks. Far right image below.


Punch at the marks' intersection.

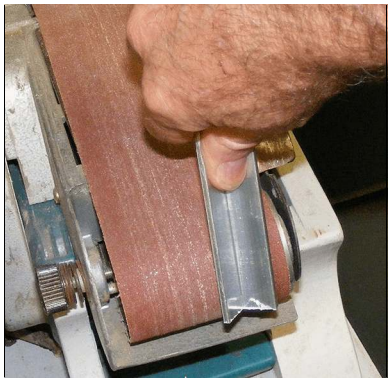

Drill the holes; drill a small pilot hole first.

A belt sander can be used instead of a file. Next page.


Mark the positions of the holes that are 3/4 inch from the ends.


File a flat on the edge at the 3/4 inch mark.

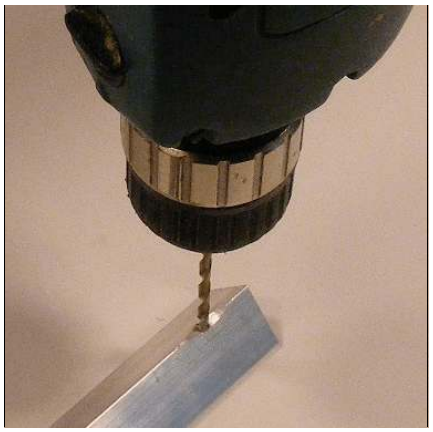
A file will work, but the roller end of a belt sander makes quick work of creating the flat sections.

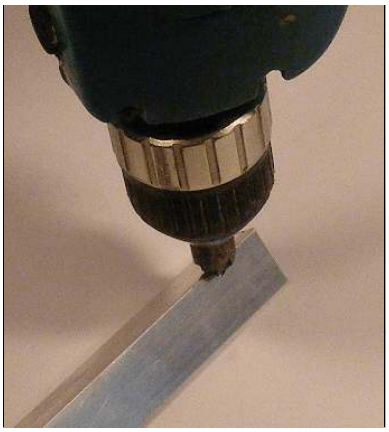

A belt sander quickly flattens the corner edge.

Punch-mark the holes' locations at the scribed marks. Lower left image.

Drill the holes. Use a small pilot bit for the first holes, then enlarge the holes to 3/16 inch.
Countersink the edge holes so the head of a #10 flat head screw does not protrude beyond the corner of the aluminum. Right image, page bottom.

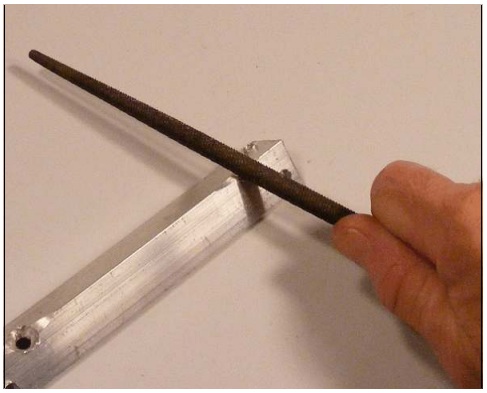

Punch on the filed flat section.

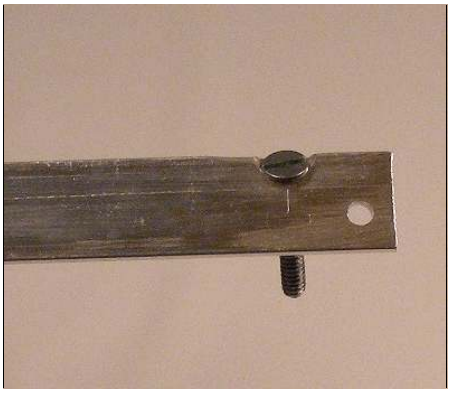

Drill the hole at the 3/4 inch mark.


Countersink the hole for the flat head screw.

The screw head will scrape the pipe rail if the head stands proud of the corner.

The countersink or depression can be made with a larger drill bit, a countersink bit, a hand file, a grinder, or a power sander.


Make a depression for the screw-head on the corner of the aluminum.

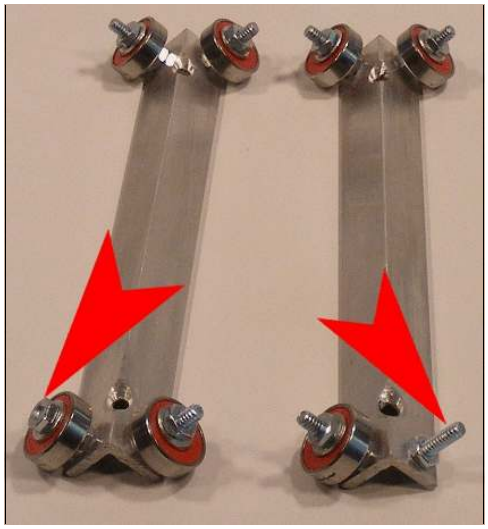

Machine screw's head should not extend above the angle's corner edge.

The countersunk recess does not have to be pretty to serve its purpose.
Be careful not to drill too deeply when using a drill bit, rather than a countersink bit, to make this recess.

If the larger drill bit does tear completely through the aluminum, use a washer with the machine screw, and enlarge the recessed area to fit the washer. It should not be necessary to re-make a new part.

Install #10 x 3/4 or 1 inch machine screws in the holes that were drilled in the legs of the aluminum angle.

Machine screws of 3/4 inch will usually work for all axes on this machine.



Install machine screws, nuts, washers and bearings. The lower outside screws on the Z trucks must be 3/4 inch. Arrows indicate the 3/4 inch screws' positions.

The Z trucks have to use 3/4 inch screws on the bottom bearings that will be near the router. Arrows in above image. Longer screws will hit the router.

Tighten the screws into place with nuts.
Then install a washer, a bearing, another washer, and a nut.

Adjust the bearings so they hold the angle away from the pipe rail. Above right image.

There should be at least 1/16 inch of clearance between the pipe and the corner of the aluminum angle.

All six of the truck assemblies can be made at one time.

Adjust the bearings on the #10 axle screws so the angle clears the pipe. Red arrow.

Make all of the truck assemblies.

Band Strap Anchor

The total length of aluminum angle required for the trucks is 34-1/4 inches. When a 36 inch section of stock is used, the remaining piece can be used as the router's band anchor.

A 1/4 inch hole is drilled in the center of this remnant.

A piece of 1/8 x 3/4 aluminum angle between 3/4 and 2 inches long will work for this component.

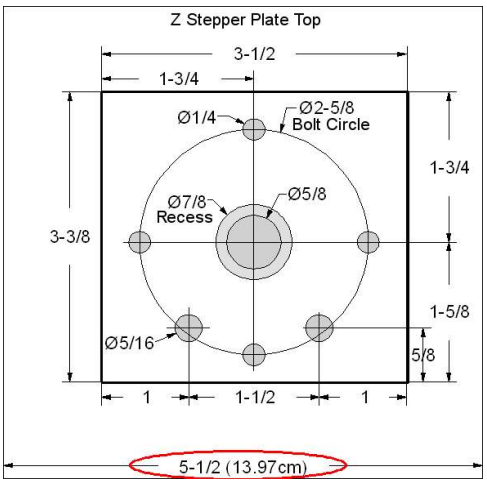
Band strap anchor.

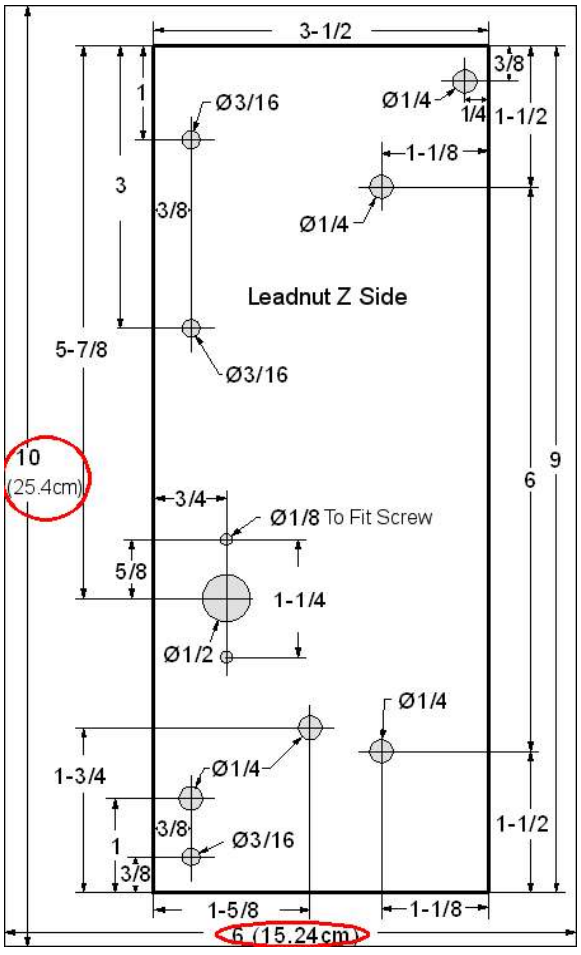
Using the Templates

The templates are scaled to print at the correct size. However, different printers will scale differently.

To address this inconsistency, each template is framed in a box that includes a dimension value in both inches and centimeters. This dimension is at the bottom or side of the templates; the dimensions are circled in red in the right and lower images.

When the framing box is not a square, a second dimension is also given in the framing box as shown in the image below.





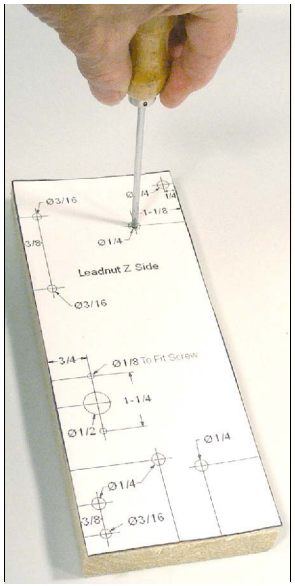
Note that the entire framing box may not appear when the image is viewed on a computer screen. It should be visible when printed, or when the image is enlarged on the screen.

The dimension of the framing box can be measured after the template is printed. The printer's scaling can then be altered to properly size the template. This will be a trial and error process, and will vary with each printer and computer.

The templates should be correctly scaled when the framing box is properly scaled.

The templates can be cut-out and taped, glued, stapled etc. to the top of their boards.

An awl, punch or nail can be used to mark the position of the holes. Right image.



Punch marks into wood through the template.

Y Rail Support

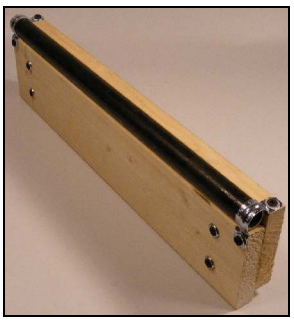
The rails are supported by four 1x4 x 16 inch boards. The two top boards require the holes that are shown here. The other two boards are not drilled at this time.

There is no template for these two pieces; using a template is more trouble than it is worth.

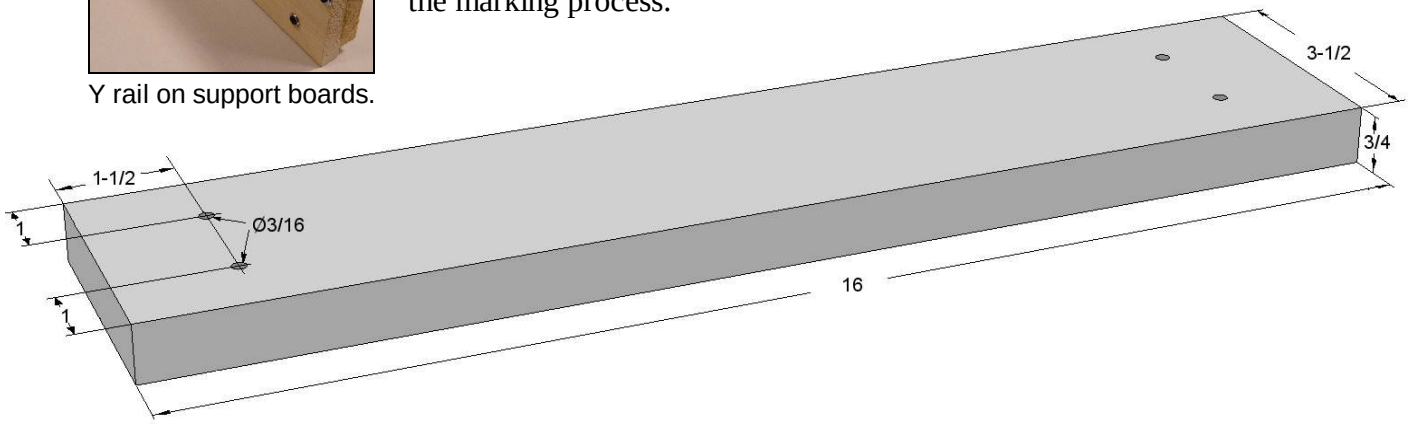
The holes are positioned the same at each end of the two boards.

The holes are 1 inch from the edges, and 1-1/2 inches from the ends.

Using a combo square set at 1 inch and then at 1-1/2 inches speeds the marking process.



Y rail on support boards.

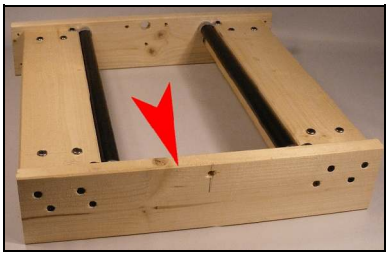


Y Front End Board

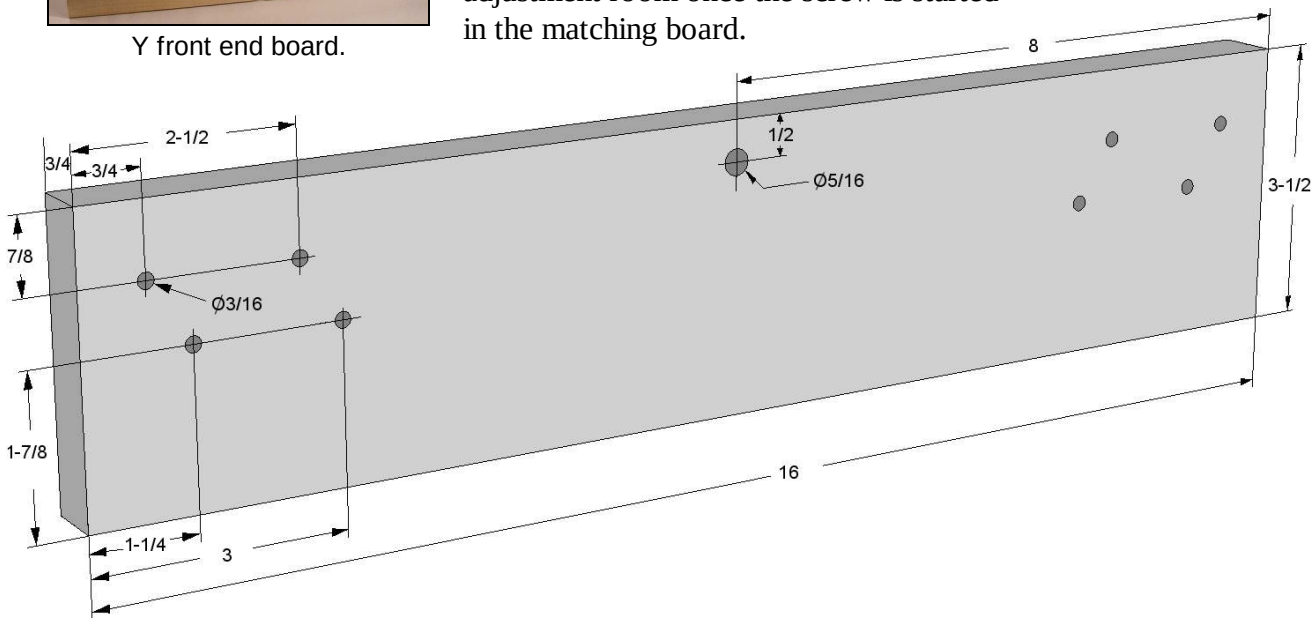
This board supports the two sets of Y rail supports, and the Y leadscrew.

The four holes on each end of this board are pilot holes for the screws that tie this board to the rail support boards.

These holes should be the diameter of the attaching screws. 3/16 inch holes are used with the drywall screws on the prototypes. The 3/16 inch hole is larger than the screw, and it leaves a little adjustment room once the screw is started in the matching board.



Y front end board.



The hole in the center section of the board is for the leadscrew, and it should be sized to allow the leadscrew to turn freely without rattling in the hole. The leadscrew will clean and enlarge the hole with use; therefore, it is not necessary to drill this hole oversized.

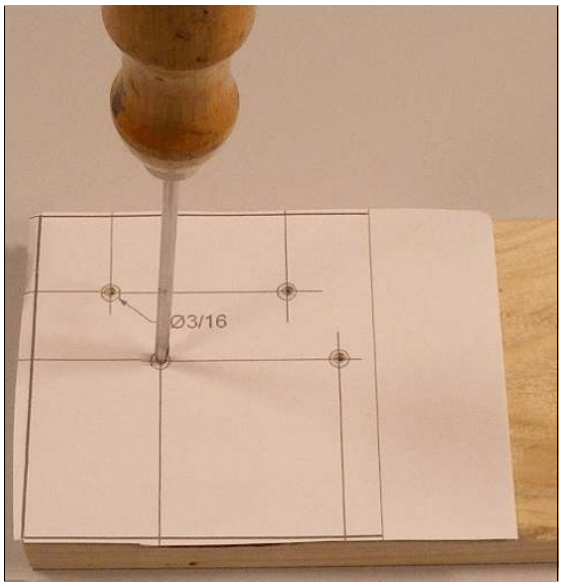
The center leadscrew hole does not have a template. Its center is 8 inches from the ends and 1/2 inch from the top edge of the board. Right image.
It is the diameter of the leadscrew, which is 5/16 inch in the prototypes.

The Y front's leadscrew hole is 8 inches from the ends.

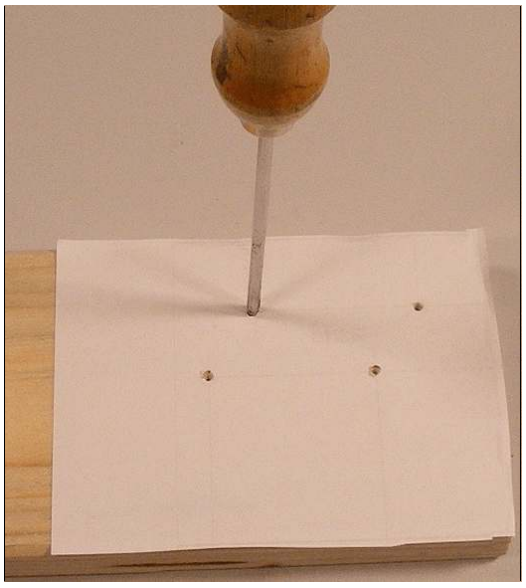
The holes in the ends of the boards are the same but mirrored.

The template can be flipped after it is used for the left end of the board. Images below.

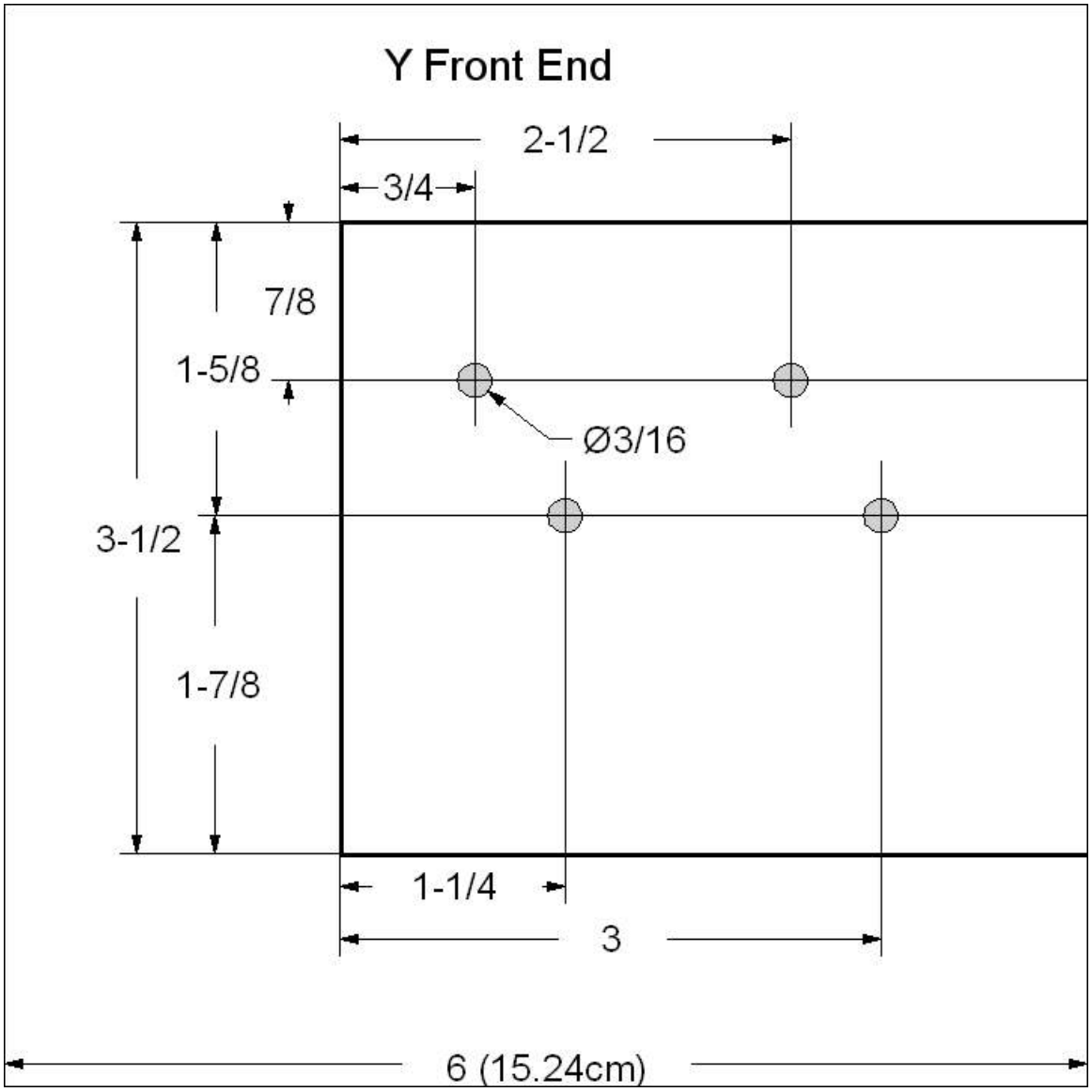
The punched holes in the template can then be used as guides for the holes in the right end.



Template with text side up.


Template flipped for right end of board.

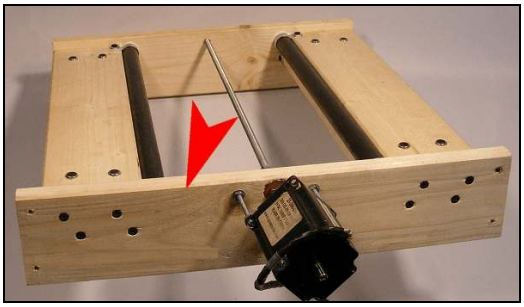
Y Front, End Template



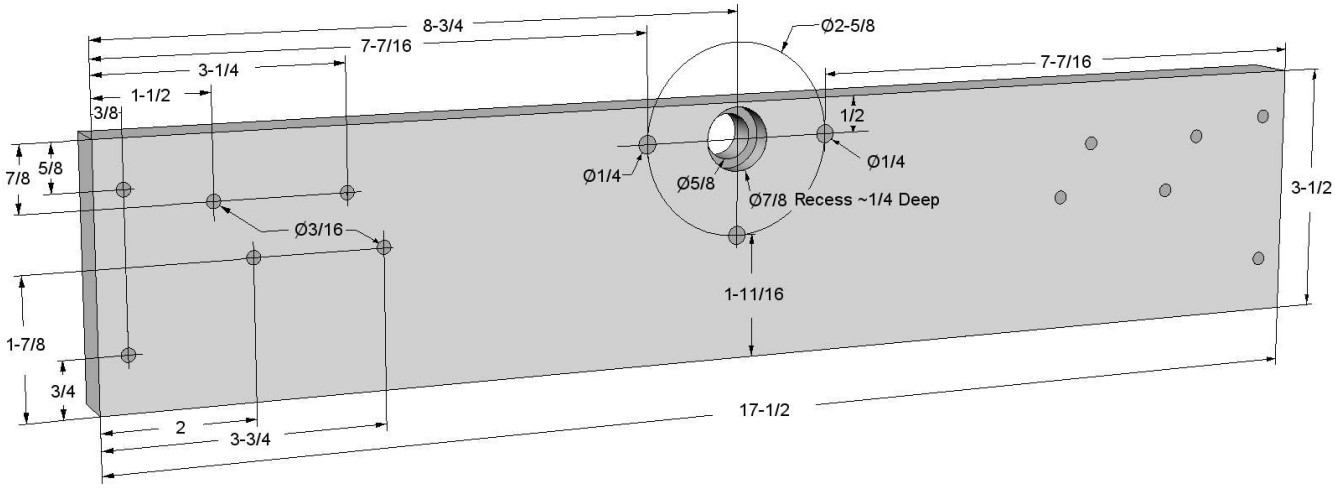
Y Stepper End

The back end of the table frame holds the Y stepper and the rail supports. It also supports the gantry ends, so it is longer than the front end of the table frame.

There are two templates for this board. One is for the stepper in the center section of the board, and the other template is for the screw holes on the ends of the boards.



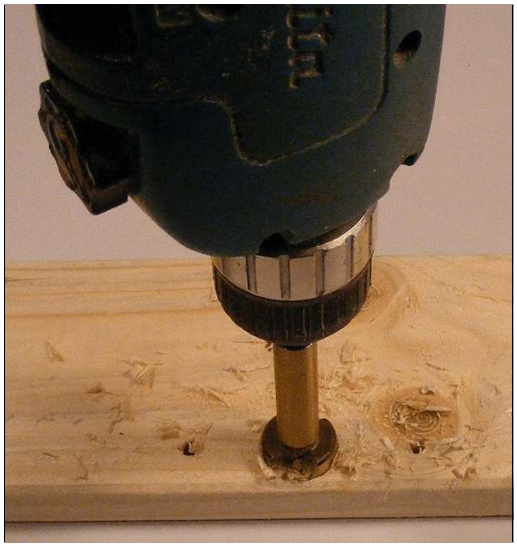
Y stepper end plate.



The 7/8 inch recess is for a bearing. The hole is drilled around 1/4 inch deep. The 5/8 inch hole is a through hole that leaves a shoulder for the bearing to abut.

The shallow 7/8 inch recess should be drilled first, then the 5/8 inch hole is drilled. Right images.

It is hard to center the larger recess when the smaller hole is drilled first.



Drill 7/8 inch recess first.

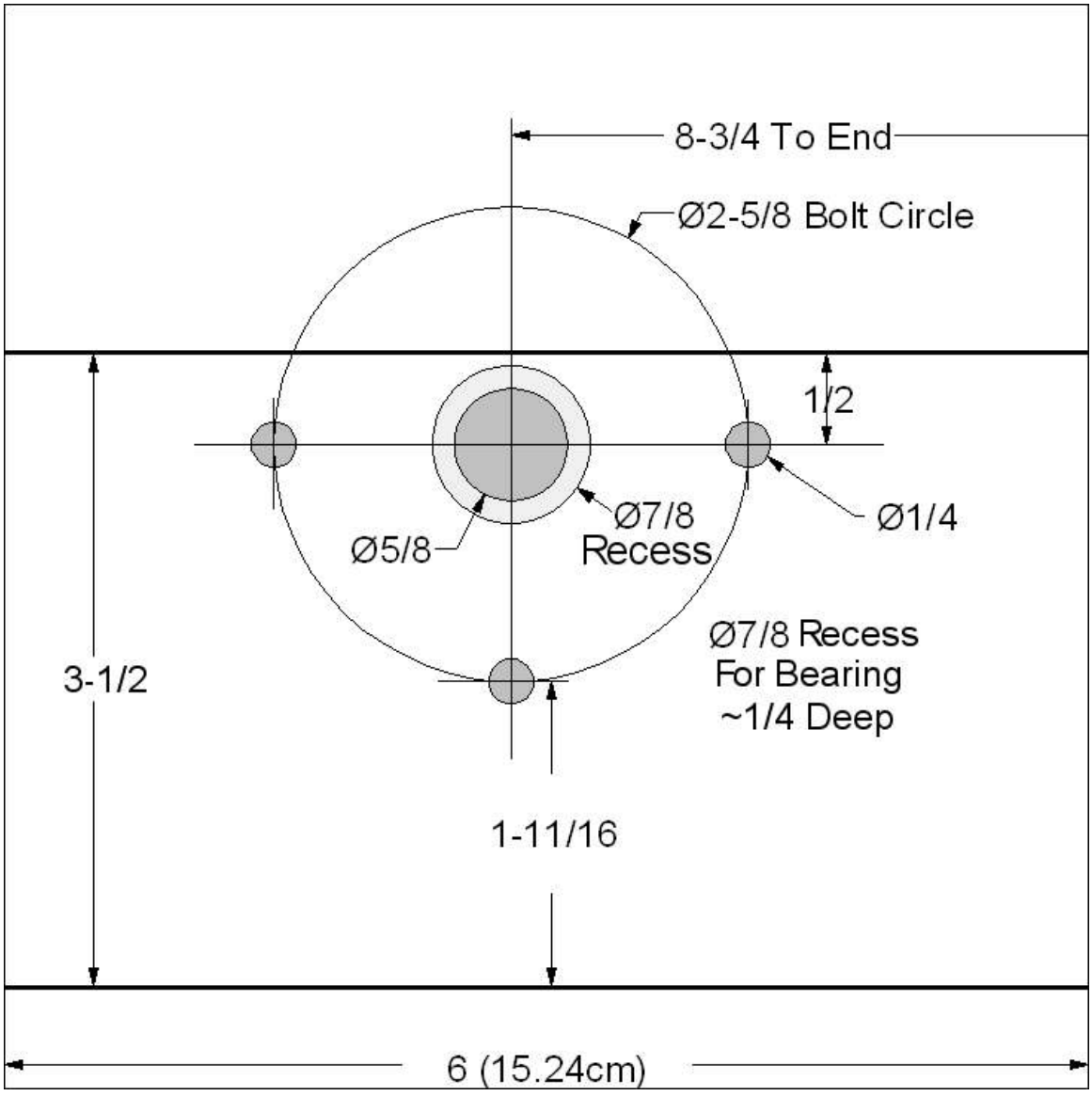
Drill the 5/8 inch through-hole last.

Y Stepper Template

The 2-5/8 inch bolt circle is shown for reference. This is the dimension for a NEMA 23 stepper's bolt holes.

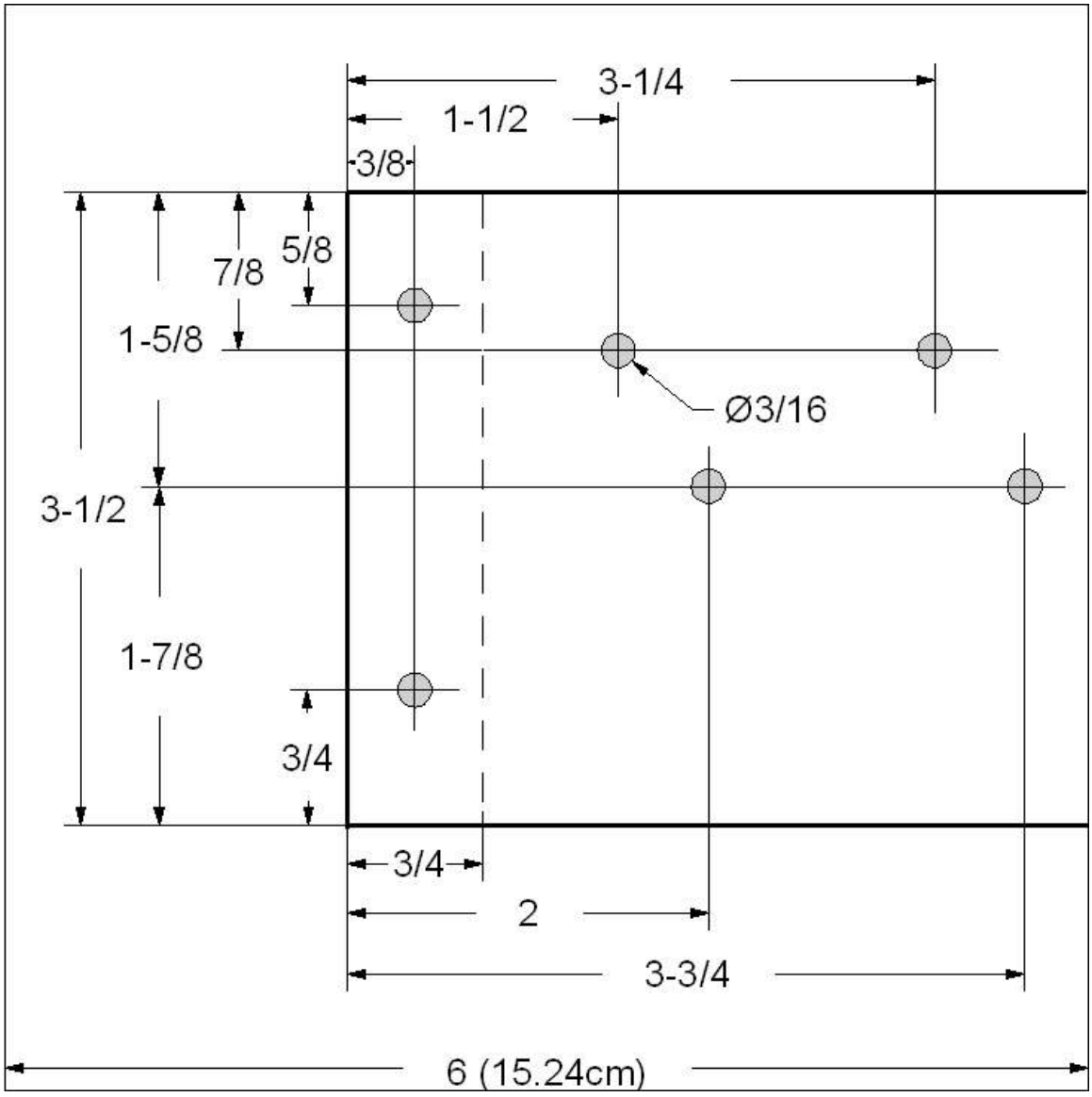
The holes for the stepper's attaching bolts are shown as 1/4 inch. These holes should be larger than the bolts or machine screws that hold the stepper, so the position of the stepper can be adjusted. Washers on the machine screws cover the oversized holes.

The center of the 7/8 inch bearing recess and the 5/8 inch through hole is 8-3/4 inches from the board's ends, and 1/2 inch from the board's top edge.

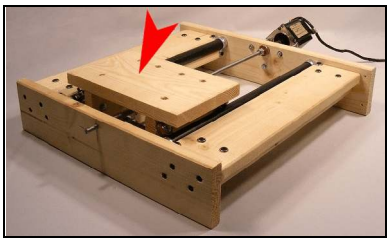


Y Stepper End Template

This template is for the screw holes that hold the Y rail support boards, and it is for the screw holes that support the gantry's vertical end boards.
The dashed line shows the position of the gantry end boards.
As with the front board template, this template is used for one end of the board and then flipped. The punched holes are used to mark the other end's holes.



Y Table Bed



Y table bed.

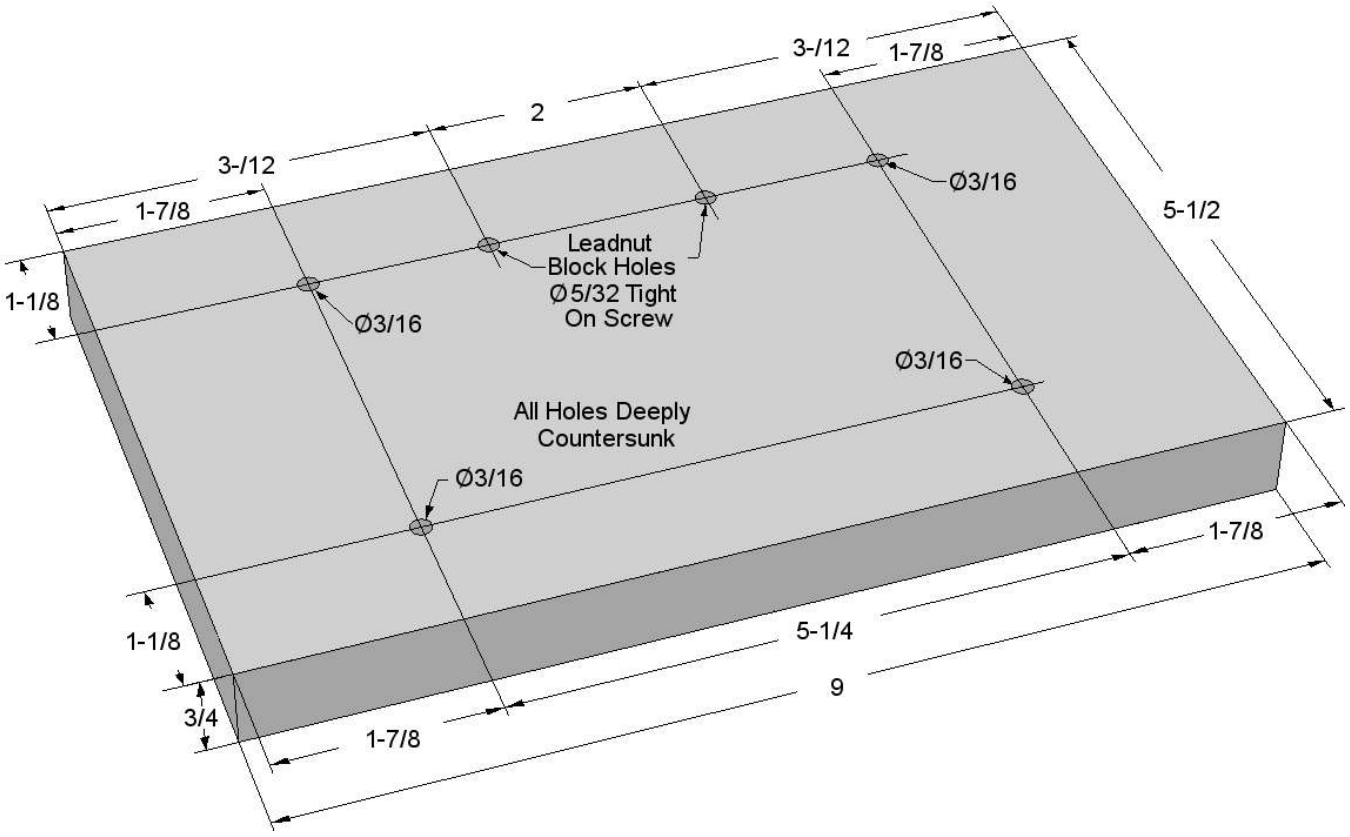
The table bed is made of a 1x6 that is cut to 9 inches long. The stock is 5-1/2 inches wide and 3/4 inch thick.

The hole locations are straightforward, and a template is unnecessary.

The surface of this board will be planed with a router bit when the machine is completed. This will ensure that the surface is level and true with the rest of the machine.

The surfacing may remove a lot of stock, so the screws should be deeply recessed or countersunk. A drill bit that is the diameter of the heads of the screws can be used to recess the holes after the through holes are drilled. The recesses should be at least 1/4 inch deep. This can be done with a 3/8 inch drill bit.

The two 5/32 inch holes should fit tightly around the machine screws that are in these holes. It will be much easier to adjust components when these two machine screws do not freewheel. The 5/32 inch diameter is for #10 machine screws. The holes can be 9/64 inch for #8 screws.

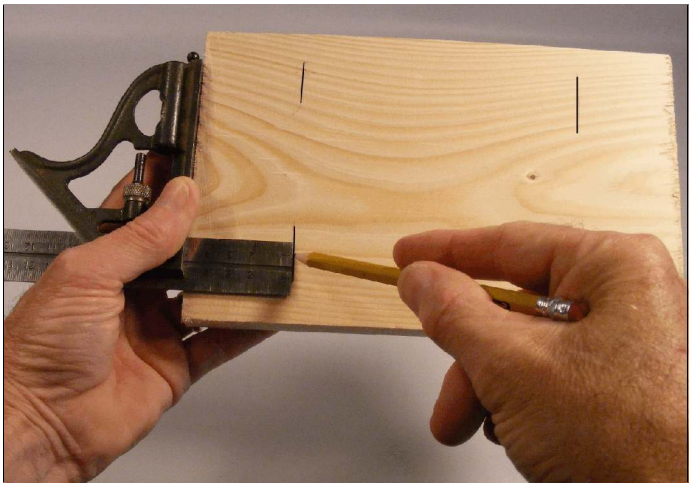


Measure, mark and drill the holes.

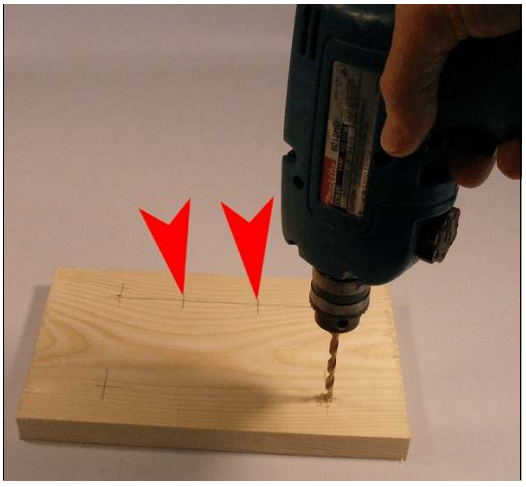
Setting the combo square to 1-1/8 inch, and then to 1-7/8 inch speeds the layout.

Punch-mark the layout lines' intersections, and drill the holes.

All of the holes have to be recessed around 1/4 inch deep.



Measure and mark the positions of the holes.



Drill the holes. The small holes near the center (arrows) should fit tightly around their machine screws.

The holes are deeply recessed.

After the holes are drilled and recessed, measure and draw a line on the bottom of this table bed that is 1-1/2 inches from the outside edge. The line can be on either edge. Right image.

This marks the outside of one of the legs, and will be used for alignment later.

The legs are made next.

Draw a line that is 1-1/2 inches from the outside edge of the board.

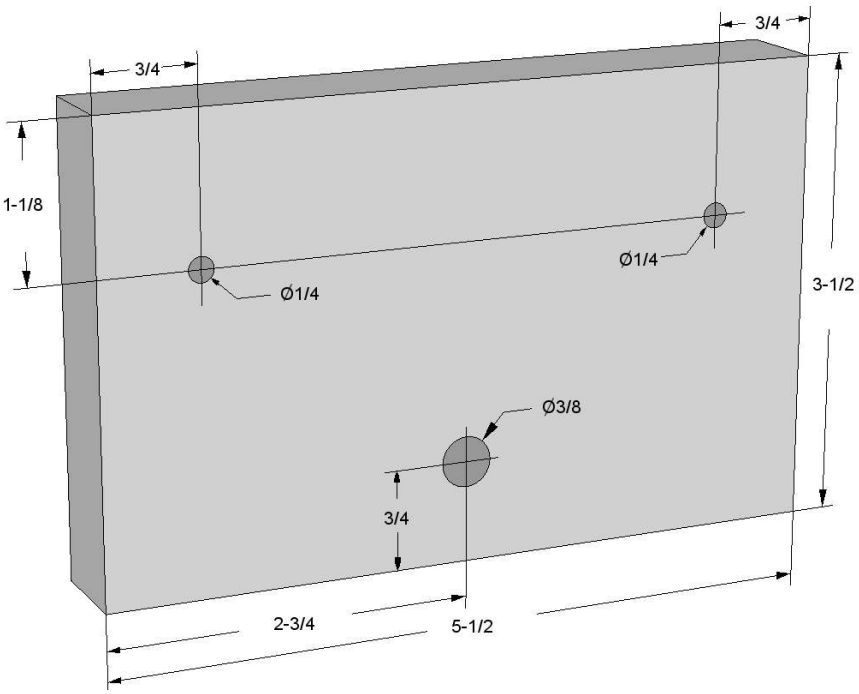
Y Table Legs

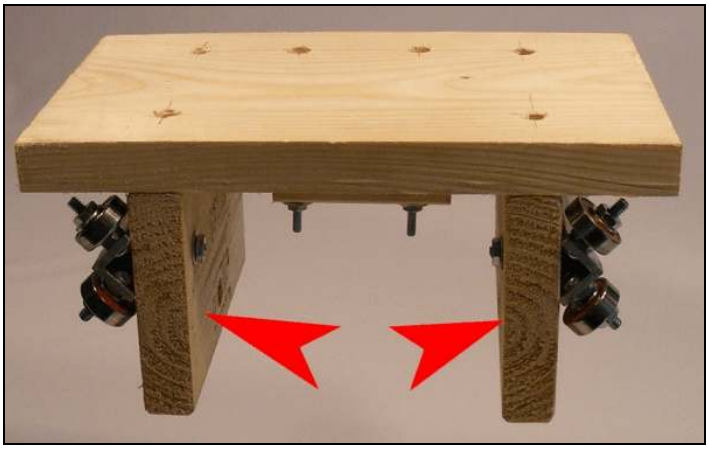
The two Y Table Legs are made of 1x4 stock that is cut to 5-1/2 inches long.
The stock is 3/4 inch thick and 3-1/2 inches wide.

These two legs are simple and do not need a template.

The 1/4 inch holes are oversized to allow for adjustment; they hold the Y bearing truck assembly.

The 3/8 inch hole is large to permit easy installation of the threaded rod (Y compression rod) that it supports.



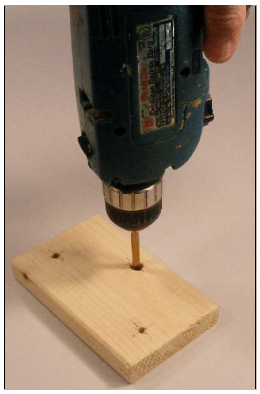


Legs on table bed.

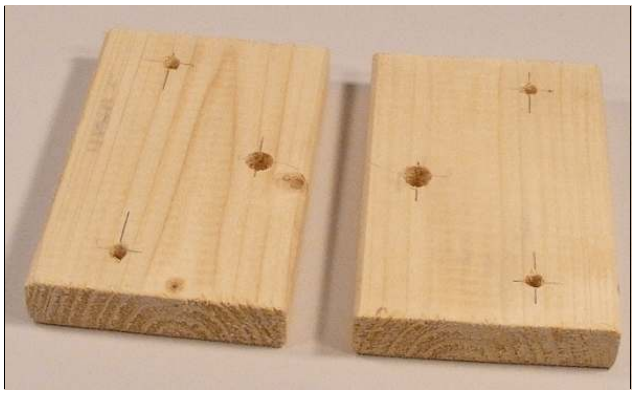
Measure and mark the hole locations.

Two of these pieces are needed.

Measure, mark, and drill the holes in the two 1x4 boards.



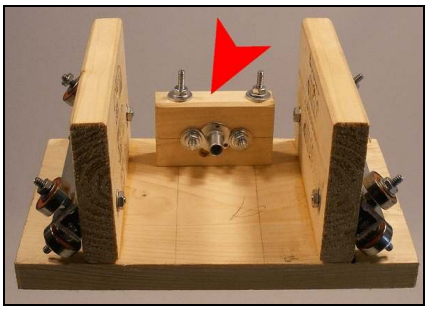
Drill the holes.



The two legs with their holes drilled.

Y Leadnut Support Block

The Y leadnut is supported by a wooden block that is attached to the bottom of the Y table bed.

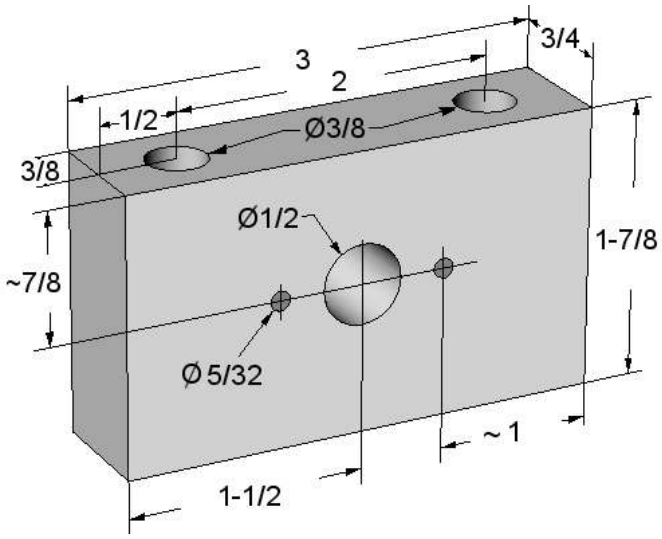


Leadnut support block.

This block of wood is cut from the 3 inch section of 1x4 that is ripped into two pieces. This block is the larger of the two pieces at 1-7/8 x 3 inches.

The two 3/8 inch holes in this block can be drilled before the table assembly begins. These two holes are oversized to permit adjustment.

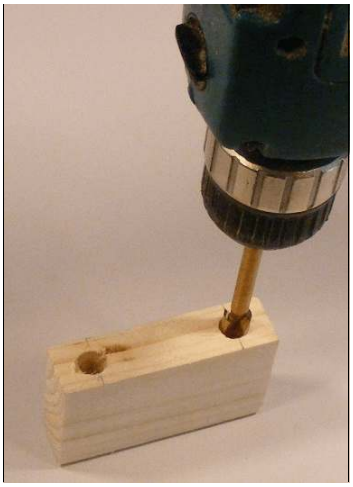
The holes for the leadnut and its supporting screws will be drilled later. These other holes will be marked during table assembly. These are the holes that are shown as ~7/8 inch from the top of the block in the right image.



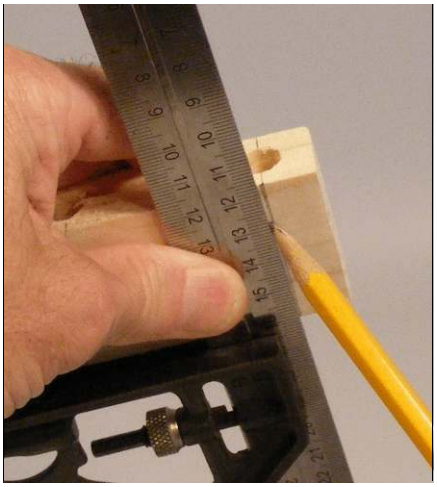
Drilling 7/64 or 1/8 inch pilot holes first will help to keep the 3/8 inch holes on course.

The pilot holes can be drilled from both the top and the bottom of the block. The holes will meet in the center of the block.

The 3/8 inch holes can be drilled after the pilot holes are drilled. The 3/8 inch holes, like the pilots, can be drilled from both the top and bottom edges of the block. The final drilled holes should be straight and clean.



Drill pilot holes and then drill the 3/8 inch holes entirely through the block.



Mark the center of the 3/8 inch holes on the side of the block.

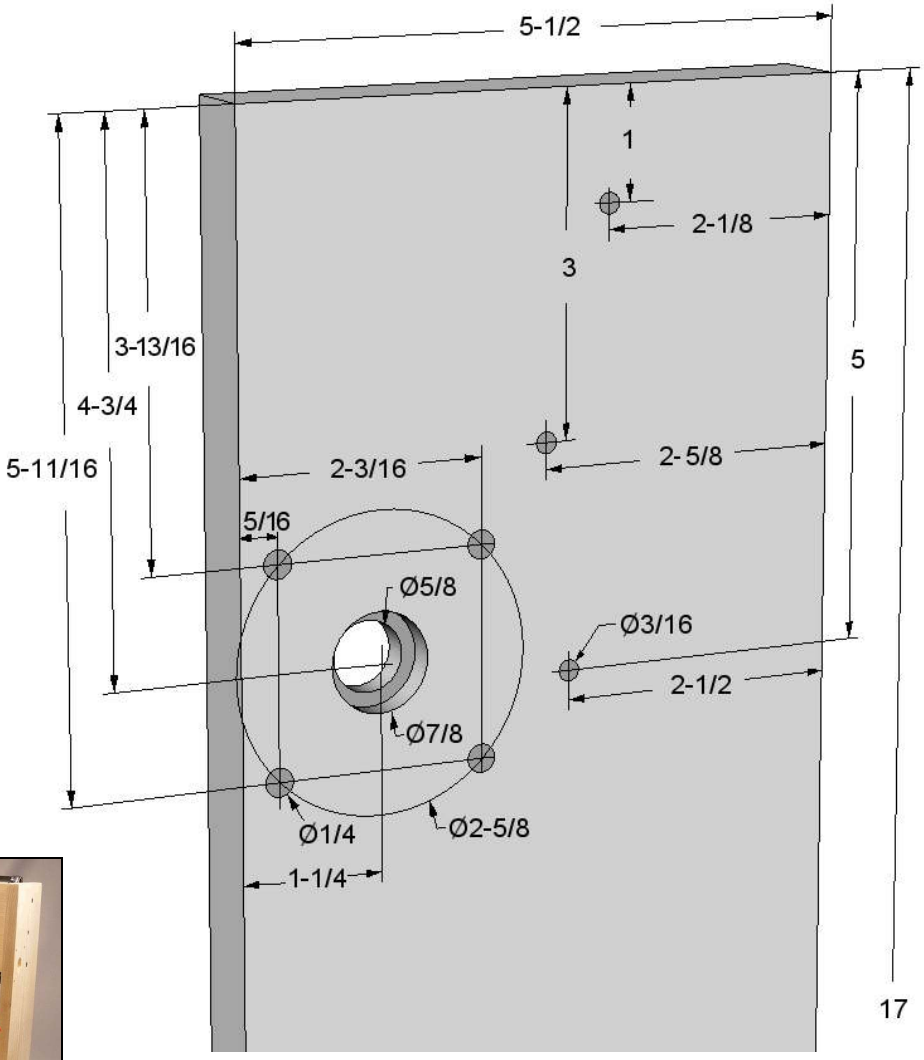
After the 3/8 inch holes are drilled, mark lines on the centerline of the holes on the side of the block. Far right image.
These lines will be used later to align the block on the bottom of the table bed.

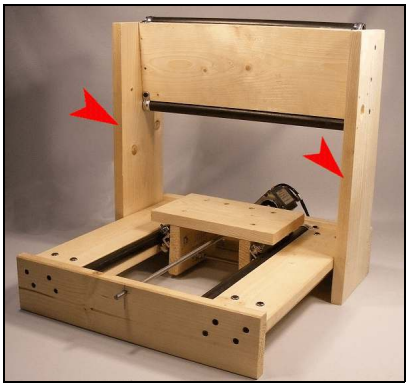
X Gantry End Plates

The ends of the gantry are 1x6 boards that are cut to 17 inches long. The stock is 3/4 inch thick and 5-1/2 inches wide.

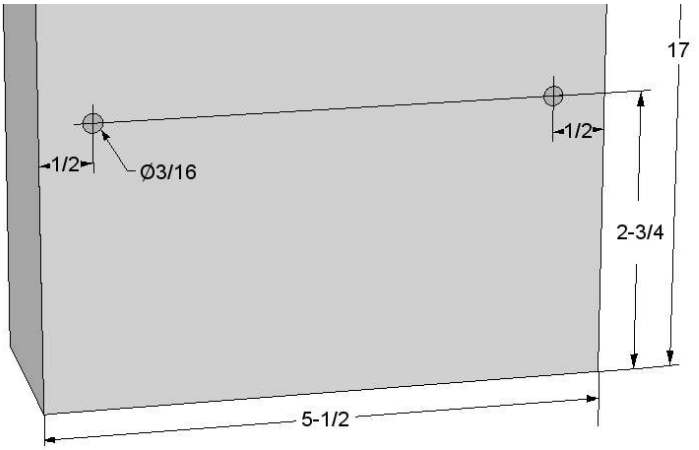
The stepper is attached to the right gantry end. As with the Y stepper end board, a leadscrew bearing is recessed into this board.

The holes in the lower right image are for the screws that attach the gantry end to the Y rail supports. The placement of these bottom holes is straightforward, and a template is not needed.





X Gantry end plates.

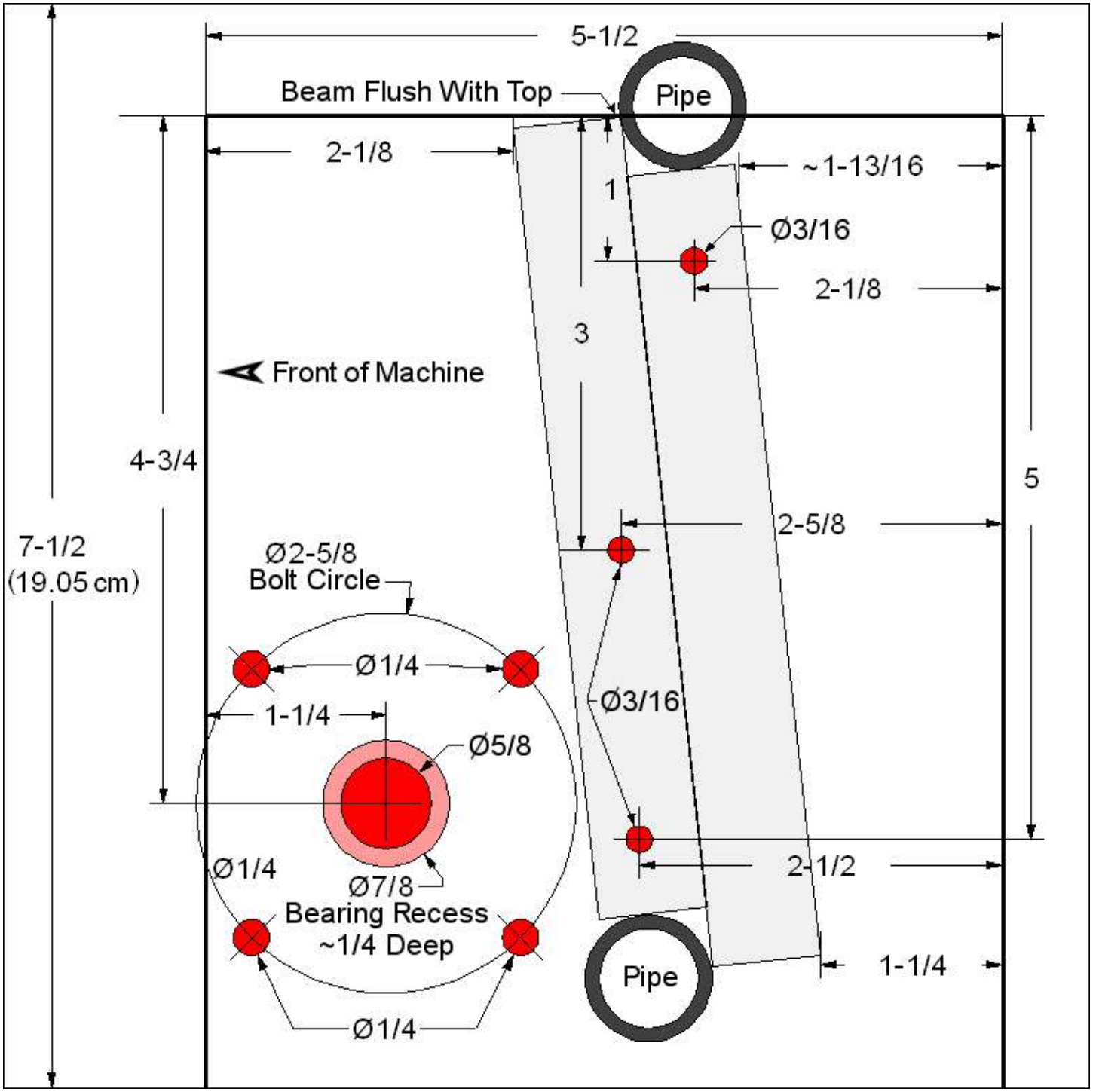


Gantry ends with holes drilled.

X Gantry, Stepper End Plate Template

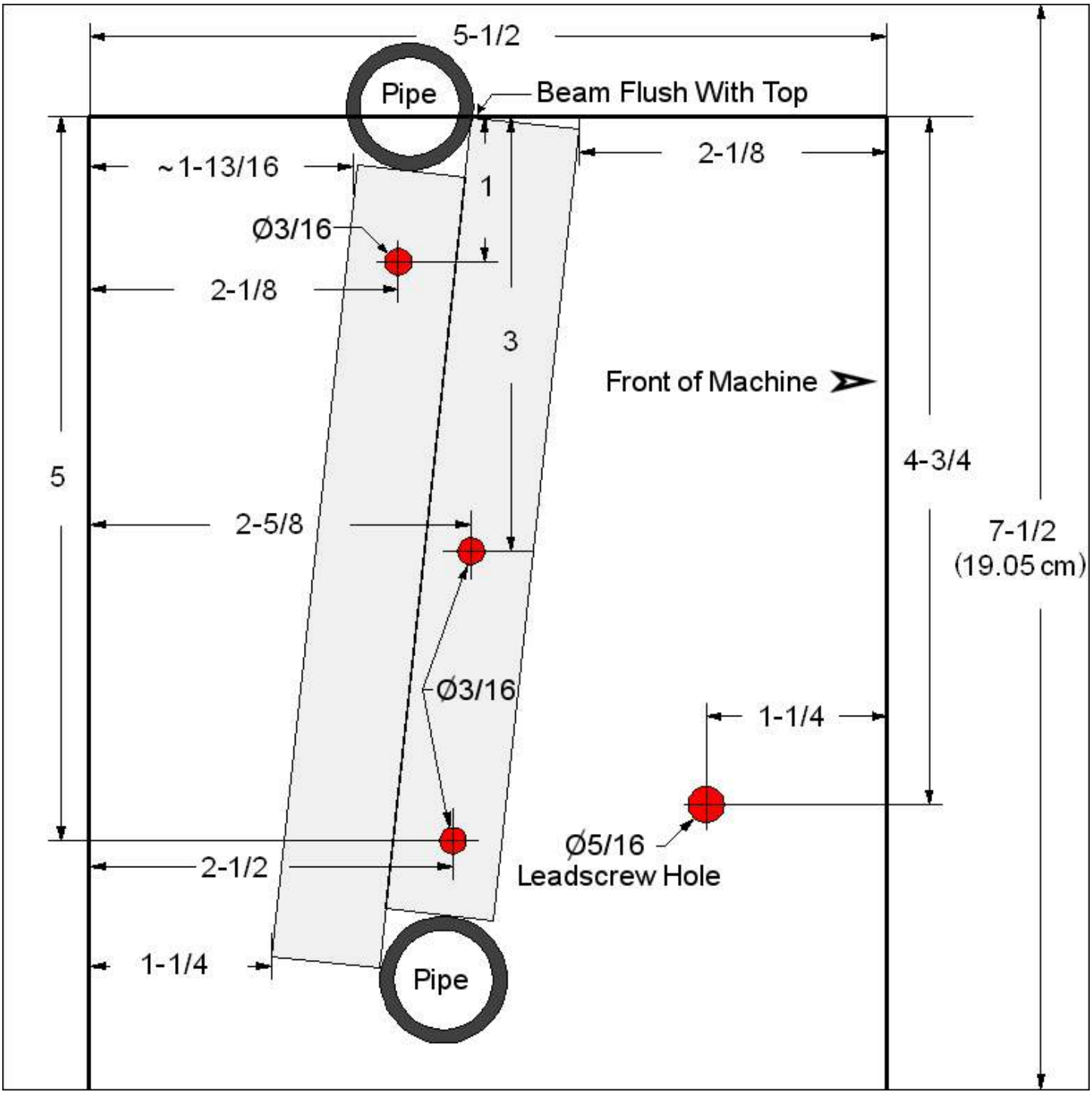
The template also shows the position of the gantry beam and its pipe rails.
For clarity, the recess and holes that should be drilled are colored pink and red.

This template's frame box is 7-1/2 inches square.



X Gantry Leadscrew End Template

This template is a mirror of the stepper end, with the exception of the stepper bolt holes and bearing. The leadscrew hole on this end plate should align with the bearing recess and hole on the other end plate.
The leadscrew hole, shown as 5/16 inch, should be the same diameter as the leadscrew.
For clarity, the holes that should be drilled are red.

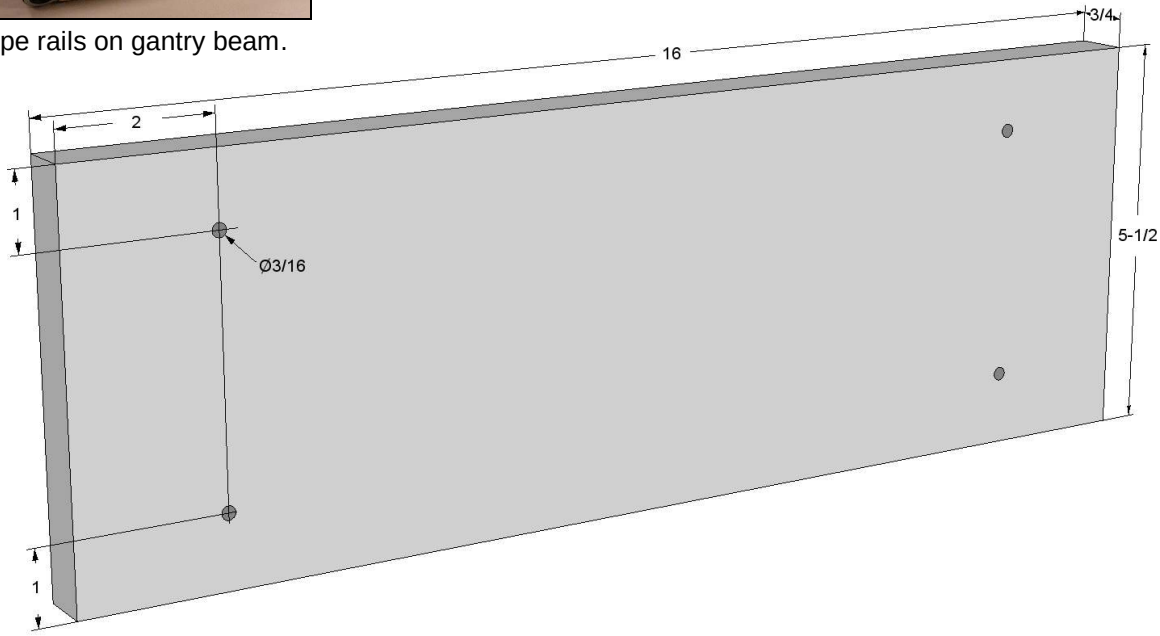


Gantry Beam

X pipe rails on gantry beam.

The gantry beam is 1x6 stock that is cut to 16 inches long. The stock is 3/4 inch thick and 5-1/2 inches wide. Two of these boards are screwed and glued together.
The four pilot holes are only drilled in one of the two gantry boards.

The holes are positioned the same at each end. Their placement is simple and a template is unnecessary.
The holes are 1 inch from the edge, and 2 inches from the ends of the board.



Mark the holes on one board and drill them with a 3/16 inch bit.

Mark holes.

Drill 3/16 inch diameter holes.

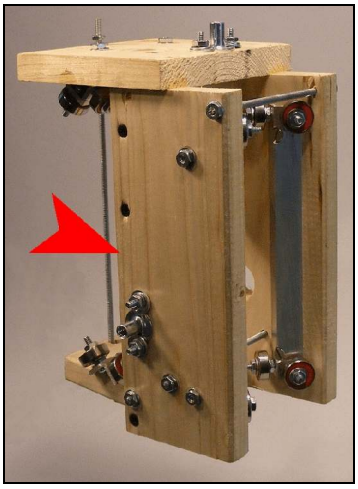
Z Carriage

The carriage's sides, bottom, and back are made of 1x4, and the top is cut from a 1x6.

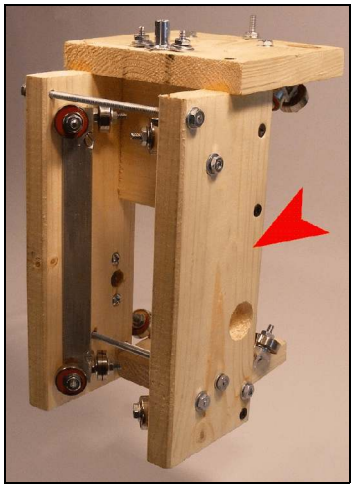
Z Sides

The two Z sides are made of 1x4 that is cut to 9 inches long. The wood's actual dimensions are 3/4 x 3-1/2 inches.

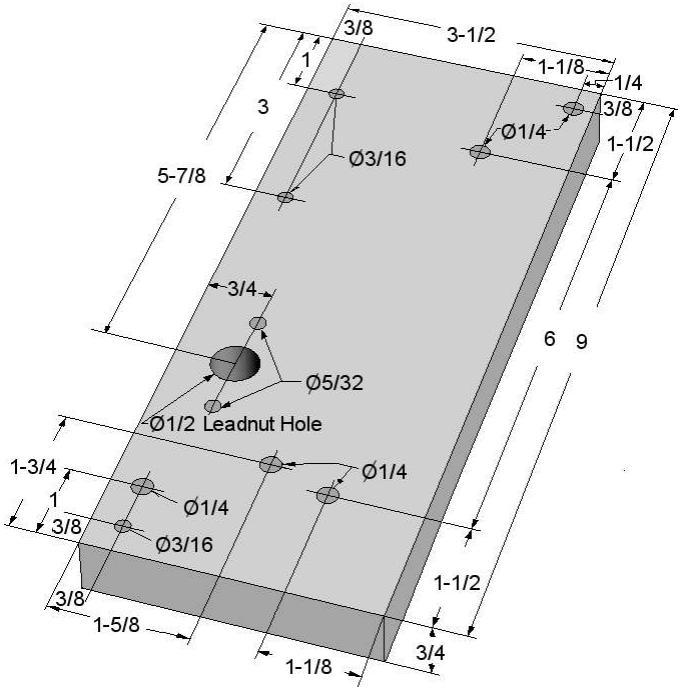
The parts are mirror images of each other with the exception of the holes for the leadnut, its attachment screws, and leadscrew.

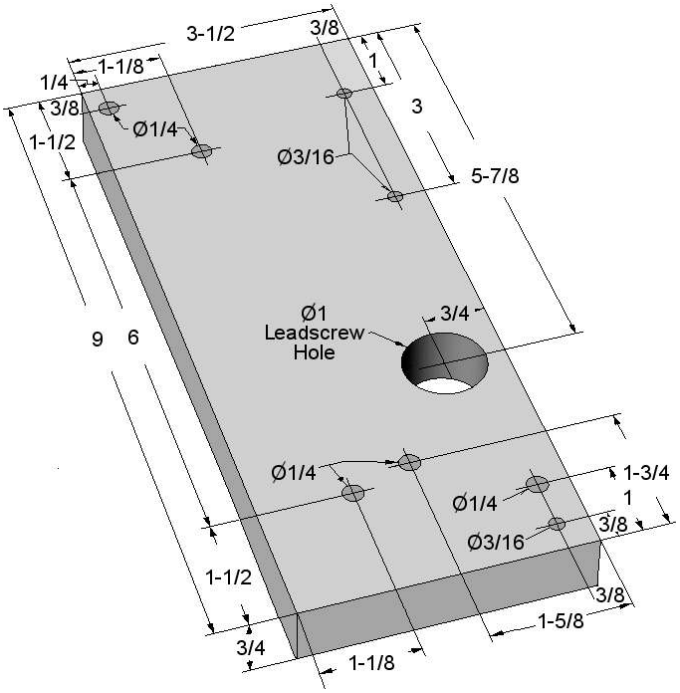


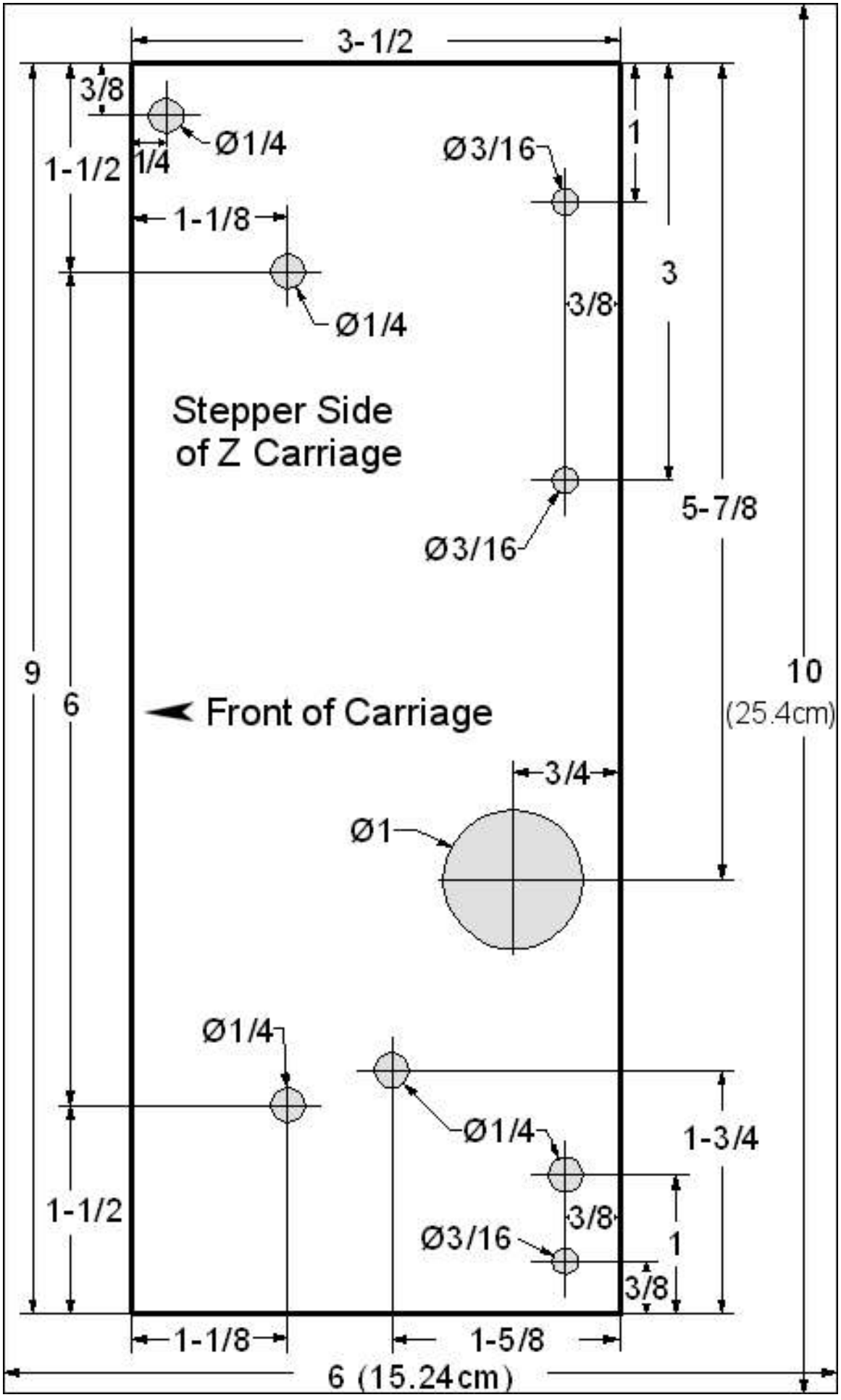
Leadnut side.

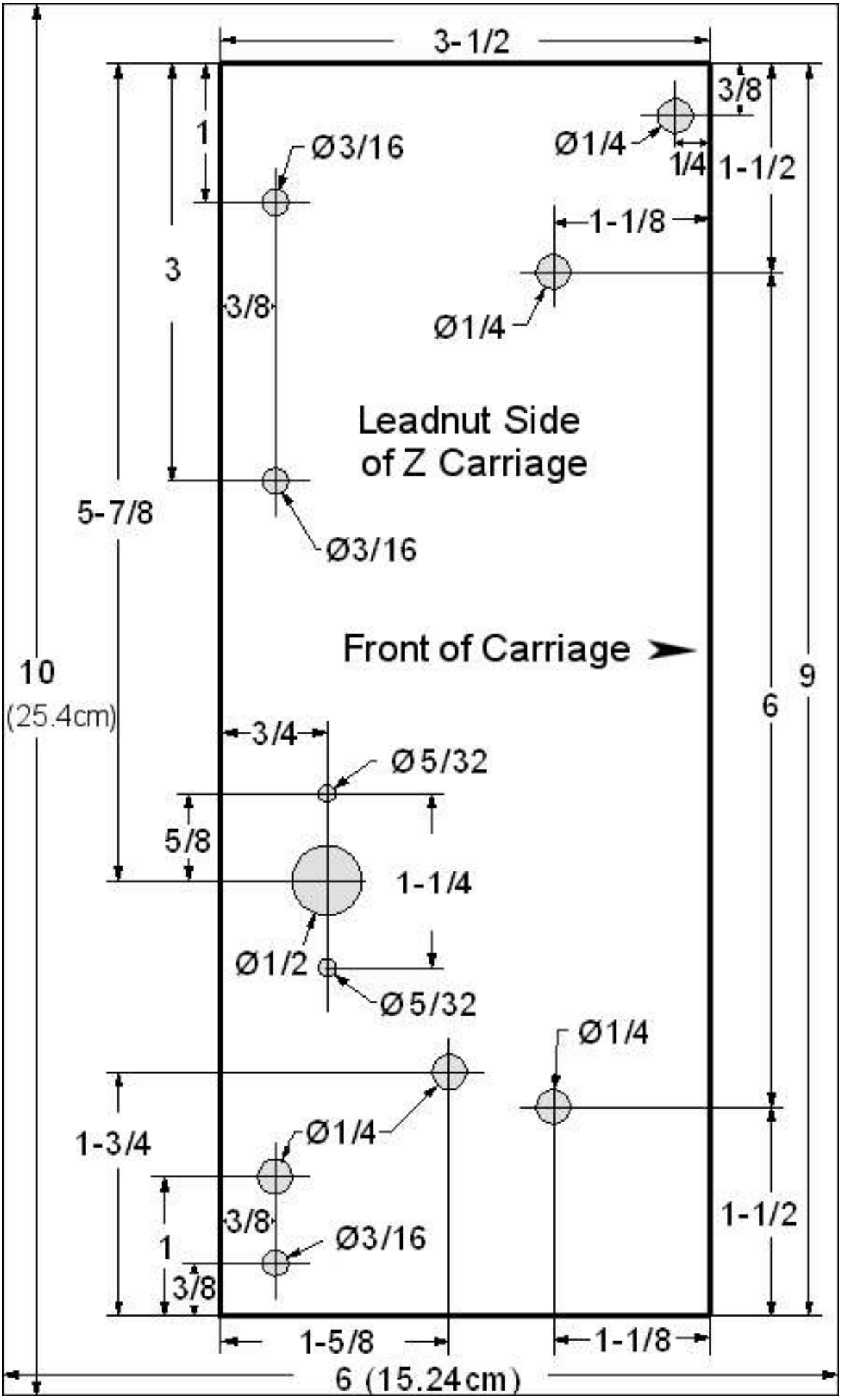


Stepper side of carriage.

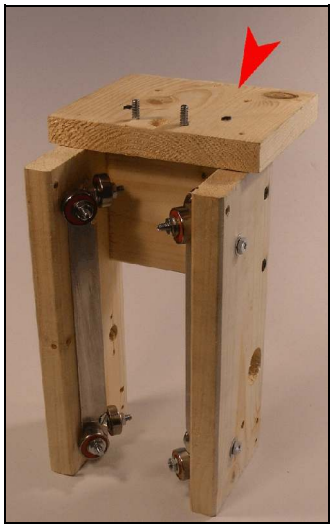








Z Top



Z top on sides.

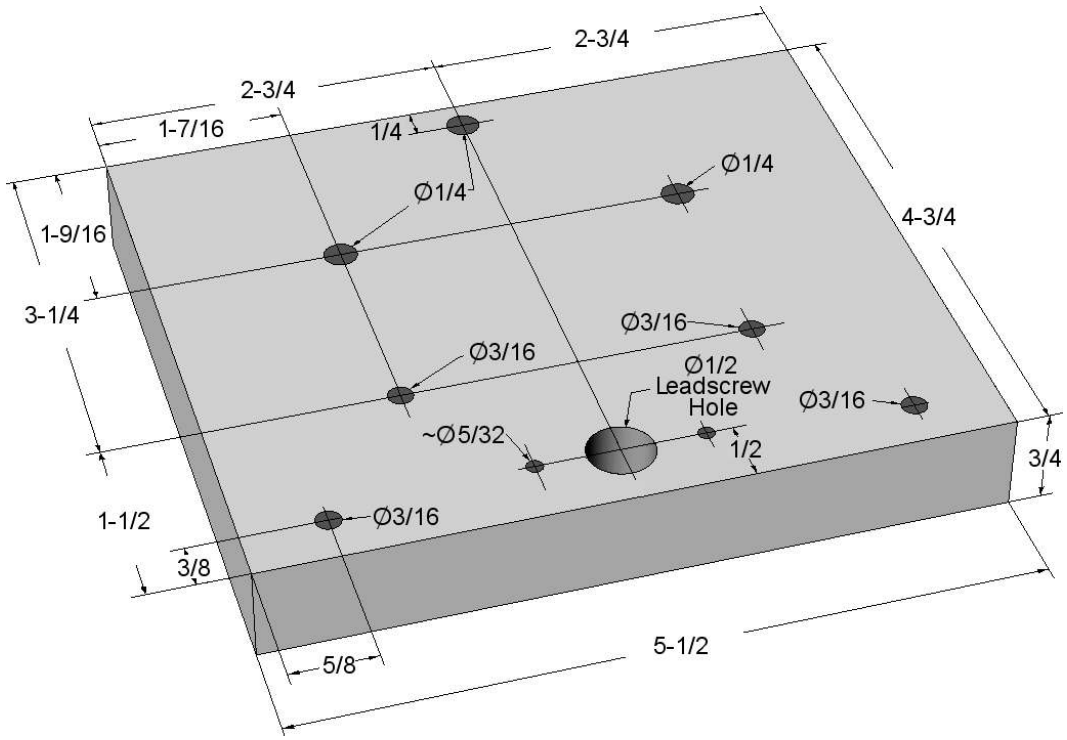
The top is cut from 1x6 stock. The wood's actual dimensions are 3/4 x 5-1/2 inches.

The top overhangs the sides, which allows a range of bearing adjustment against the Z rails. This adjustment permits the use of pipe rails other than the ones specified in these plans. It also is forgiving of offsets that accumulate during construction.

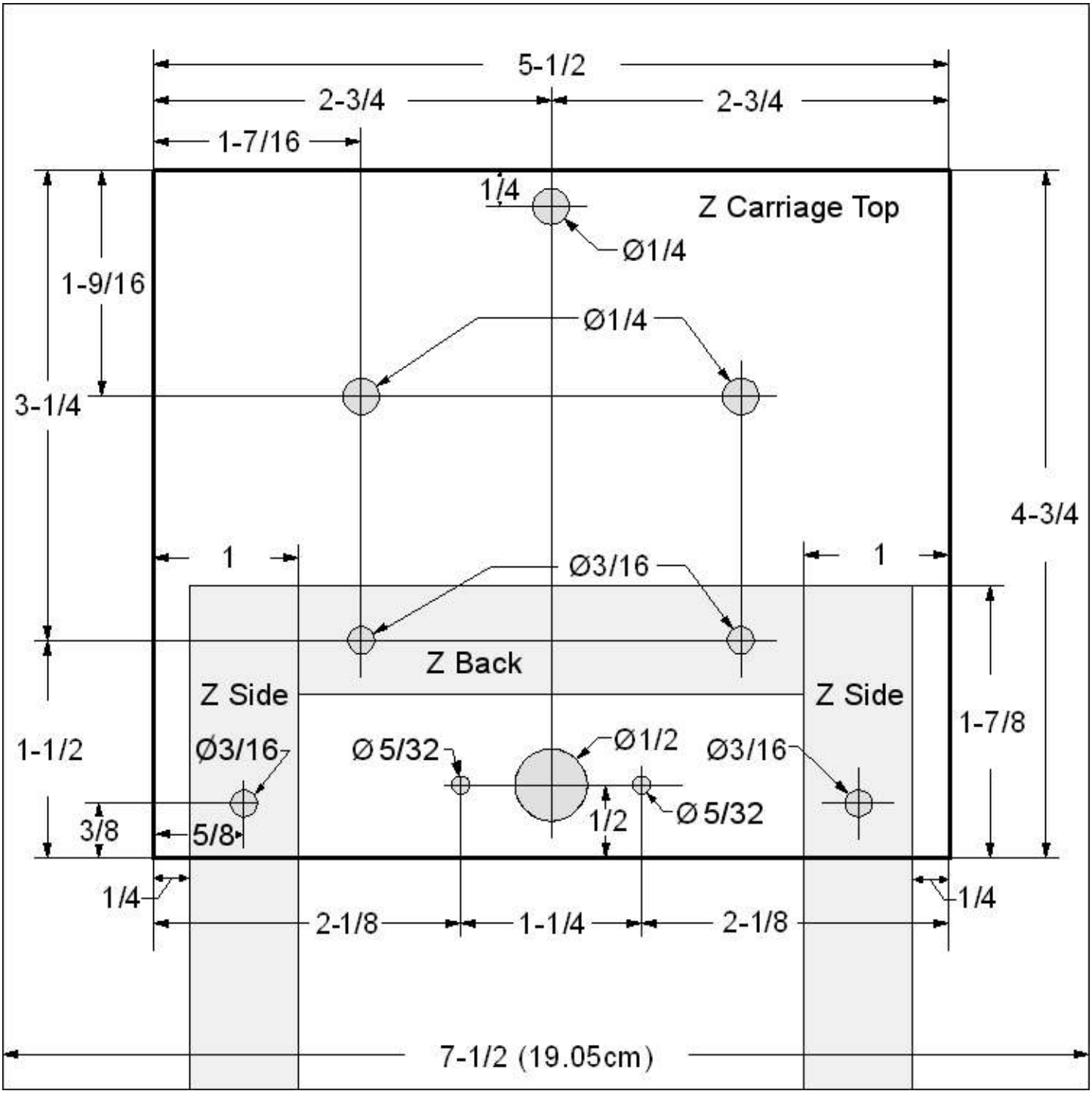
The positions of the sides and back are shown on the template on the following page.

The 5/32 inch holes beside the 1/2 inch leadscrew hole are for the #10 machine screws that attach the leadnut to the carriage top.
These two holes should be small enough to fit tightly around the machine screws. These holes can be 9/64 inch for #8 machine screws.
The screws should not freewheel in the holes. This will make later leadnut adjustments much easier.

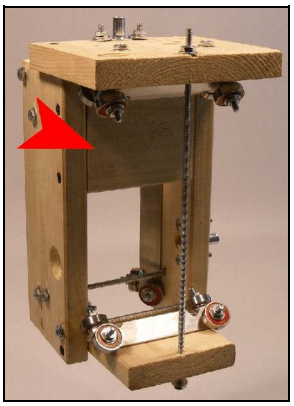
This top plate is oriented so the wood's grain runs front to back. Tension rods will pull this top plate and the bottom plate together. Were the wood's grain oriented sideways, the boards would be likely to split as the tension rod was tightened.



Z Top Template



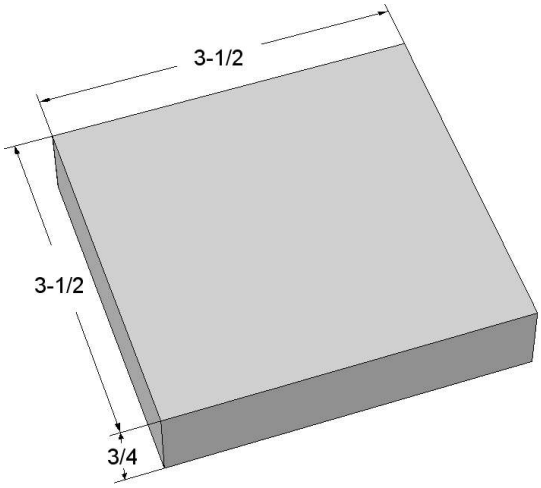
Z Back



Carriage back.

The Z back is simply a section of 1x4 that is cut to 3-1/2 inches long. It is a square block that is 3/4 inch thick. No pilot holes are drilled in it until the carriage is assembled.

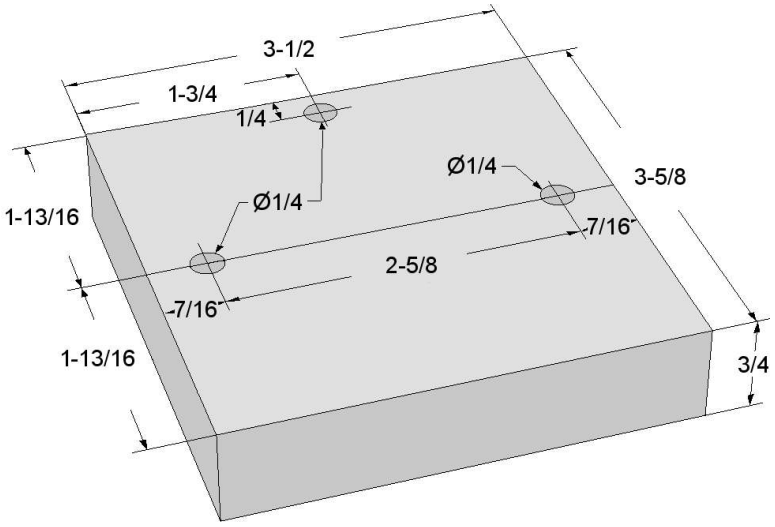
There is no template for this part.

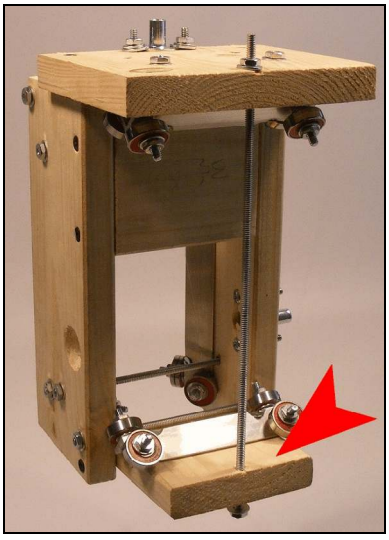


Z Bottom

The bottom is a piece of 1x4 that is cut to 3-5/8 inches long. Three 1/4 inch holes are drilled as shown.

Like the top plate, this piece of wood is oriented so its grain runs from front to back. This grain orientation helps to prevent the wood from splitting as the tension rod is tightened.

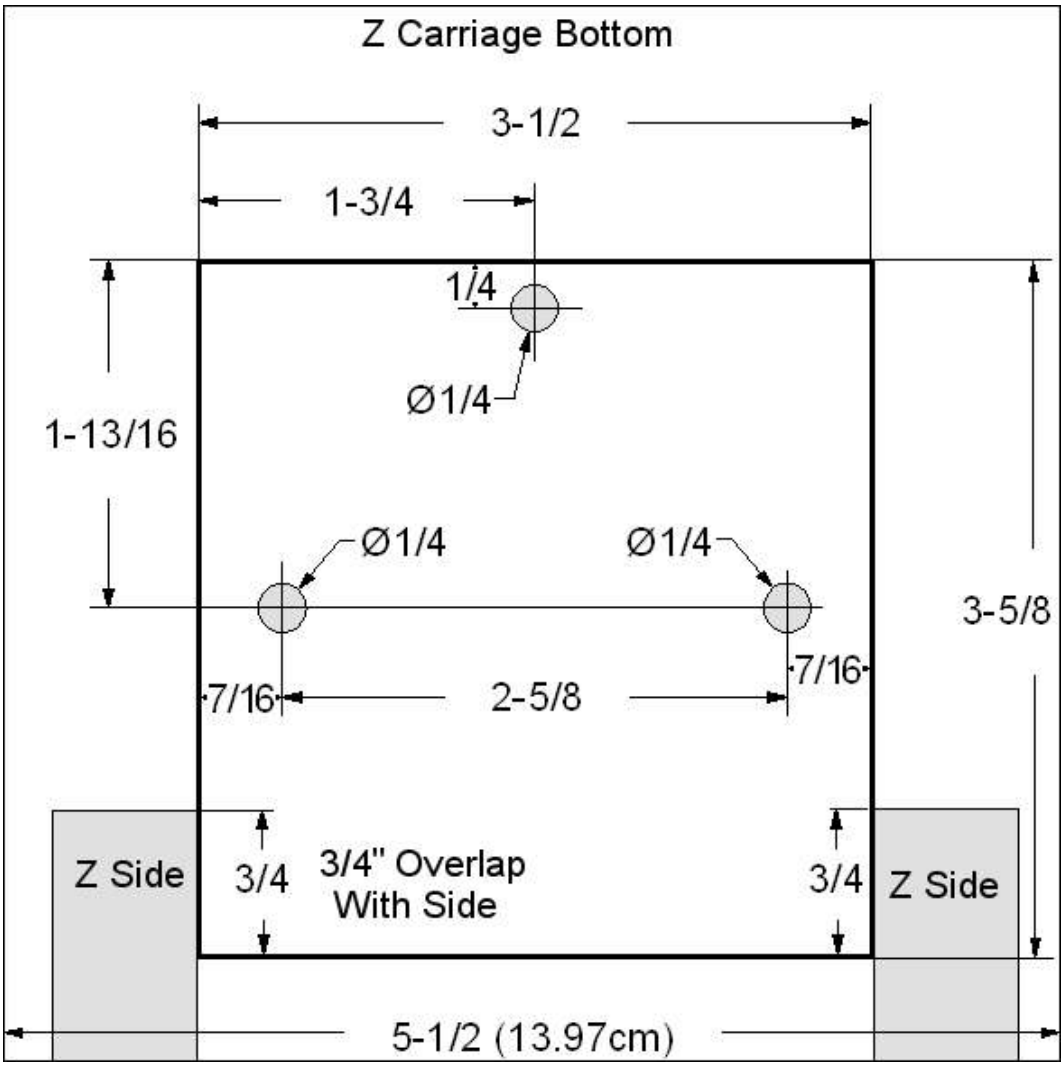




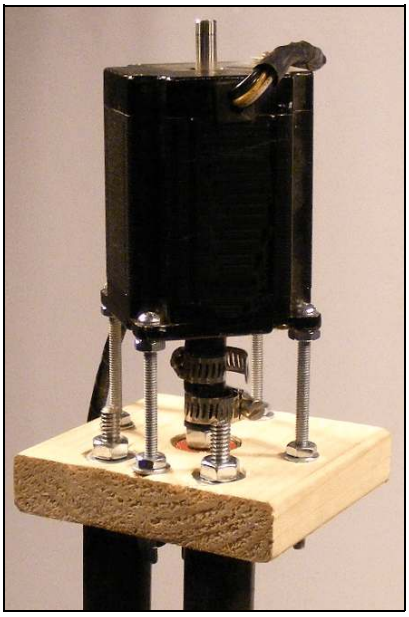
Z bottom plate.

The template on the following page shows the position of the sides in relation to this bottom plate.

Z Bottom Template



Z Stepper Plate



Z stepper plate.

The stepper plate is a piece of 1x4 that is cut to 3-3/8 inches long. It is oriented so the wood's grain runs front to back. This orientation helps to prevent the wood from splitting. This piece is supported near its front edge by the pipe rails, and the load could split the block were the grain oriented sideways.

A recess for the leadscrew bearing is drilled in the top of this plate. The 7/8 inch diameter recess is around 1/4 inch deep.
The 5/8 inch diameter through hole is drilled after the 7/8 inch recess is drilled. Otherwise, it will be difficult to position the bit for the 7/8 inch hole.

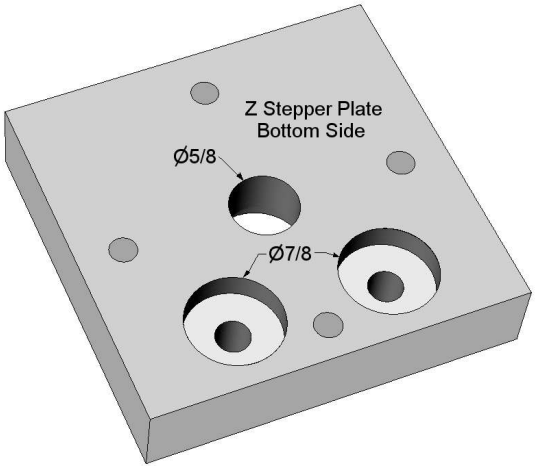
Recesses that support the pipe rails are drilled into the bottom side of this stepper plate.
These recesses can be 1/8 inch deep or deeper. Enough material should be left in the bottom of the hole for the wood to be firmly clamped onto the rails with the tension rods.

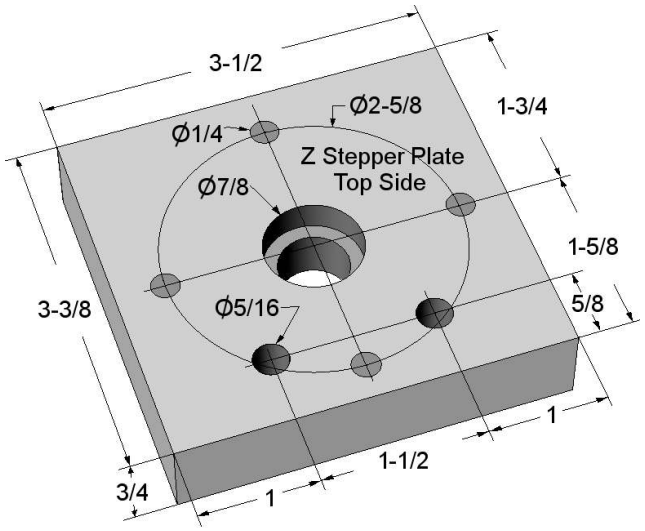
The recesses can be different depths to accommodate pipe rails that are slightly different lengths.

Small pilot holes of ~1/8 inch should be drilled at the location of the 5/16 inch holes before the 5/16 inch holes and 7/8 inch recesses are drilled.

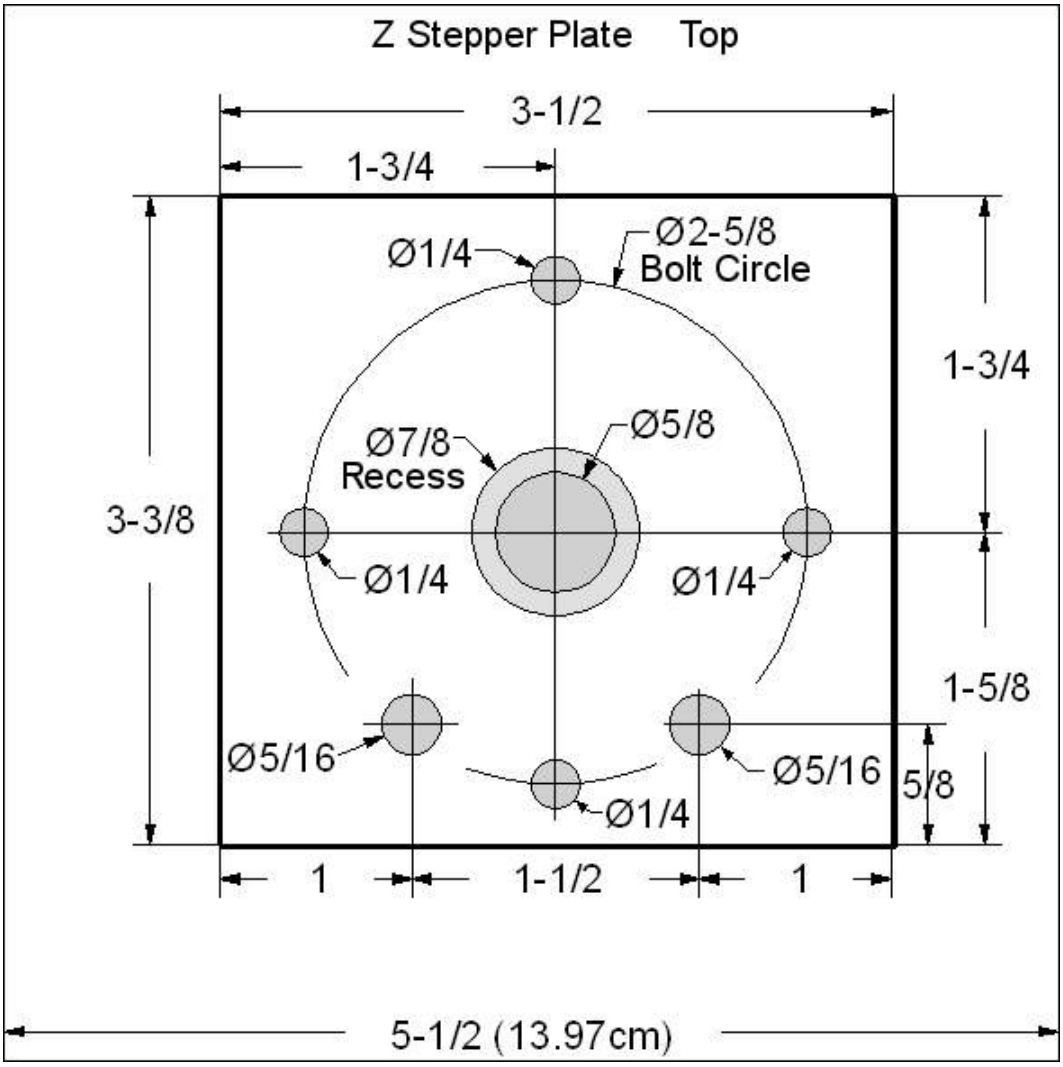
The 7/8 inch recesses for the pipe ends are drilled after the pilot holes, then the 5/16 inch through holes are drilled. Again, this sequence makes it easier to position the larger recesses.

The recesses for the pipe ends can be sized slightly differently for pipes other than those specified in these plans. The sides of the Z carriage can be flexed somewhat, so the bearings can accommodate different rails.





Z Stepper Plate, Top Template

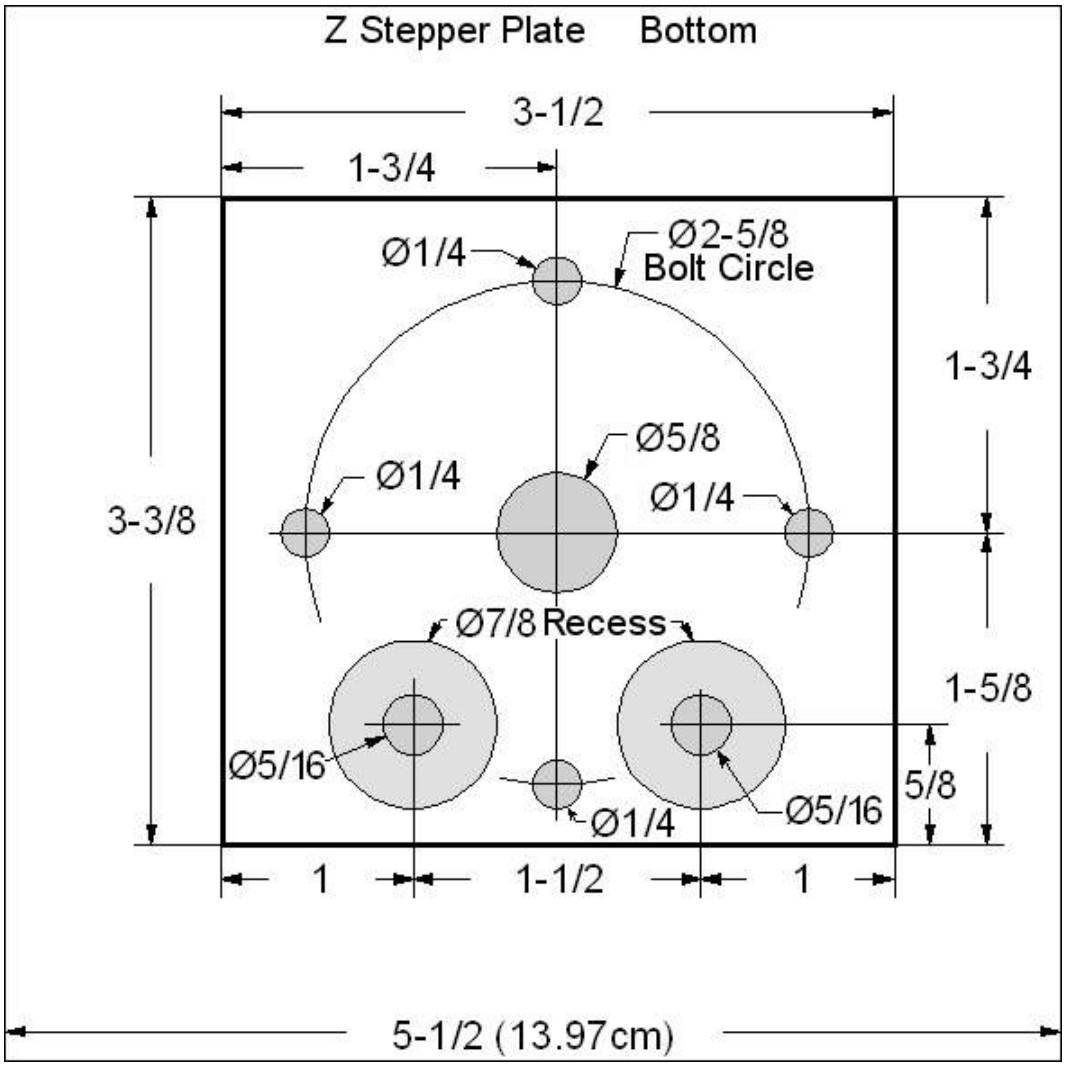


The template for the bottom is on the next page.

The 2-5/8 inch bolt circle is shown for reference.
The stepper's attachment holes are 1/4 inch to permit adjustment.
The 7/8 inch bearing recess is around 1/4 inch deep. This section of the stepper plate carries the weight of the router, so the wood should not be too thin at this location.

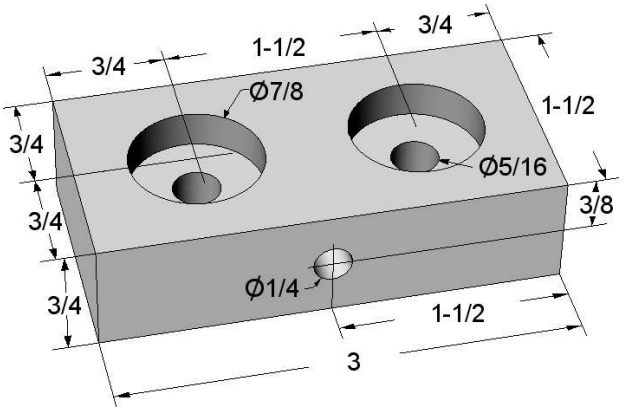
Small pilot holes of ~1/8 inch should be drilled at the location of the 5/16 inch holes before the 5/16 inch holes and the bottom 7/8 inch recesses are drilled. Drilling the pilot holes will make positioning of the 7/8 inch drill bit much easier.

Z Stepper Plate, Bottom



Z Router Mount

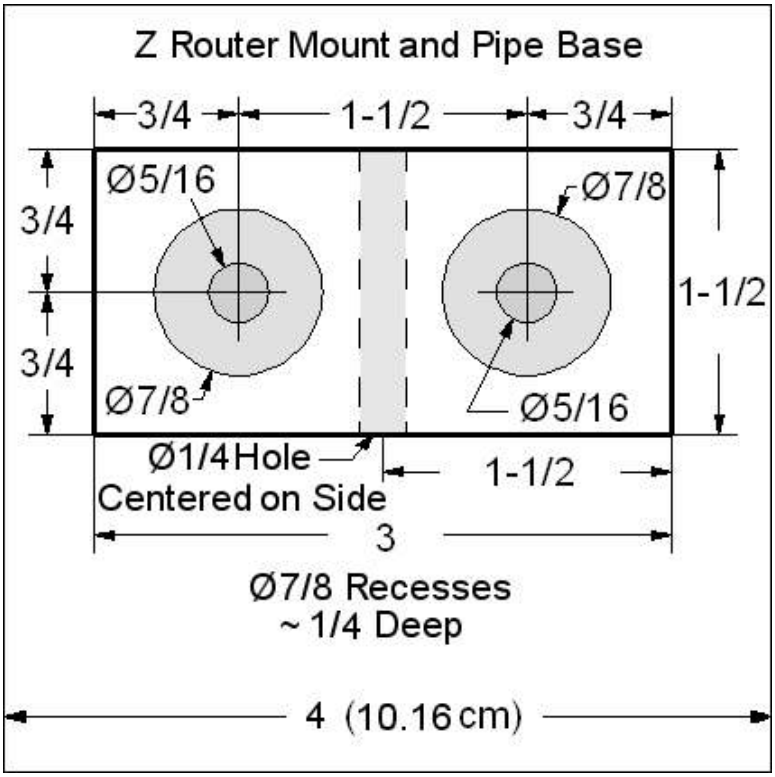
This piece of wood is the remainder from the 3 inch block that was ripped for the Y leadnut block.
It is 3 x 1-1/2 inches.



Z router mount.

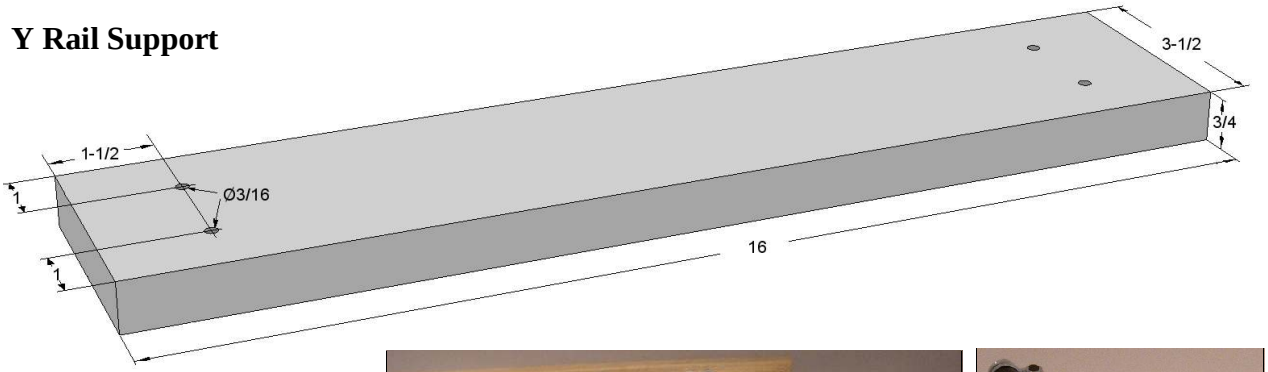
The Z router mount is drilled to accept the pipe rails and the tension rods.
It is also drilled through the center of its side to accept the bolt that ties the router to the axis.

Like the Z stepper plate's 7/8 inch recesses, this router mount's recesses can be different depths to accept pipe rails of slightly different lengths. Again, it is important not to drill too deeply; enough wood should be left to support the rails when the tension rods are tightened.



Assemble Y Axis

Y Rail Support



The pipe rails are supported by four 1x4 by 16 inch boards.
The top two boards are drilled as shown in the above drawing.
Once drilled, each of the top boards is glued and screwed to one of the bottom 1x4 by 16 inch boards.


Table bed frame with 1x4 rail supports installed.


Pipe clamped to two 1x4 boards.

Half inch EMT conduit clamps hold the pipes into place. Right image.

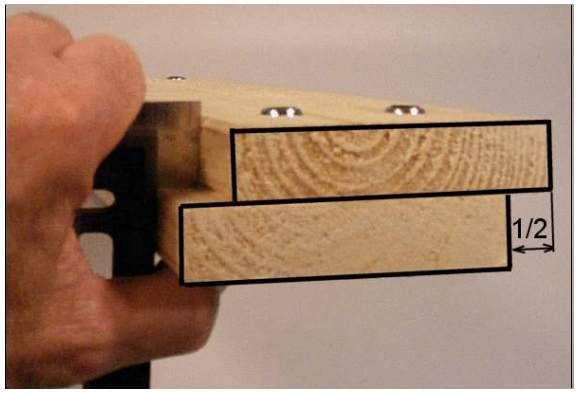
The boards are offset 1/2 inch to cradle the pipe.

Glue is spread on the 1x4 boards, and the boards are pressed together.

The 1/2 inch offset is measured, and the boards are screwed together with 1-5/8 inch drywall screws.

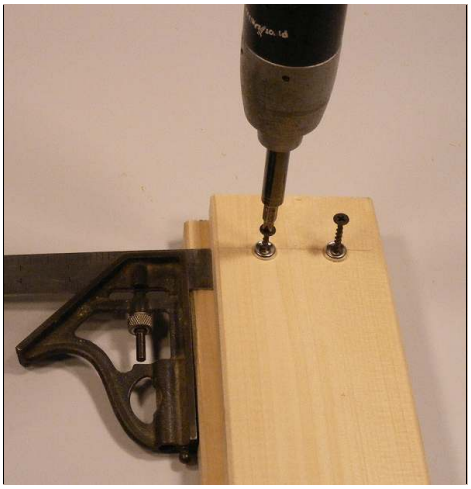
Number 8 finish washers, or flat washers, can be used with the drywall screws to prevent them from protruding through the backs of the boards.


Spread glue



Offset is 1/2 inch

Measure offset

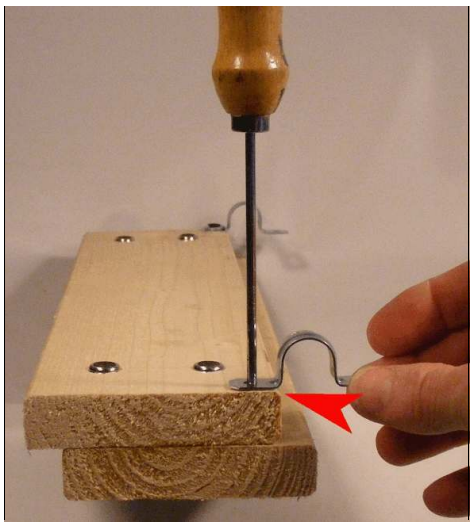


Tighten screws

After the two pairs of boards are screwed together, the EMT clamps are aligned and installed with the pipe rails.

The sides of the clamps are flush with the ends of the boards. The arches of the clamps are aligned with the edge of the boards. Right image.

Metal plumbing tape can be used in place of the clamps. It is soft and bends easily.



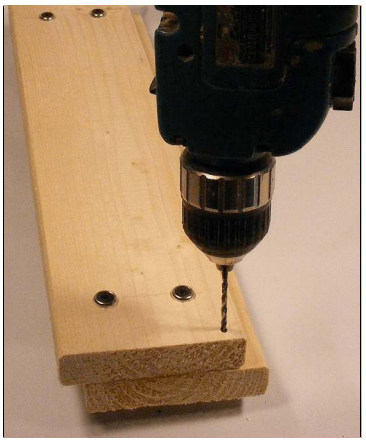
A half inch EMT clamp is aligned with the edge of the board. (Red arrow) Mark the clamp's hole with a punch.

Align an EMT clamp with the edge of the board, and mark the position of the clamp's hole. Right image.

Drill a pilot hole for a 1-5/8 inch drywall screw with a 7/64 inch bit. Left image below.

The pilot holes are necessary because the screws are near the edges of the boards. The wood could split were the screws driven without pilots.

Tighten the clamp into place with a drywall screw and washer. Right image.



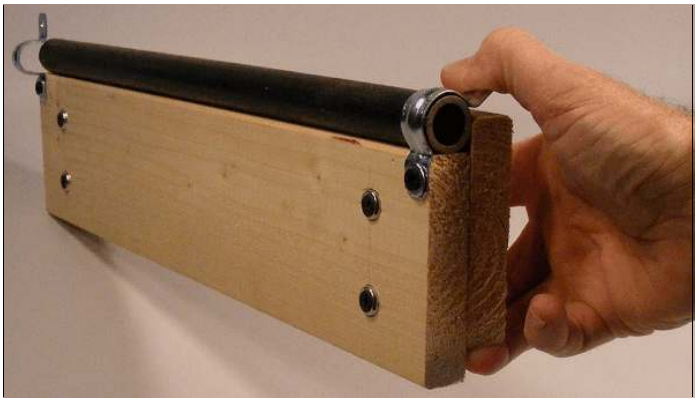
Drill a 7/64 inch pilot hole for the EMT clamp's mounting screw.

Screw the EMT clamp onto the boards. Use a washer with the drywall screw.

Install two clamps on the two pairs of boards.

Place the 15-7/8 inch length of 1/2 inch pipe on the edge of the 1x4s, and bend the clamps around the pipe. Middle right image.

Install clamps on both ends of the rail support boards.



Install pipe into EMT clamps.

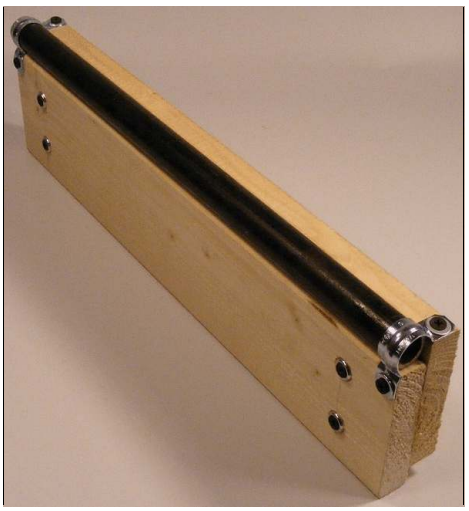
Bend clamp around pipe.

Drill a 7/64 inch pilot hole for a drywall screw through the clamp's hole. Direct the drill so the bit does not hit the first drywall screw. Left image below.
Stop drilling if the bit hits the clamp's other drywall screw. Trying to go around the screw may break the bit.

The spruce-pine-fir 1x4 is soft enough to allow the second drywall screw to find its way around the first screw.
When harder wood is used the hole should be re-drilled at an angle if the bit hits the first screw.
Tighten the screws into place.

Repeat for both rail support assemblies.

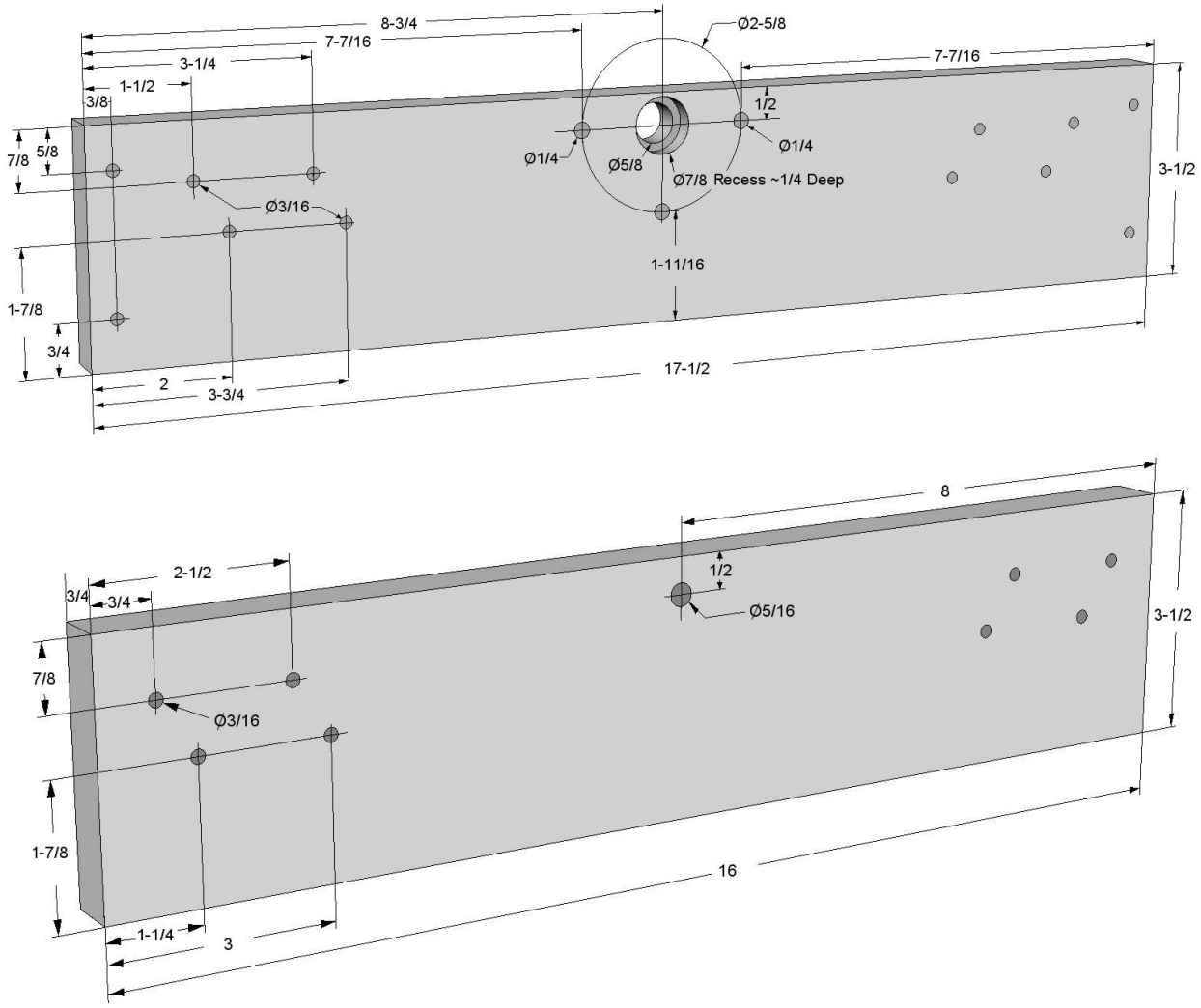
Drill a 7/64 inch pilot hole through the EMT clamp's hole. Attach the clamp with a drywall screw and washer.



Pipe clamped onto rail support boards.

Attach Rail Supports to End Plates

The back and front end plates need to be cut and drilled before assembly begins. Refer to pages 22-27.



Install Back End Plate

The rail supports are raised to the correct height of 1-1/2 inches from the work surface by resting them on top of extra 1x4 or 1x6 boards.

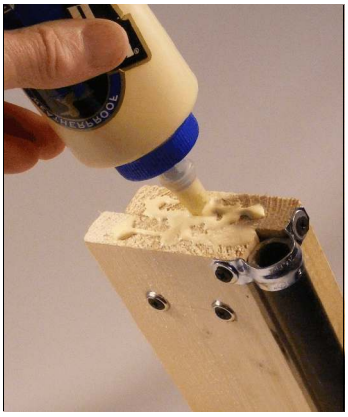
The gantry end and beam pieces can be used for this blocking.

Place rail supports on extra boards.

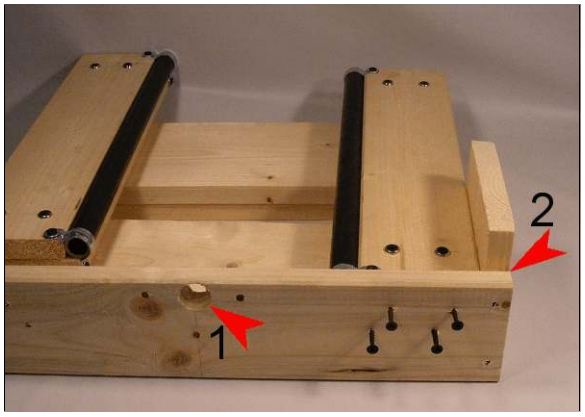
Glue is spread on the end of one of the rail support assemblies. Right image.

Apply glue on one end at a time, just before screwing the parts together.

Glue is worth the trouble; it significantly stiffens the joints, which reduces chatter.



Spread glue on end of the boards.



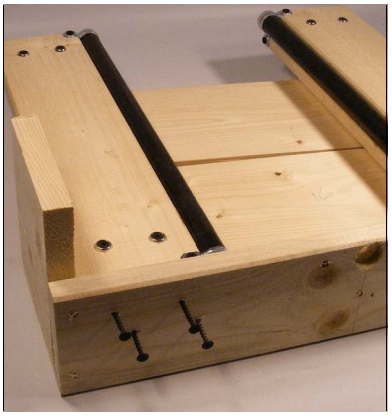
Align rail support boards with stepper end board. Bearing recess faces out (Arrow 1). Use an extra board as a spacer to align edges (Arrow 2). Tighten screws.

The ends are screwed to the rail supports with four 1-5/8 inch drywall screws at each junction. Above and middle right images.

The back stepper end board is attached first. This is the longer 17-1/2 inch end plate that has the holes for the stepper and bearing.

The stepper's bearing recess should face outward. Right top image, arrow 1.

An extra piece of 1x4 or 1x6 is used as a temporary spacer to offset the rail support assembly from the end of the Y axis end plate. Arrow 2 in top right image.



Attach other rail support.

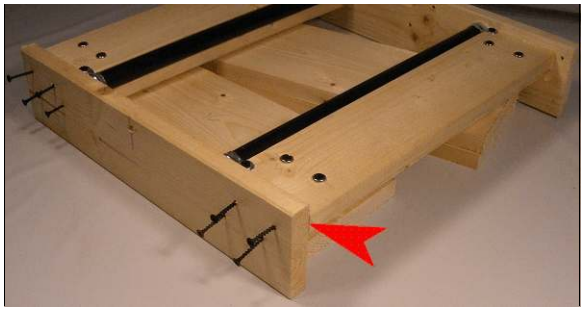
Tighten the four 1-5/8 inch drywall screws when the rail support is aligned with the end plate. Washers are not needed with these screws.
Pilot holes into the ends of the rail supports are not needed unless harder wood is used.

Repeat this process for the second rail support. Right image above.

Install Front End Plate

The front Y end plate is installed the same way, except the rail supports are flush with the ends of the Y end plate. Arrow in right image.

Check for square and level after all of the parts are screwed together. The table assembly should lie flat on a level surface without rocking.
Screws can be loosened while the glue is still uncured to adjust for square. The wood is soft



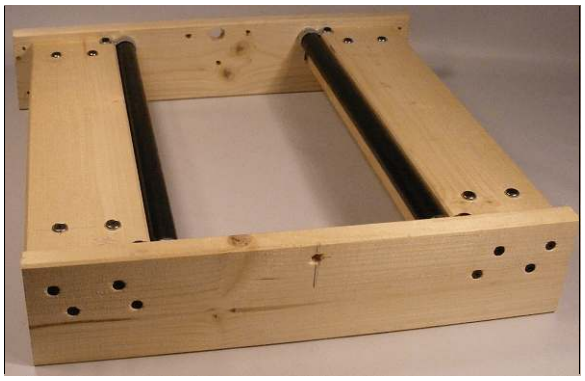
Align the end of the front board with the side of the rail support board. The parts are flush at the arrow.

enough that racking the components by twisting them can pull the parts into alignment.

If needed, clamp or block the table bed assembly to a square level surface while the glue cures.

The floor can be the level surface, and bricks can be used as weights or blocking to hold the unit in place as the glue sets.

The Y moving table bed can be assembled and installed after this Y table frame is completed; this is addressed next.



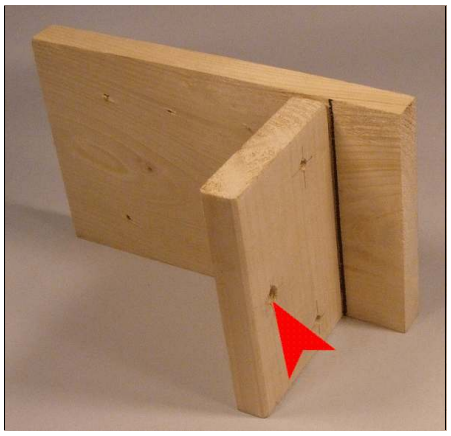
Front view of completed Y table frame.

Assemble Y Table

Assembled Y table.

The table bed and legs have to be cut and drilled before assembly begins. This is covered on pages 28-30.

The legs have no front or back, so they can be installed with either side facing outward.



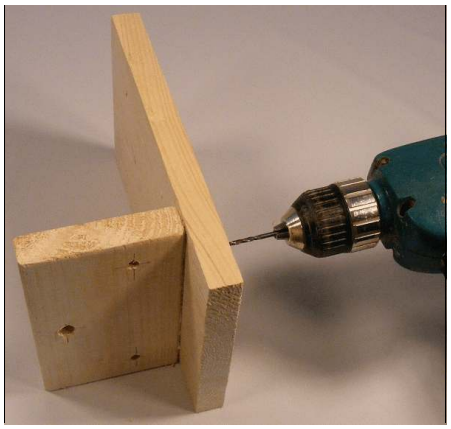
Align a leg with the line that was drawn on the bottom of the top board. Arrow points to 3/8 inch hole.

Align a leg with the line that was drawn on the bottom of the table bed. Note hole positions. The large 3/8 inch hole is farthest away from the table top. Above right image.

Make sure the outside edge of the leg is well aligned with the line that was drawn. The leg should be parallel to the edge of the table top board.

Drill 7/64 inch pilot holes into the top edge of the leg through the existing holes in the top of the table.

Glue and screw this one leg into place. Use 1-5/8 inch or longer drywall screws.



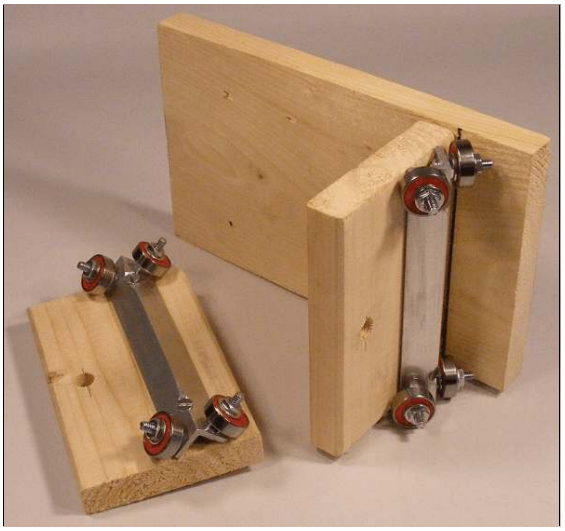
Drill pilot holes into the edge of the leg. Use the existing holes in the table top as guides.

The other leg is installed after the trucks have been attached to the legs.

Attach the 5-1/2 inch long truck assemblies to the legs with #10 x 1-1/2 inch flat head machine screws. Use a washer with each nut.

Finger tighten the nuts.

The screws may barely protrude through the back of the leg. Deepen the countersink depression in the aluminum if a screw does not extend far enough to attach a nut with a washer. Longer screws can be used.



Attach the 5-1/2 inch trucks to the legs. Use flat head #10 x 1-1/2 inch machine screws.

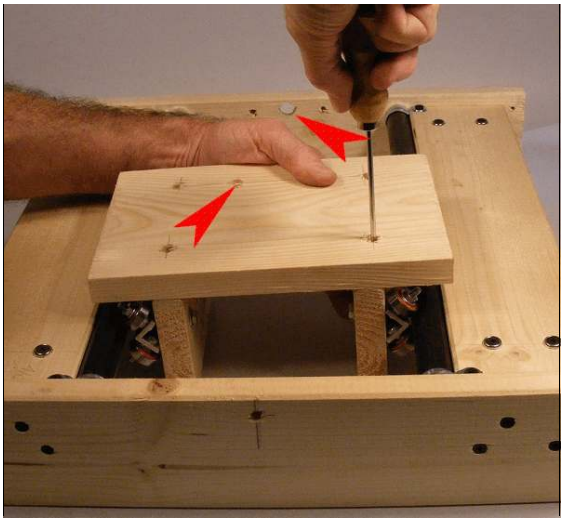
Place the table bed with its one attached leg inside the table frame.

The table bed should be placed so the leadnut block holes are near the back stepper end plate.
Arrows in right image.

Align the trucks with the rails.

Position the loose leg and truck assembly underneath the table, and align its bearings on the rail. Right image.

Firmly press the bearings against the rails, and insert a punch or awl through the top plate's existing hole to mark the position of the loose leg's screw hole. Right image.

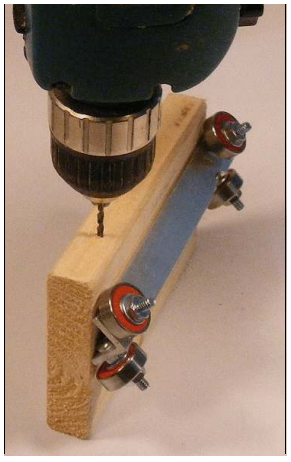


Align table bed bearings on rails. Mark leg for screw. Arrows show bed orientation with leadnut block holes near stepper end board.

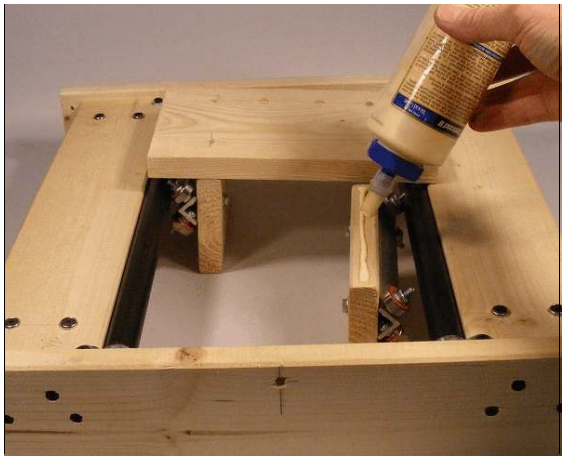
It is important for the bearings to be very tight against the rails. It is best for the leg to be square against the table top.

Remove the loose leg and drill a pilot hole at the mark that was just made.

Spread glue on the edge. Right image.

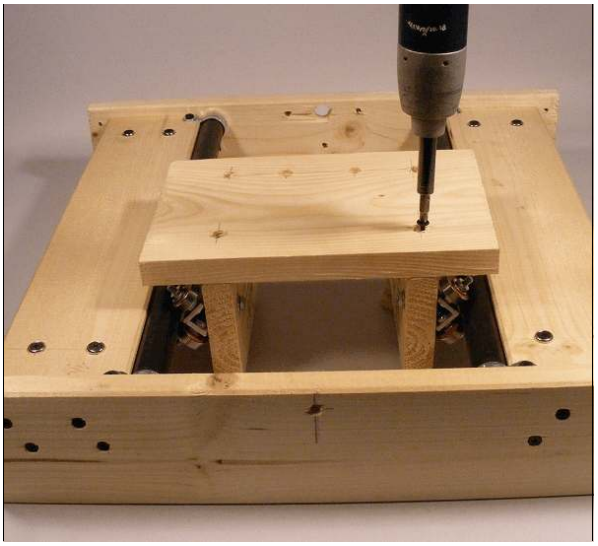


Drill a pilot hole in leg.

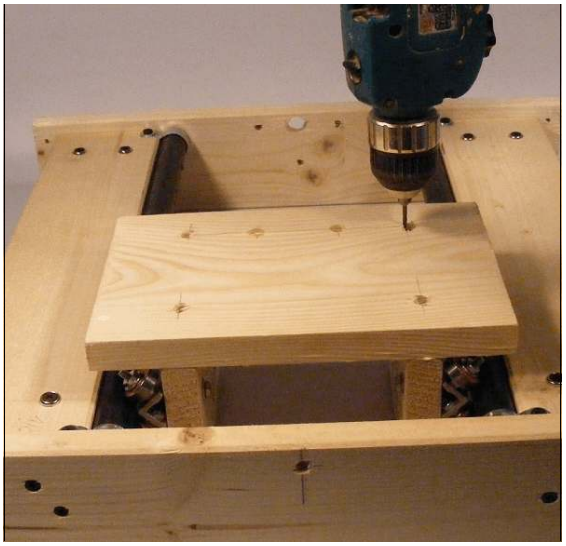


Spread glue on the leg's edge.

Place the leg back under the table bed, and screw it into place with a 1-5/8 inch drywall screw.
Press the leg and its bearings tightly against the pipe rail, and drill a second pilot hole.
Drive in the second screw.



Drive in 1-5/8 inch drywall screw.



Drill second pilot hole and install screw.

Install Y Compression Rod

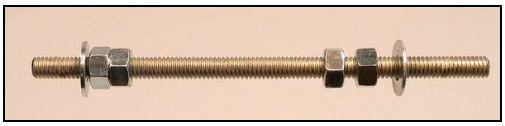
The compression rod is a 6 inch long section of 5/16-18 threaded rod.

This larger diameter rod is used here, instead of the smaller rods used on the other axes, because the smaller rods will bend when subjected to the compression load applied in this axis' configuration.

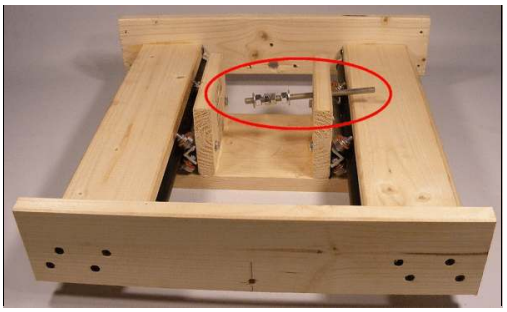
Flip the entire assembly upside-down so it rests on the top of the moving table bed.

Slide the compression rod through the 3/8 inch hole in one leg.
Install a washer, four nuts, and another washer. Then slide the rod into the other leg's 3/8 inch hole.

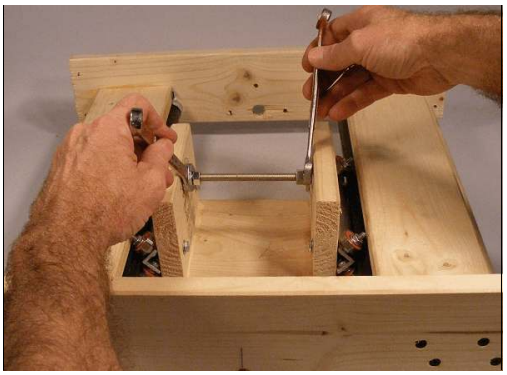
Tighten the outer nuts against their washers to press the legs and their bearings into the rails. Right image.



Compression rod with four nuts and two washers.

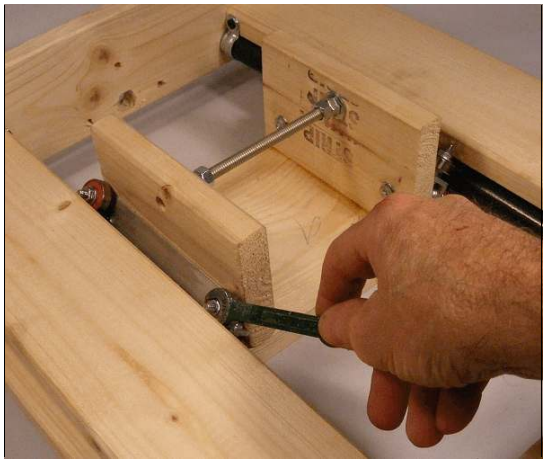


Install 5/16-18 compression rod.



Tighten the nuts against the legs to press the bearings into the rails.

Individual bearings can be moved so they firmly ride the rails. Right image.

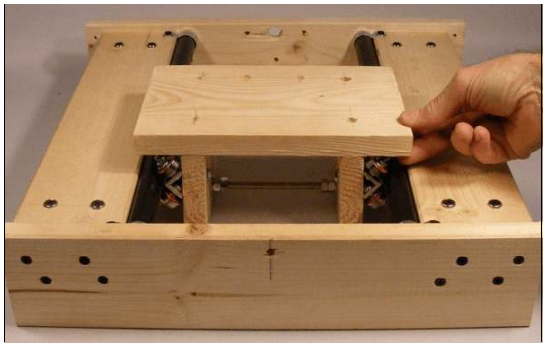


Individual bearings can be moved to firmly ride the rails, if needed.

The bearings should be pressed against the rails so tightly that it is difficult to prevent the bearings from turning when they are pinched with fingers while the table is moved on the rails.

The travel may not be smooth because of the rough surface of the rails. This is not a problem. The bearings will wear flat tracks in the pipes. The pipes can also be filed or sanded if needed. This will be done after the machine has been operated for a few test runs.

Turn the table back upright and test the movement of the table bed. It should move with no play from end to end on the rails.



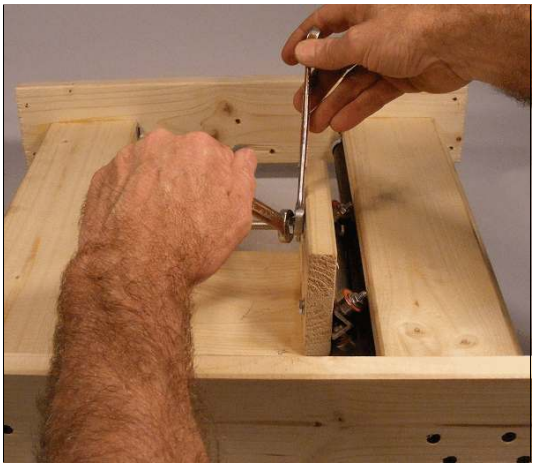
Flip the table frame back upright and test for tight movement.

It is not a problem if there is more tension against the bearings at one end of the Y travel than there is at the other.

It is important for the table to move without rattling on the rails due to the bearings being too loose. Make further adjustments with the tension rod if needed.

Again, it is okay for there to be a little coarseness in the travel because of the imperfect surface of the pipes. This will work-out with use.

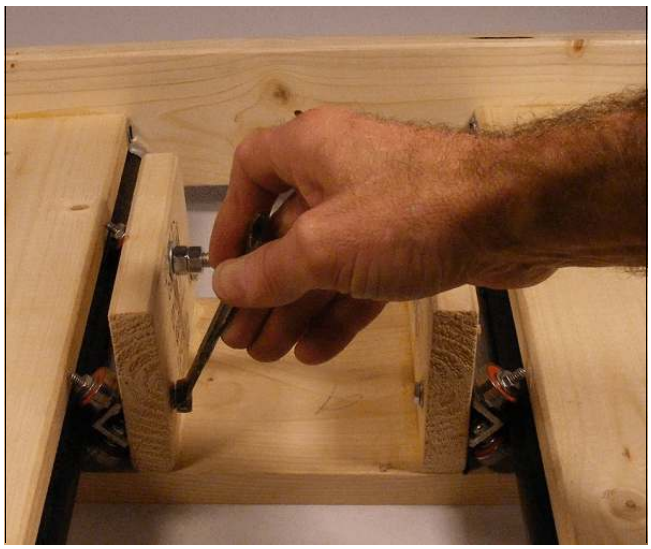
When the table moves smoothly, flip it over again and tighten the second set of compression rod nuts against the nuts that were tightened against the washers. These second nuts will lock the compression rod into position. Right image.



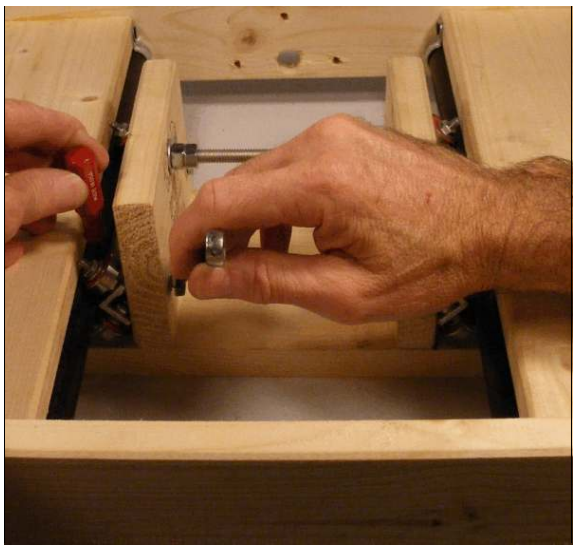
Tighten the inside nuts against the outside nuts to lock the nuts into place.

Tighten the trucks' flat head machine screws into place. Lower left image.

The flat head machine screws may turn as their nuts are tightened. Slide a small screwdriver into the side of the screw head's slot to stop the screw from freewheeling. Right image below.



Tighten the nuts on the trucks' flat head machine screws.



A small screwdriver can be used to prevent the machine screw from freewheeling.

Install Y Leadnut Block

This block has to be cut and partially drilled, as shown on page 31, before the following is begun.

On the bottom of the table bed, mark the center lines of the leadnut block screw holes that go through the table bed. Extend the lines to the back edge of the table bed. Right image.

Draw lines from the leadnut block screw holes to the edge of the table bed.

Align the marks on the leadnut block with the ones on the table bed, and abut the block against the stepper end of the axis.

Draw a circle on the block around the perimeter of the end plate's bearing hole. Right image.

Drill a half inch hole that is centered in the circle that was just drawn on the block. Image below left.

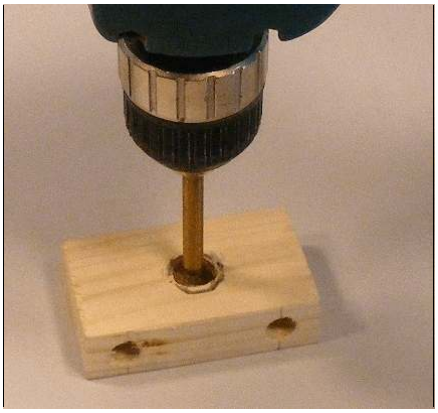
Center the leadnut over the hole that was just drilled.

Drill 5/32 inch diameter holes 1/8 inch from each side of the leadnut. Center image below.

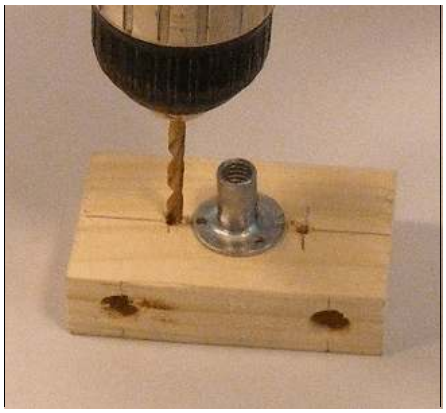
These holes will hold the leadnut support screws. There should be room to adjust the position of the leadnut between the screws.

Align the marks on the table bed and block, and mark the position of the end plate's bearing hole onto the block.

Drive two #10 by 1-1/4 inch machine screws through the holes in the block. The heads of these screws are on the side of the block that was originally marked for the 1/2 inch hole. The threads will face the front of the table, away from the stepper end. This will give ample wrench access to the nuts, which will make adjusting the leadnut easier.



Drill a 1/2 inch hole in the circle that was drawn on the block.



Drill two 5/32 inch holes 1/8 inch from the leadnut.

Drive #10 x 1-1/4 inch machine screws through the block.

Center the leadnut between the ends of the machine screws.

Put a 1/4 inch washer, a #10 washer, and a nut on each screw. Right image.

Finger tighten the nuts to hold the leadnut in place.

Place washers and nuts on the screws.

Drive three inch long machine screws through the table top's leadnut block holes. Left image below.
Drive the screws so their heads are deeply recessed into the table top.

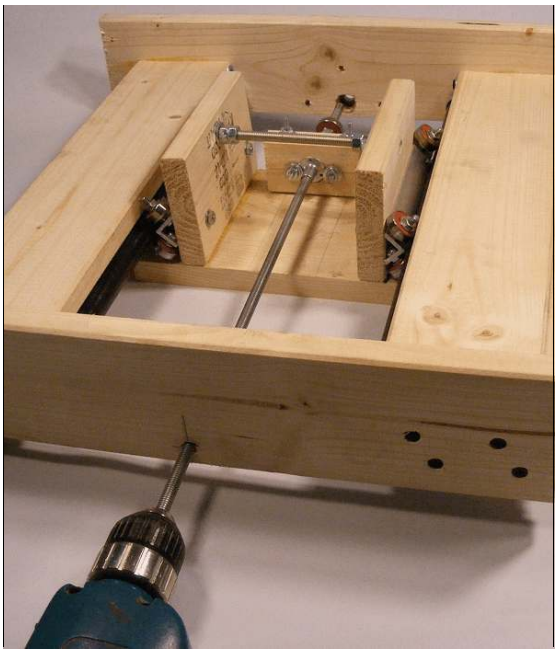
Drive three inch screws into the table top.

Put the leadnut block on the screws. Put washers and nuts on the screws.

Flip the table over and put the leadnut block with its leadnut on the 3 inch screws.

Put a 1/4 inch washer, a #10 washer, and a nut on both of the 3 inch long screws. Right image.

Install Leadscrew



Install the leadscrew. A drill can speed the process.

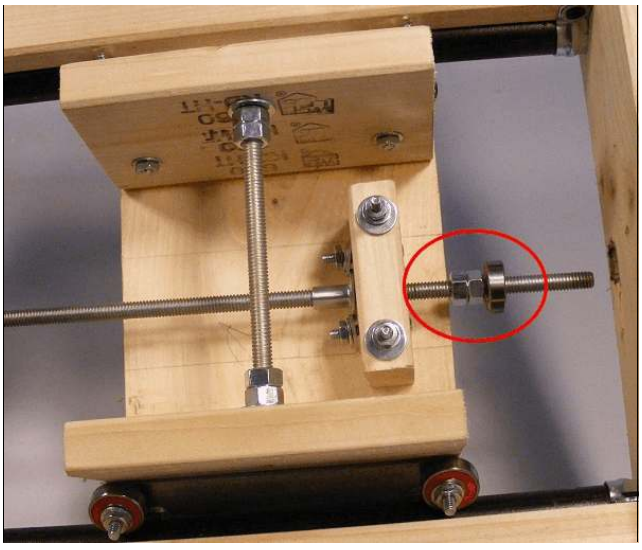
Install the 5/16 inch threaded rod leadscrew in the machine.
Start from the front of the machine.
The rod should be at least 18 inches long. A length of at least 19-1/2 inches will permit the rod to extend from the front of the machine far enough for a knob to be attached to it.
A knob can make moving the axis for set-ups easier, but a knob is not required.

A drill can be used to quickly drive the rod through the end plate and the leadnut. Right image.

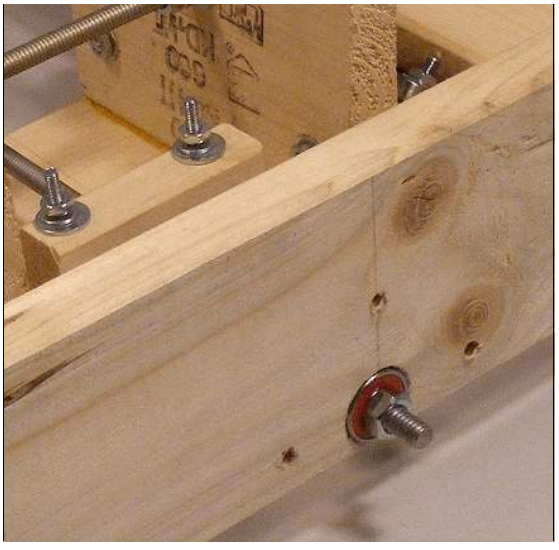
Install two nuts and a bearing on the leadscrew after it passes through the leadnut. Left image below.
The nuts will be used to hold the bearing in place.

Pass the leadscrew through the back end plate, and insert a bearing into the recess. Put a nut on the leadscrew. The leadscrew extends 1/2 inch beyond the nut. Right image below.

After the leadscrew is installed, the nuts that hold the tee nut in place can be loosened so the tee nut can freewheel as the leadscrew is turned. The tee nut will be tightened into position later.



Put two nuts and a bearing on the leadscrew.



Place a bearing and nut on the leadscrew.

Install Y Stepper

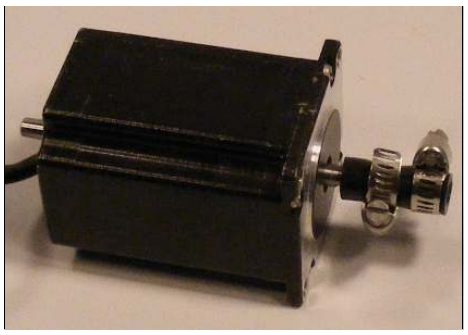
Cut a piece of 1/4 inch inside diameter fuel line to ~1-1/4 inch long. This can be cut with a knife or hacksaw.

Cut fuel line.


Size # 4 hose clamps.

Two #4 hose clamps are used to tighten the fuel line to the leadscrew and stepper.

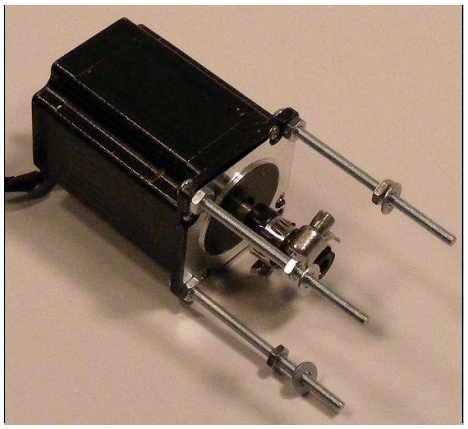
Slide the hose onto the stepper's shaft and loosely install the two hose clamps.


Hose and clamps on stepper.

Insert three 3 inch long machine screws through the stepper's mounting holes.

Finger tighten a nut against the stepper on each screw. Install another nut and then a washer on each screw.

Insert the machine screws into the holes in the machine's end plate.
Thread the leadscrew into the fuel line.

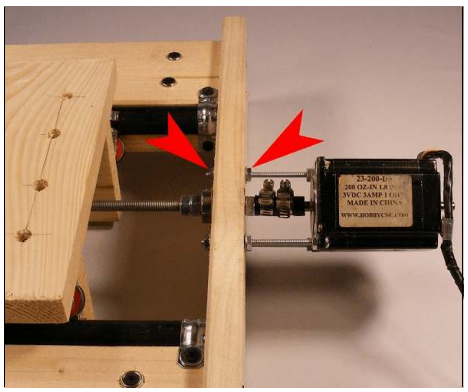

Machine screws on stepper.

Abut the end of the stepper shaft against the end of the leadscrew inside the fuel line.

Install a washer and nut on the ends of the stepper's 3 inch machine screws so the end plate is sandwiched between two washers and nuts. Bottom image.

Adjust the nuts on the 3 inch screws so the stepper is in line with the leadscrew, and is squarely aligned with the end of the machine.

Tighten all of the nuts so they are finger tight. There is no need for a wrench yet.


Nuts and washers sandwich the end.

Attach the stepper to the drive, and activate the stepper. This requires having the computer and software set up. This information is covered by the software supplier, such as Mach3, and the drive and stepper supplier such as Xylotex or HobbyCNC.
See pages 82 and 83 of these plans for more information.

Jog the stepper and check that the leadscrew and stepper are in line.

Tighten the hose clamps on the fuel line. The hose clamps should be as close together as possible while one clamps the leadscrew and the other clamps the stepper's shaft. The hose will twist between the clamps when the clamps are far apart. The twisting will permit chatter and backlash.

Jog the stepper in both directions, and incrementally tighten all of the nuts on the 3 inch machine screws.

The nut between the bearing and the fuel line should press the bearing into its recess. Do not load-up the stepper by pulling the stepper hard against the end plate by over tightening the end nuts on the machine screws.

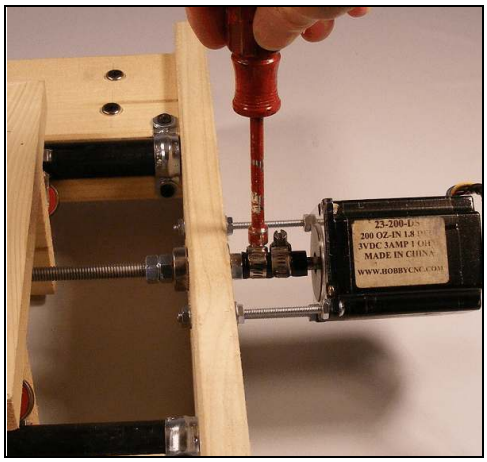
The nuts should hold the stepper so it is straight in line with the leadscrew. Minor offsets can cause excess drag and stalling.

This is a trial and error process. Sometimes the last tightening of a nut will pull things out of alignment enough to cause the stepper to stall. Keep working in circles around the nuts until the stepper can move through a range of speeds without stalling.

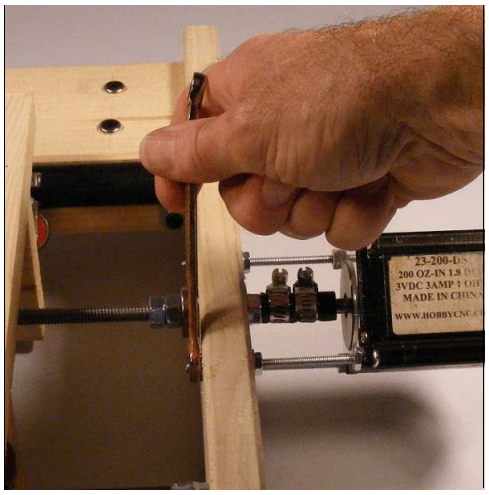
Around 25 inches per minute has proved to be a reasonable starting speed for the initial stepper alignment. As parts are tightened, the speed can be increased to at least 30 inches per minute. The prototypes were able to achieve over 40 ipm with the HobbyCNC 200 oz.in. system.

After the axis moves without the stepper stalling, adjust the nuts that press the inside leadscrew bearing against the end plate. Firmly finger tighten the nut against the bearing so the bearing presses against the end plate. Then tighten the second nut against the first nut to lock the nuts and bearing into place. Right image.

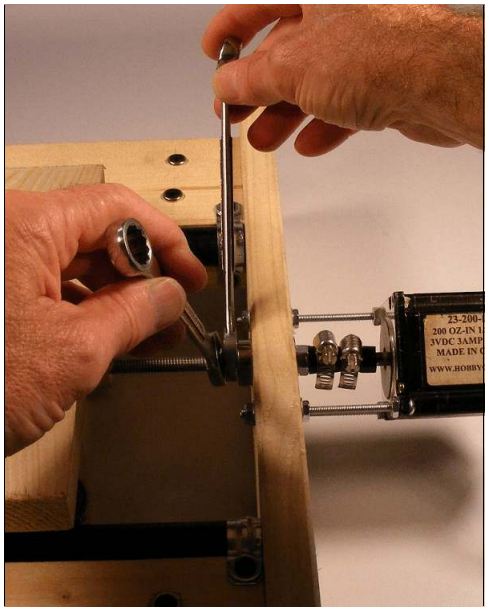
The two bearings on the leadscrew carry the thrust load that would otherwise be carried by the stepper. The stepper's internal bearings are not always designed to carry these loads. Excess thrust loads on the stepper can contribute to backlash, and/or premature stepper failure.



Tighten hose clamps.



Tighten all of the nuts on the screws.


Tighten the two nuts against the bearing.

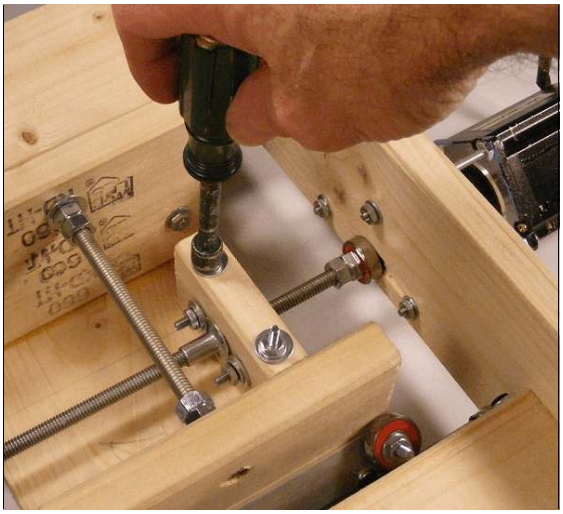
Adjust Y Leadnut

After the stepper can move the leadscrew through a range of speeds, the machine is flipped over so the leadnut can be accessed.

Rest the ends of the machine on extra blocks of wood so the table can be jogged while the machine is upside down.

The leadnut has to be in line with the leadscrew. This alignment is done by moving both the leadnut and the leadnut block. The block is tightened to the table top first, then the leadnut is tightened against the block. This is an incremental process.

Finger tighten all nuts and jog the machine.

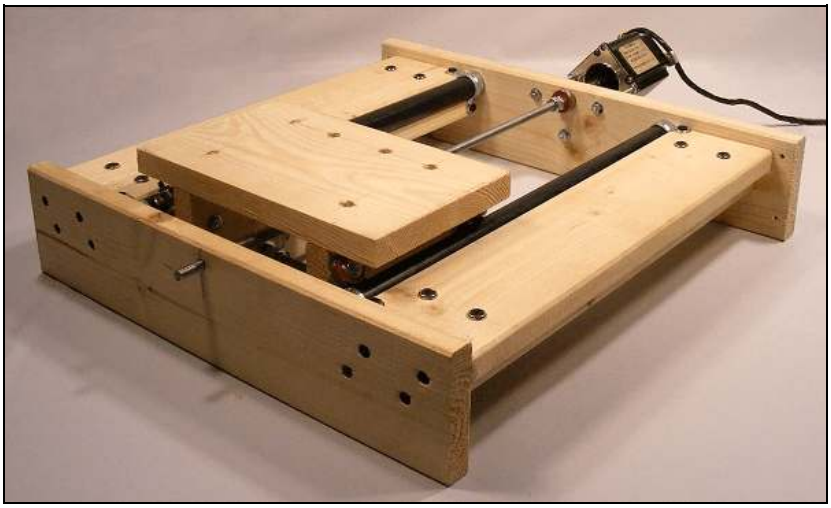


Tighten the block into place.

Tighten the leadnut into place.

Working incrementally, while checking for excess drag by jogging the stepper, will align the axis. Again, it is a trial and error process that is done by tightening each nut a small amount at a time.

Note that the heads of the tee nuts are not always square with the tee nut's threads. Rotating the tee nut on the leadscrew can often resolve excess drag.

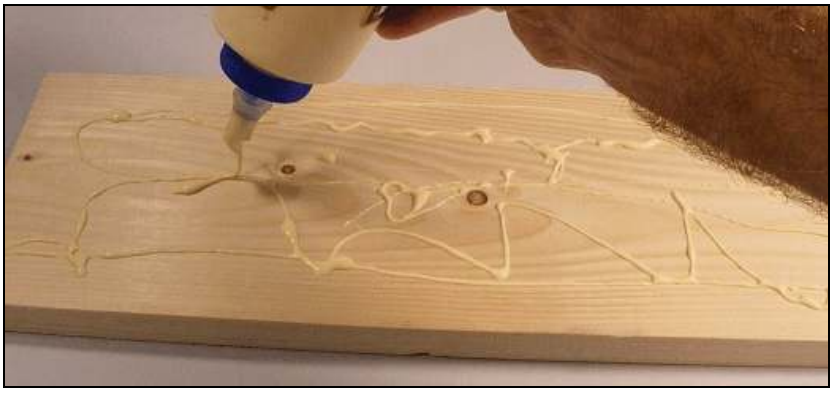


Completed Y table frame and bed.

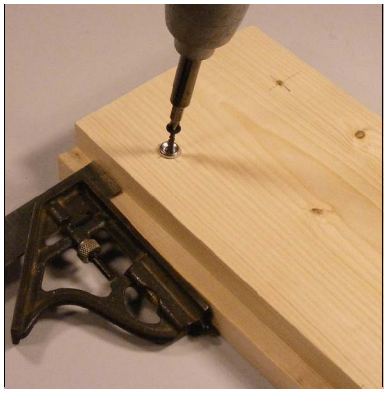
Gantry Beam

The boards for the beam have to be cut and drilled as shown on page 35 before the following work is started.

Spread glue on the boards, and glue and screw the boards together. The boards are offset from each other by 1/2 inch, like the Y table frame boards.



Spread glue.



Drive screws.

The screws are 1-5/8 inch drywall screws. Finish washers or flat washers with the drywall screws will keep the screws from protruding through the back of the gantry.

The rails are installed the same way as the Y table frame's pipe rails were installed, as shown on page 48.

Install a rail.

Both rails installed.

Attach Beam to Ends

These two end boards have to be cut and drilled as shown in the template section, page 32.
The gantry beam is glued and screwed between these two end plates.

The beam is angled to give clearance for the stepper hardware. Right image.

Match marks for the gantry beam alignment are drawn at the top, and at 6 inches from the top edge of the gantry ends.

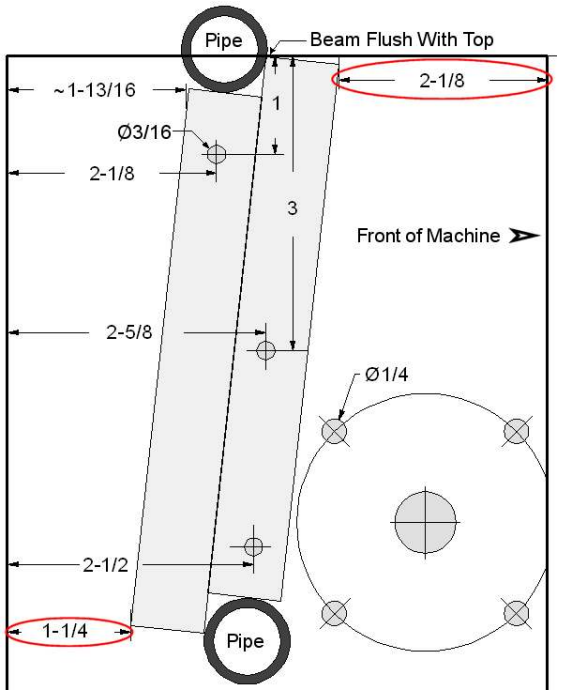
Gantry screwed together. The beam is angled.

The top mark is 2-1/8 inches from the front of the gantry end, and the bottom mark is 1-1/4 inches from the back edge of the gantry end. Right image.

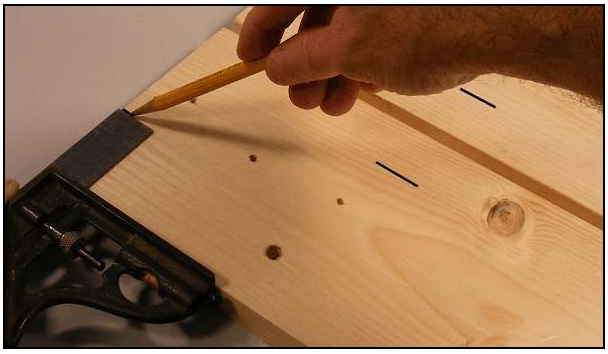
Draw the marks on the insides of both gantry ends. Spread glue on an end of the gantry beam, align the beam with the match marks, and drive 1-5/8 inch drywall screws into the end of the beam through the holes in the gantry end.

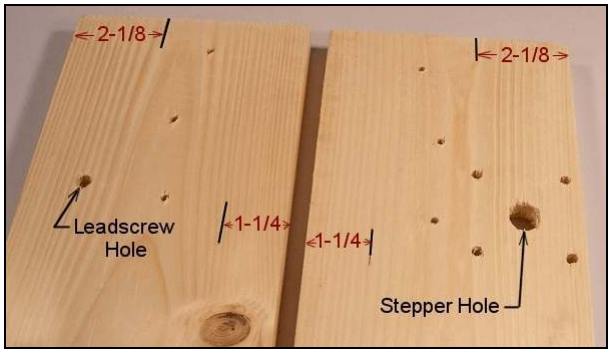
The four screws that tie the gantry beam together can be toward either the front or the back of the machine. It is important for the pipes on the beam to be oriented as shown, with the top pipe rail toward the back of the gantry beam.

The first end is easier to align when the gantry beam is stood on its end, and the gantry end is placed on top of the beam's end. Bottom middle image.
The second gantry end is installed with the gantry placed on the ends' edges on a flat surface. This will position the ends so they are aligned with each other. Bottom right image.



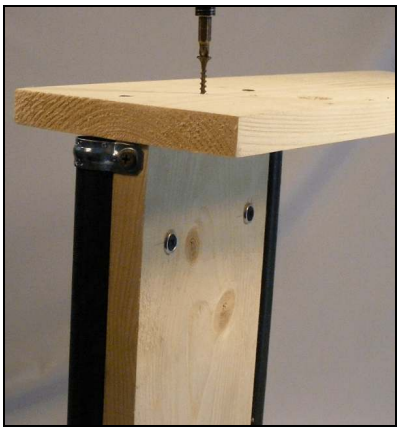
Match marks for the gantry beam on the stepper end. This view is from the inside of the gantry. The leadscrew end is mirrored.

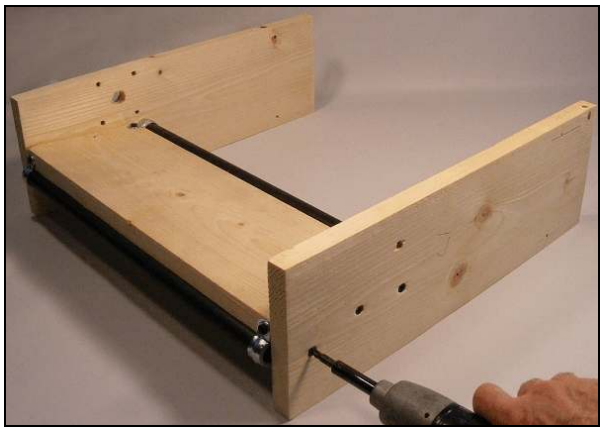

Draw the match marks.



Match marks are mirrored from each other.


Glue end.


Drive screws in one end.


Glue and screw the second end.

Attach Gantry to Y Table Frame

There are two holes drilled in each gantry end for the screws that tie the gantry to the Y frame's rail supports.
There are also two screw holes at each end of the Y table frame's stepper end plate.

The gantry may have to be adjusted for square later, so the gantry is not glued into place yet.

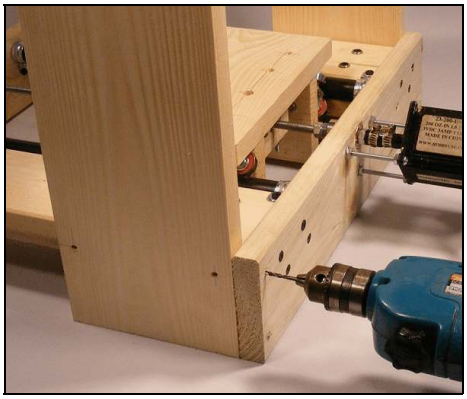
This squaring will be done by offsetting one end of the gantry from the Y stepper board. Hopefully this will not be necessary, but offsets do accumulate.

Gantry on table frame.

Place the X gantry on the Y table frame so the gantry ends abut the Y axis' stepper end board.

Drill pilot holes into the gantry end boards through the existing holes in the stepper end board. Right image.
Screw the end to the gantry. Third right image.

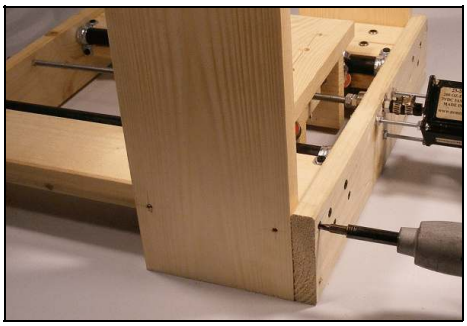
Should adjustments have to be made, these screws will be in the same position, but with shims between the gantry ends and the Y frame's back stepper board.



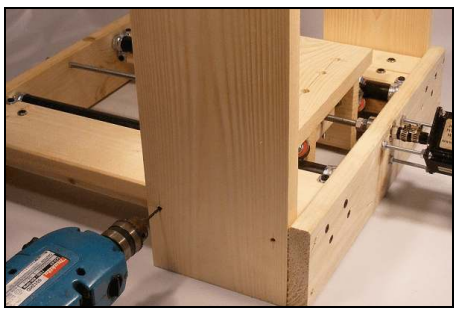
Drill pilot holes through the holes in the Y stepper board.

At this time, only the front screw is driven through each gantry end into the Y rail supports. Bottom images.
If it is necessary to realign the gantry later, it will be easier to reposition only one screw per side, rather than removing two screws and re-drilling two sets of pilot holes.

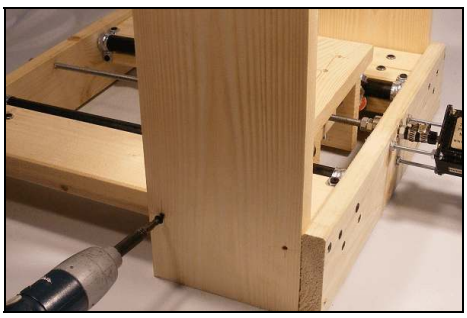
Drill one pilot hole per side, and screw the gantry end plates to the Y rails supports. Images below.



Drive 1-5/8 inch drywall screws.



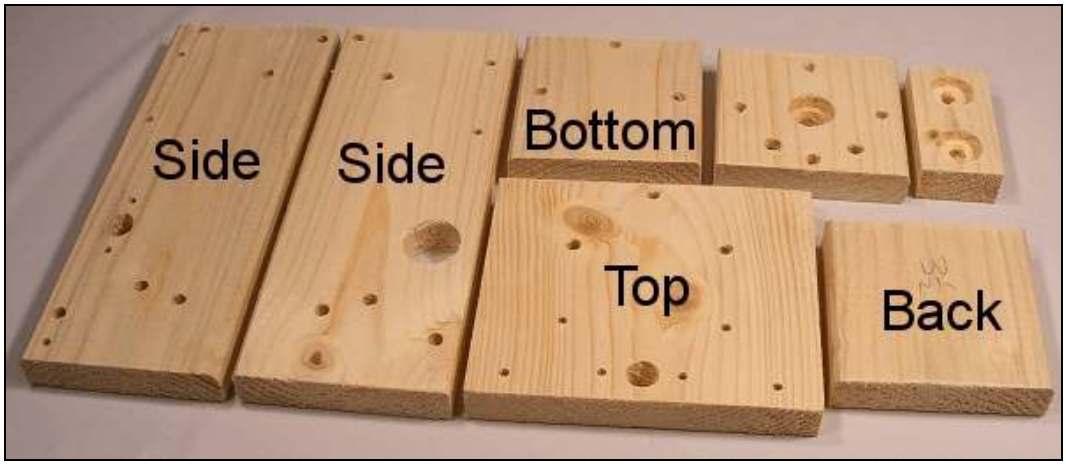
Drill only the front pilot hole in the side.



Drive one screw into the Y rail support.

Z Carriage

Cut and drill the parts as shown in the templates section on page 36.

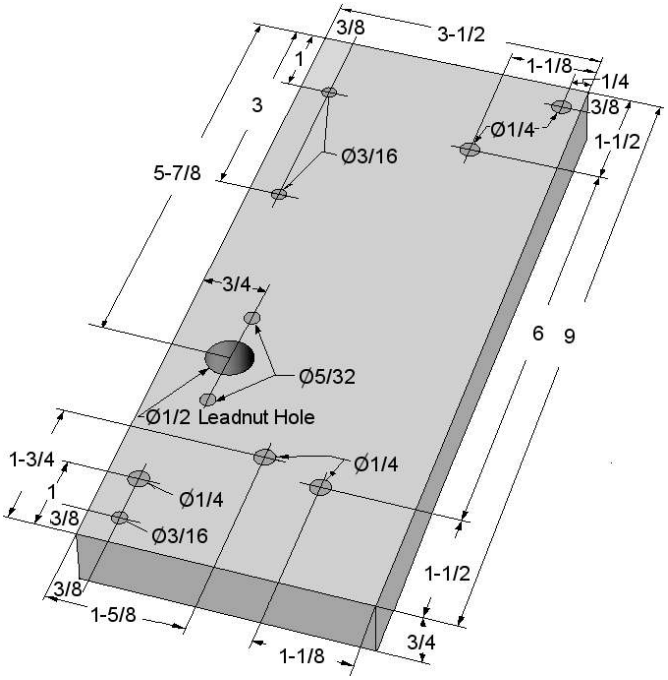


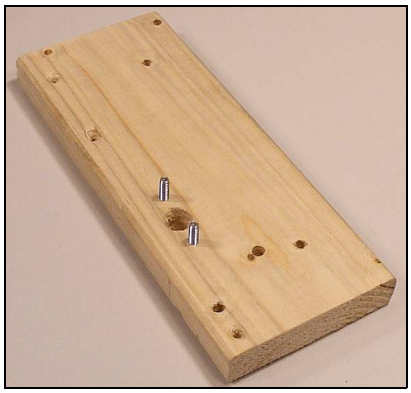
Wooden carriage components made of 1x4 and 1x6 boards.

Attach Sides to Back

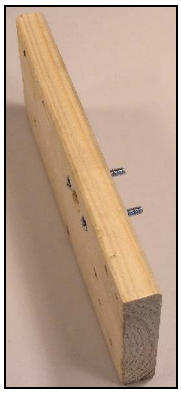
Install two #10 x 1-1/4 screws into the two 5/32 inch holes that are on each side of the 1/2 inch leadnut hole. This can be done later, but it is easier to do now while there is easy access to the inside of this part.

The screw threads should point outward as shown in the images below.





Install 1-1/4 screws in small holes.



Screws are tight in holes.

Attach the two side pieces to the back. The back is 3-1/2 x 3-1/2 inches. The wood's grain of the back is oriented width-ways as shown in the images.

The process is the same as was done with the other 1-5/8 inch drywall screw connections.

Align the parts. The top and back edges are flush. Far right image.

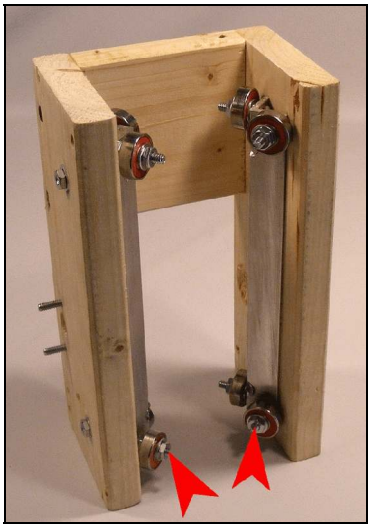
Use the existing holes in the sides as guides for 7/64 inch pilot holes.
Glue and screw the parts together.

Glue and screw the sides to the back.

The back and top edges of the pieces are aligned.

Install Trucks

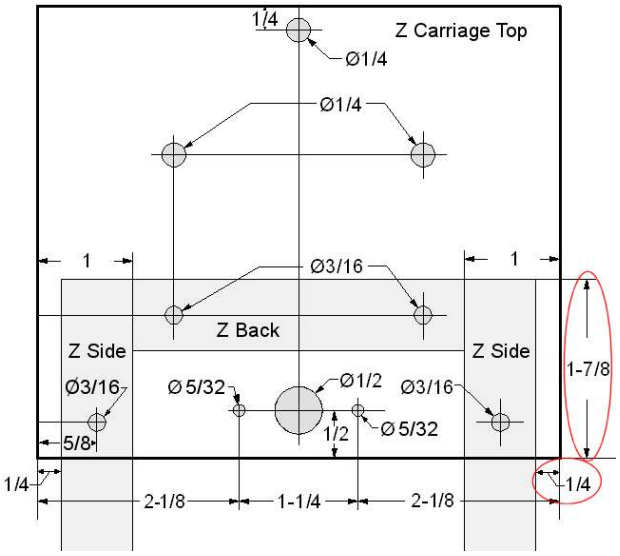
Install the trucks on the inside of the carriage. The holes for the trucks' mounting screws are 1-1/8 inch from the front edge of the carriage sides.
The trucks are held in place with 1-1/2 inch flat head #10 machine screws. Use washers with the nuts on the outside of the carriage.



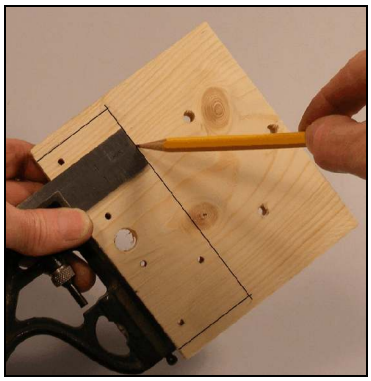
Install trucks with #10 x 1-1/2 flat head machine screws. Bottom front axles are 3/4 inch.

Install Top

Draw the match marks for the carriage sides on the bottom of the carriage top plate. Either side of the plate can be the bottom.

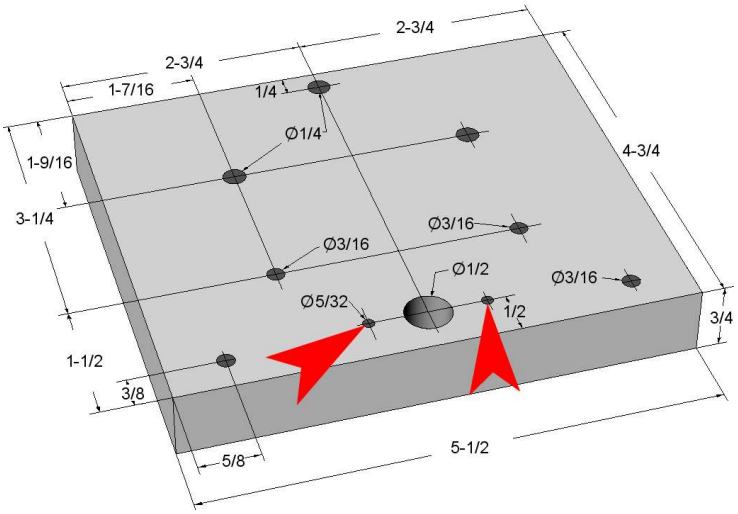


The back of the carriage is 1-7/8 inch from the front edge of the top.
The sides are 1/4 inch from the top's edges. See the above and right images.



Draw the match marks for the carriage body.

Drive #10 x 1-1/4 inch machine screws into the 5/32 inch holes in the top plate. Drawing below.
The heads of the screws are on the bottom side of the plate. The bottom is the side on which the match marks were drawn.



Holes for #10 x 1-1/4 machine screws.

Drive in the screws for the leadnut.

Align the carriage body with the top plate's match marks. Near right image.

Drill pilot holes through the existing holes in the top plate into the top edge of the back plate. Far right image.

Spread glue on only the top edge of the back of the carriage. Lower left image.

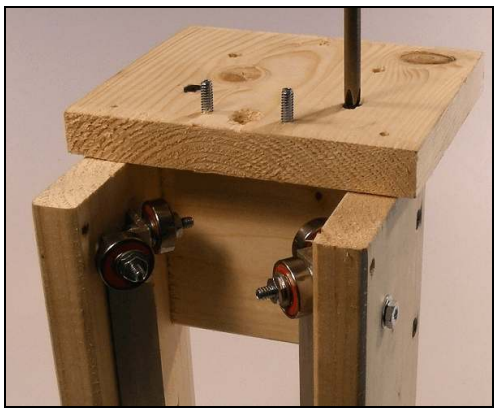
Align sides and back to match marks.

Drill pilot holes into back only.

Do not glue the tops of the sides. The sides need to be able to be flexed to tighten the bearings against the Z rails.

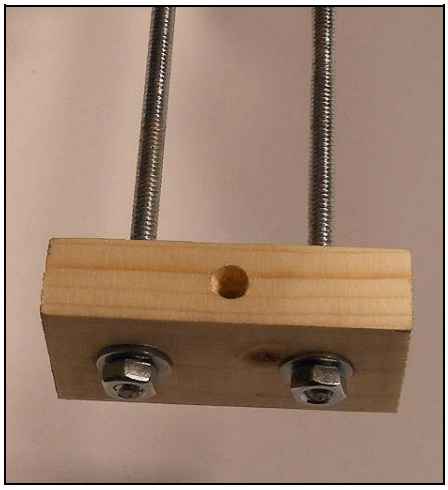
Drive 1-5/8 inch drywall screws into the two holes.
Do not drill or drive screws into the tops of the sides at this time.

Spread glue on top of back only.



Screw top to back.

Assemble Z Rails



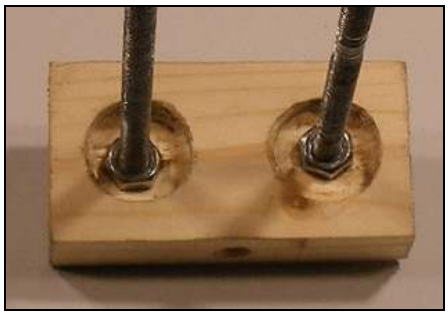
Attach threaded rod to the Z router mount. Nuts and rod ends are flush.

The Z router mount and Z stepper plate need to be cut and drilled before assembly begins. Directions are in the template section, pages 43-46.

Insert the 1/4-20 x 17-1/4 inch threaded rods into the Z router mount.
For ease of construction, these rods should be at least 1-3/4 inches longer than the Z pipe rails.

Nuts with washers are used on the bottom of this part.
The ends of the threaded rods are flush with the bottom of the nuts. Above image.

Nuts can also be used on the inside of this piece, but they are not required. Tightly sandwiching this Z router mount between the two sets of nuts will make later adjustments easier because the threaded rods will not freewheel in their holes.
The inside nuts do not require washers. They will seat themselves in the wood, which will help to hold them in place.



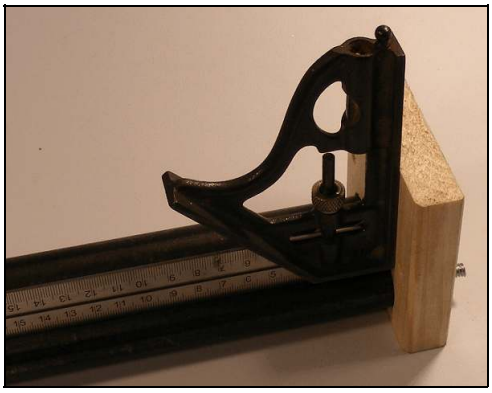
Optional nuts on the inside ease further adjustments.

After this Z router mount is on the threaded rods, the pipe rails can be slid over the rods.

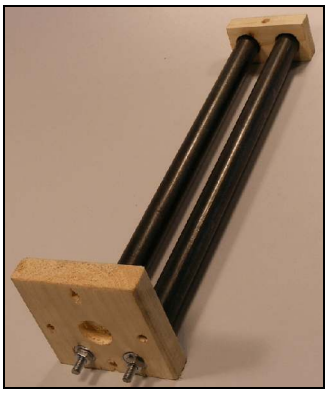
The Z stepper plate is then attached to the rods with nuts and washers.

Different lengths of pipe and different depths of recesses can be addressed by using large washers as shims. Left image below.
The Z stepper plate should be square with the rails. Center image below. Firmly tighten the nuts on the rods.

Place pipes on threaded rods. Washers can be used as spacers.



The Z stepper plate should be square with the pipe rails.



Z rails clamped between the Z stepper plate and the Z router mount.

Install Z Rails


Slide rails into carriage.


Rails installed.

The Z rails are installed into the carriage.
Place one rail in the bearings with the other rail resting on the edges of the other set of bearings. Note the orientation of the Z stepper plate. It overhangs the carriage top.

Twist the rail assembly so it slides past the top-outside bearings and rides on both sets of bearings. It may be necessary to flex the carriage sides, or to remove the two outside bearings to snap the rails into place.

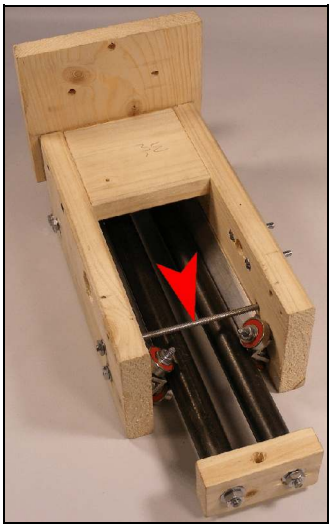
The Z tension rods are now installed.

The rods are #10 threaded rod cut to 5-1/2 inches long.
These rods should be long enough to protrude from the sides of the carriage with just enough stock to support a nut and washer at each end. The rods can be cut down later if they protrude too far and restrict carriage movement by bumping into the gantry ends.

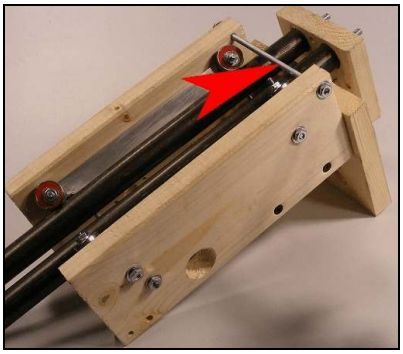
The back tension rod is inserted through the 1/4 inch holes that are 1-5/8 inches from the back of the carriage side. Right image.

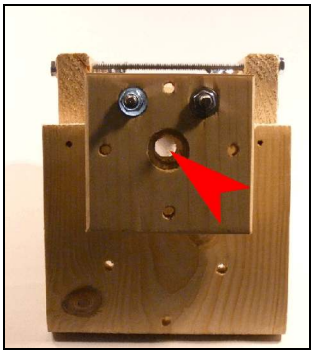
The front tension rod goes in the holes that are at the very top front corners of the carriage sides. Left image below.

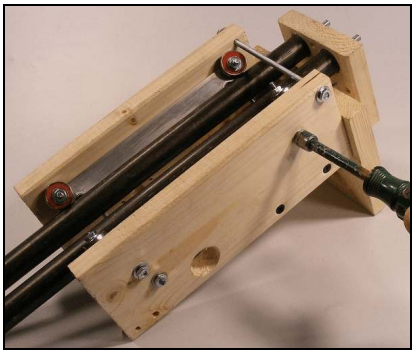
The Z rails and trucks have to be aligned before the tension rods are tightened.


Install back tension rod.

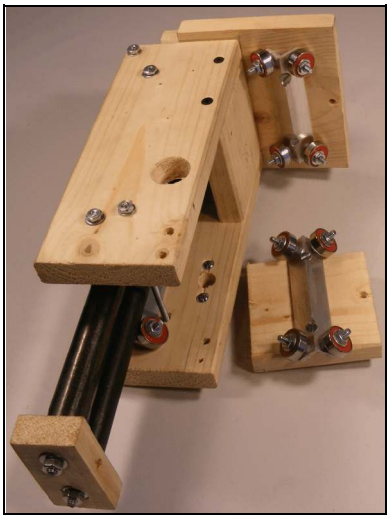
Align the leadscrew hole in the Z stepper plate with the leadscrew hole in the top of the carriage. Middle image below. Tighten the trucks and top tension rod so the rails remain aligned as they move. Final adjustment is done later.


Install front top tension rod.


Align holes in carriage top and Z stepper plate.


Tighten trucks and top tension rod.

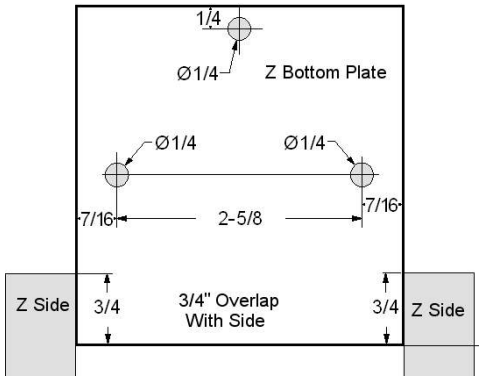
Install X Bearing Trucks and Z Bottom



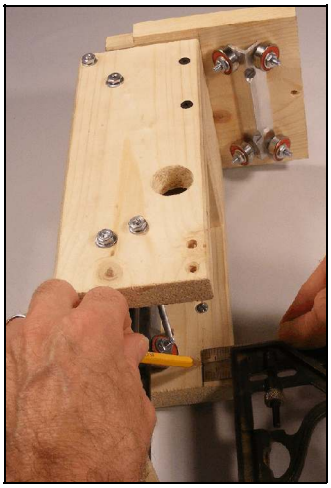
Attach the Y trucks to the carriage top and bottom plate.

Install the X trucks onto the carriage top and bottom plate.
The trucks are the shortest ones made for this machine.
Like the bearing trucks on the other axes, they are held in place with flat head #10 x 1-1/2 inch machine screws.
Washers are used with the nuts.

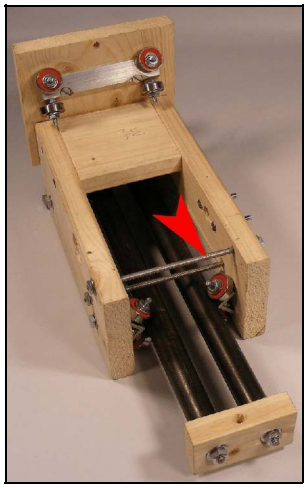
Draw a match mark on the inside of each carriage side.
The marks are 3/4 inch from the back edge of the carriage and next to the two bottom back holes. Left photo below.
These marks give a rough guide for the alignment of the bottom plate against the carriage sides.



Sides overlap the bottom by 3/4 inch.



Draw match marks at 3/4 inch for bottom plate.



Install the bottom plate tension rod.

Loosely install the bottom plate tension rod in the 1/4 inch holes in the bottom back of the carriage sides. Far right image.

This rod is the same as the Z bearings' tension rods. It is cut from #10 threaded rod and is around 5-1/2 inches long.
This rod adds stability to the bottom of the carriage by clamping the sides to the bottom plate. Wood screws alone are insufficient.
This tension rod will be firmly tightened after the carriage is riding on the rails.

Install the bottom plate so it aligns with the match marks. The 1/4 inch hole near the back edge of the bottom plate is positioned away from the carriage. The bottom plate can be against the tension rod. The plate will be adjusted later. Tighten the tension rod enough to hold the bottom plate between the carriage sides.

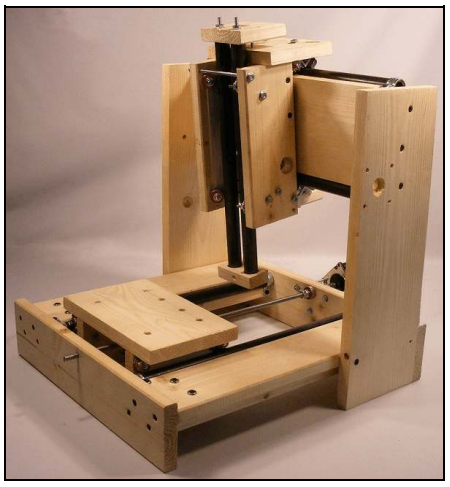
Install bottom plate.

Install Carriage

Move the table bed to the front of the machine.

Move the table bed to the front of the machine. Otherwise, it will get in the way of the Z rails while parts are assembled. The table bed's leadscrew can be turned by hand to move the bed.
If using a drill to turn the leadscrew, disconnect the stepper from the drive. The stepper will act as a generator, and could damage the drive.

For the machine to work properly, the Z rails need to be perpendicular to the table bed, and the gantry leadscrew has to clear the carriage as the leadscrew spans the two gantry end plates.
This is accomplished in a number of steps. The order of the steps is not critical. It is likely that it will be necessary to "work in circles" while incrementally adjusting the parts.



Hang carriage on gantry.

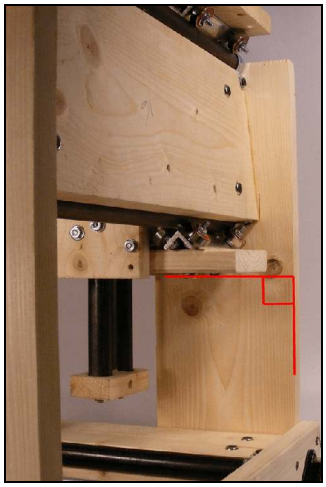
Hang the carriage on the gantry pipes by the carriage's top bearings. If needed, swing the carriage's bottom plate down to clear the bottom gantry rail.

Lift the bottom plate's bearings against the bottom gantry rail. The bottom plate tension rod should be tight enough to hold the bottom plate in place.

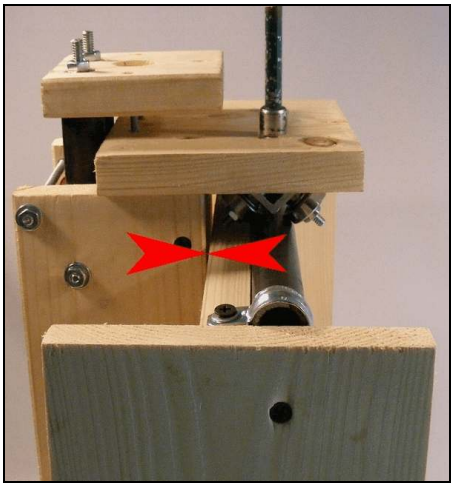
Align the bottom plate so it is square with the gantry ends. Lower left image. It does not have to be exactly true, but if it is off too far, it may be difficult to align the bearings and X tension rod.

The back of the carriage is initially spaced 1/8 inch from the gantry beam. Far right image.
This spacing is not critical.
It is important for the carriage to not drag on the gantry, and later, for the leadscrew to move freely.

This spacing is done by moving the top bearing truck on the top plate. Tighten the top truck's flat head screws' nuts to hold the truck into place.
Right image.

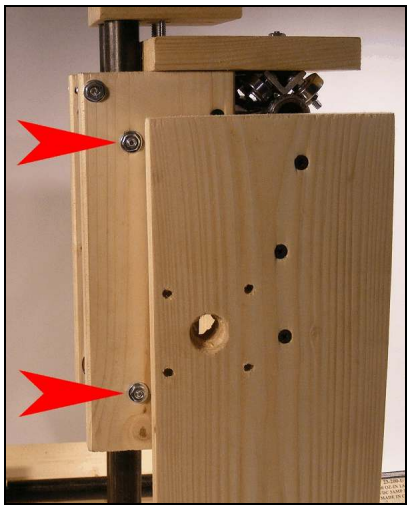


Square Z bottom plate with the gantry ends.



Space carriage 1/8 inch from gantry, and tighten the nuts on the screws.

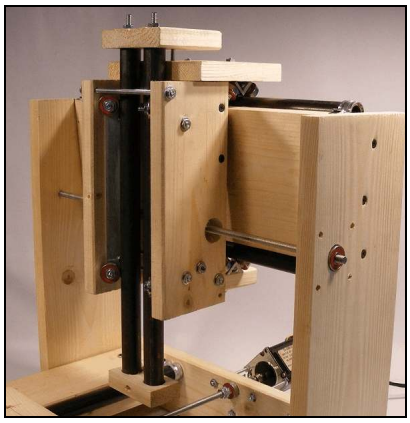
The carriage can be aligned with the gantry ends by aligning the two Z bearing truck attachment nuts with the end of the gantry. Right image.
The nuts should be spaced the same distance from the edge of the gantry end plate.


Align carriage with gantry.

Adjust the X bearing trucks, and/or the carriage bottom plate to align the carriage. The bottom plate does not have to align with the match marks that were drawn at 3/4 inch inside the carriage sides.

Temporarily install the leadscrew. Insert a bearing into the gantry recess to support the leadscrew. Right, second image.

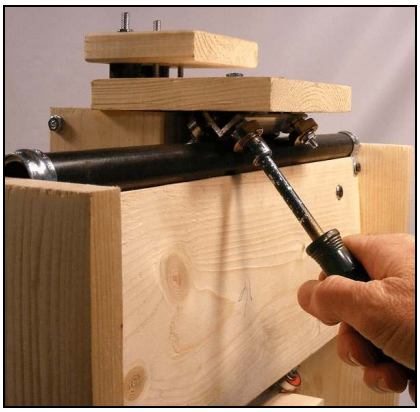
Hopefully the holes in the carriage will allow the leadscrew to pass from gantry end to gantry end. However, this may not be possible. Due to the softness of the wood, and other offsets, the leadnut hole in the carriage may not be aligned well enough for the leadscrew to properly fit.

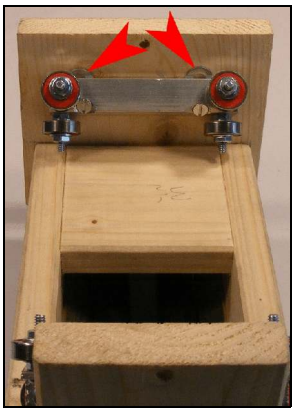

Install leadscrew with bearing.

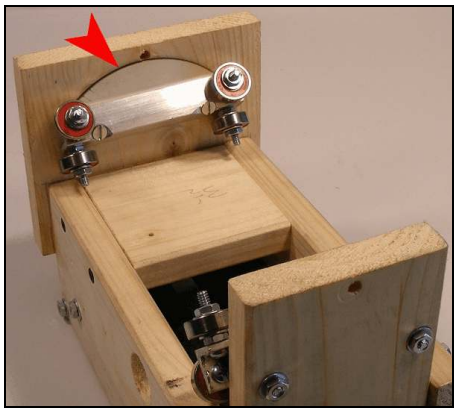
There are a number of ways to resolve this misalignment.
One is to enlarge the hole for the leadnut. But this may require moving the leadnut support screws, so re-drilling is not the first choice. But it is not a problem if this turns out to be the necessary solution.

The carriage can be raised by moving the bearings on the top truck on their #10 axles. Not all bearings have to be moved, and adjusting the ones that are easily accessible from the back of the carriage may suffice. Lower left image.

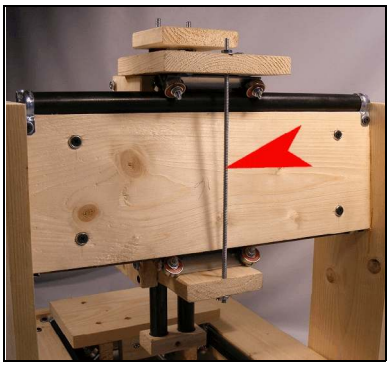
Should more lift be needed, spacers can be placed between the truck's aluminum angle and the carriage top plate. Washers, sheet metal, or pieces cut from an old CD can be used as spacing shims. Lower middle and right images.


Adjust bearings on axles.


Washers as shims.


Piece of CD used as shim.

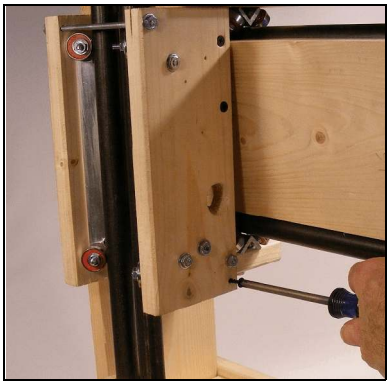
Once the carriage can travel without dragging on the leadscrew, the X tension rod can be installed.


Install tension rod.

The tension rod is made from #10 threaded rod that is cut to 10-1/2 inches long. It passes through the holes in the back of the top plate and bottom plate.
It may have to be removed for further carriage alignment, so there is no need to tend to its final positioning at this time.

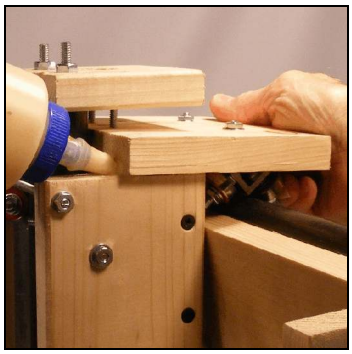
The tension rod is tightened enough to check that the carriage can still move without dragging on the leadscrew while the bearings are aligned on the rails.
The top plate is not completely secured into place, so do not tighten the tension rod too tightly.

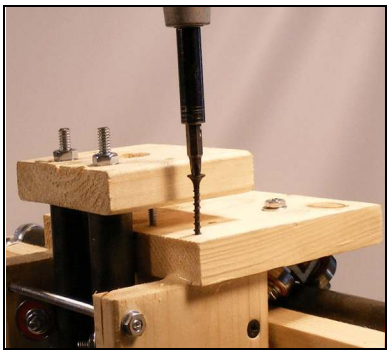

Drill pilot for bottom plate.


Drive screws into bottom plate.

After the alignment is good, drill a pilot hole into each side of the bottom plate. Drill through the existing 3/16 inch hole in the bottom of each carriage side. Right image.
The holes do not have to be centered in the sides of the bottom plate.

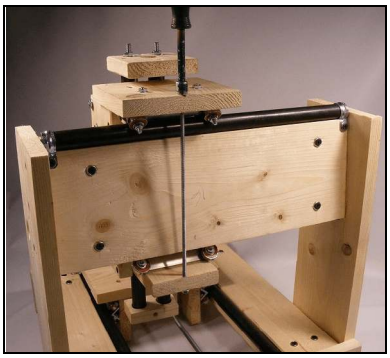
Drive 1-5/8 inch drywall screws through the carriage sides and into the sides of the bottom plate.


Open joint and glue.


Screw top to carriage sides.

Check that the Z rails are vertical and still move well in their bearings. Adjust the Z trucks and tighten both Z bearing truck tension rods.

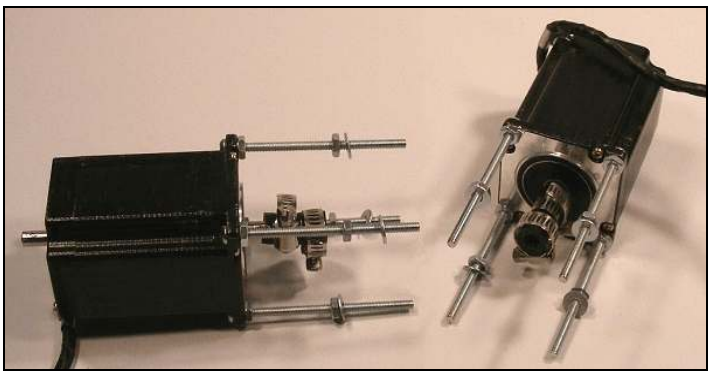
The top can be glued and screwed into place now.
Drill pilot holes into the top of the sides of the carriage through the existing 3/16 inch holes in the top plate.
With the X tension rod loose, press down on the back of the top so its front edge pulls away from the carriage sides. Squeeze glue into the void. Above image.
Drive 1-5/8 inch drywall screws through the top and into the sides. Above right image. Use longer screws if the 1-5/8 inch screws do not hold the top securely. There will be substantial loads here.


Tighten X tension rod.

The X tension rod is tightened into place. The rod is tightened so the bearings ride firmly on the rails.

Check that the carriage and Z rails move well, and tighten all hardware into place.

Install Leadscrews and Steppers



Steppers with hose, clamps and machine screws.

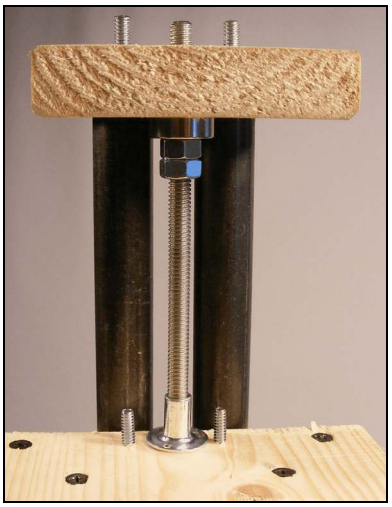
The steppers and leadscrew assemblies for the X and Z axes can be installed after the carriage and Z axis move smoothly and firmly.

The steppers, leadnuts and leadscrews are installed the same way as was done on the Y table bed axis, except four, rather than three, 3 inch long machine screws with nuts and washers tie the steppers to their supporting boards. Hose and hose clamps attach the stepper shafts to the leadscrews. Above image.

The leadscrews are supported by bearings that are in recesses in the X gantry end and Z stepper plate.

Each axis' leadscrew is installed before its stepper is put in place.

Leadscrew with bearing, nuts and leadnut.



Leadscrew with nuts and bearing supporting the stepper plate.

Z Leadscrew and Stepper

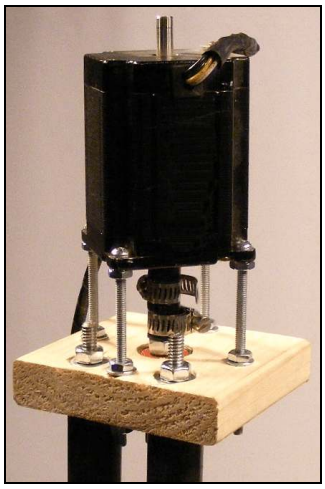
Insert the Z leadscrew through the leadscrew hole in the stepper plate. The leadscrew is 5/16-18 x 7 inch threaded rod.
From underneath the stepper plate, install a bearing, two nuts and the leadnut onto the leadscrew. Upper left image.

Insert the bottom end of the leadscrew through the leadscrew hole in the carriage top plate.

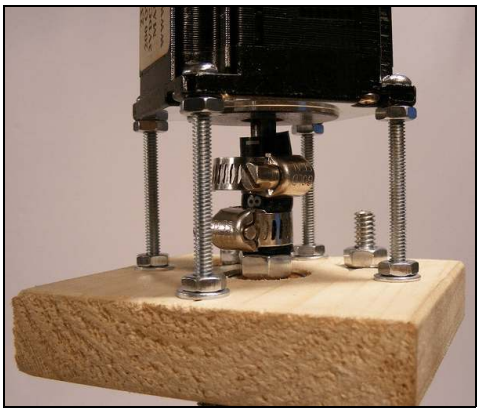
Press a bearing into the stepper plate's top recess, and thread a nut onto the leadscrew. The leadscrew extends past the nut ½ inch. Near right image.

The stepper, and its hose, clamps and machine screws, are loosely mounted to the stepper plate.

Top bearing with nut.

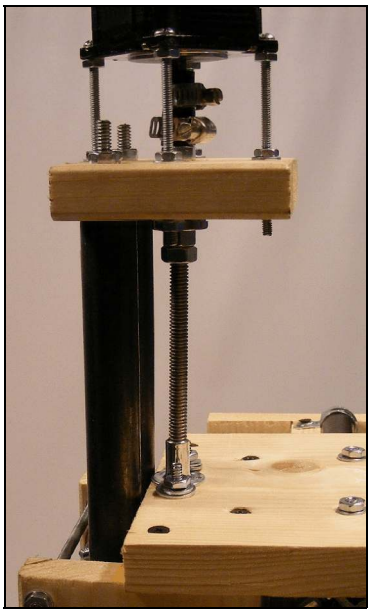


Stepper on plate.



Hose with hose clamps. The hose abuts the nut that is against the bearing.

The bottom Z bearing is supported by two nuts that are tightened against each other.

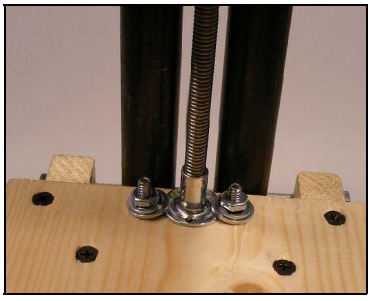


Z Stepper mounted on axis.

The bottom Z leadscrew bearing is abutted to the bottom of the Z stepper plate, and held in place with the two nuts. Middle image above.
This bearing, instead of the stepper, should carry the weight of the axis.

Nuts with washers are threaded on the screws that are next to the leadnut on the carriage top plate. Right image.
A 1/4 inch and #10 washer is used with each nut.

The stepper is powered on, and jogged as the hardware is incrementally tightened into place.
The stepper's speed should initially be set low as parts are first aligned and tightened. The speed is increased as alignment is improved.

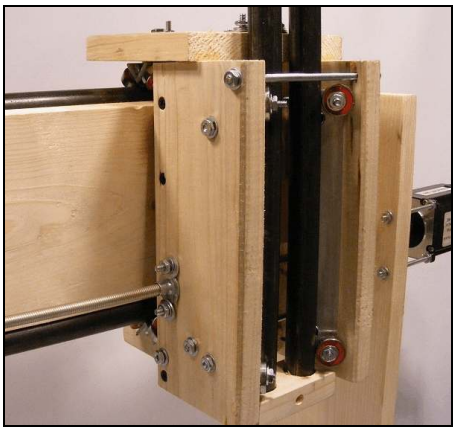


The leadnut is held in place with nuts and washers on the machine screws.

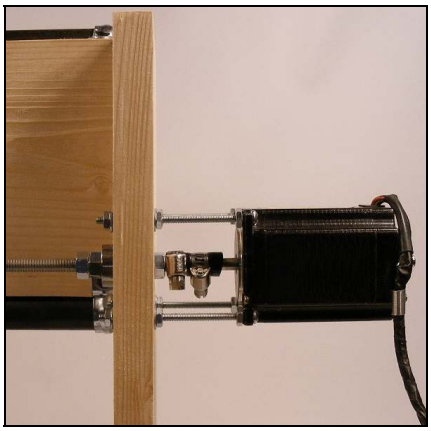
X Leadscrew and Stepper

The installation process is the same for the X axis. The leadnut, nuts and bearings are installed on the leadscrew as it is passed through the gantry and carriage.

The stepper is installed and then activated for the final adjustments.



X leadnut on carriage side.



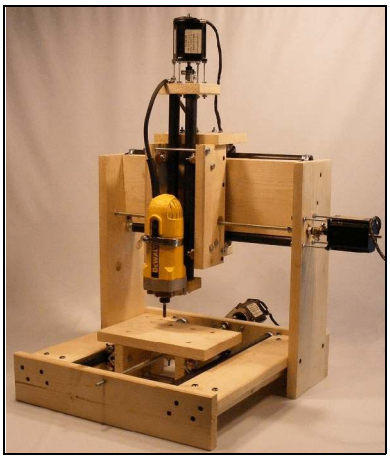
X Stepper on gantry end.

Install Router

The router is tied to the Z rail's bottom block with a 1/4-20 x 2 inch bolt and washer. The 2 inch bolt threads into the router base's existing tapped hole.

A band clamp or strap ties the middle section of the router to the pipe rails.

For clarity, the Z rails were removed from the machine in the following photos. However, the router installation is done with all axes assembled.



Router on carriage.

The band clamp or section of metal plumbing hanger tape is bent to fit between the pipe rails. Right images.

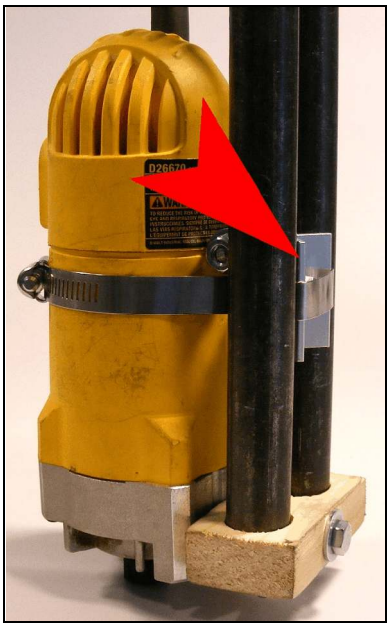
The band clamp is for 4 inch duct. The clamp should not have thread-slots completely around its band, or it will break at the slots when bent.

Four inch band clamp.

A 12 inch section of plumbing hanger tape can be used in place of a band clamp. The metal plumbing tape is softer and much easier to bend into shape.

A 1/4-20 x 1 inch bolt, with washers and a nut, is used to close the plumbing tape around the router. Near right image.

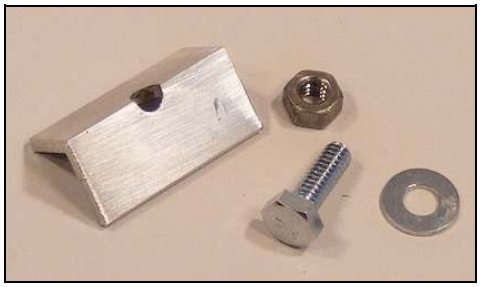
Plumbing tape with bolt, nut and washers.



Aluminum angle band anchor.

A 1-1/2 inch long section of 1/8 x 3/4 inch aluminum angle prevents the band strap from pulling through the rails. Red arrow in above right image.

A 1/4-20 x 3/4 inch bolt with a nut and washer passes through the aluminum angle anchor. The nut and washer will be between the strap, and will prevent the angle from twisting sideways between the rails.

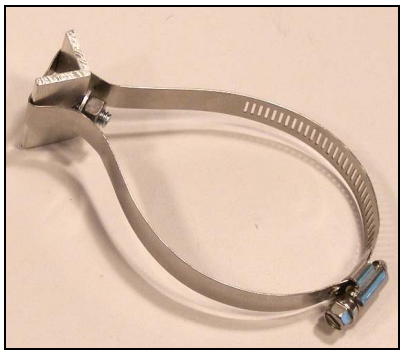


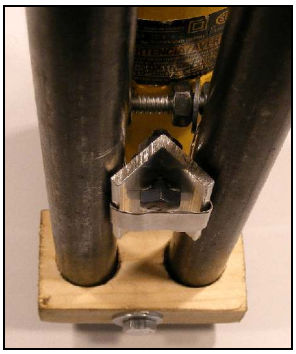
Parts of band anchor.

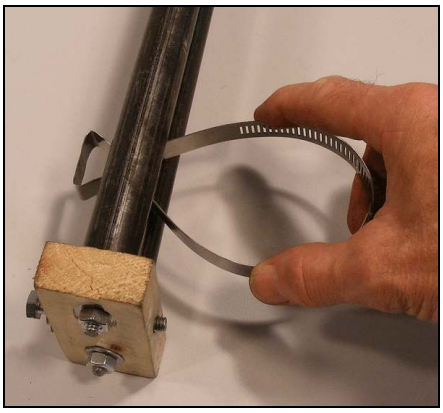
Band anchor.

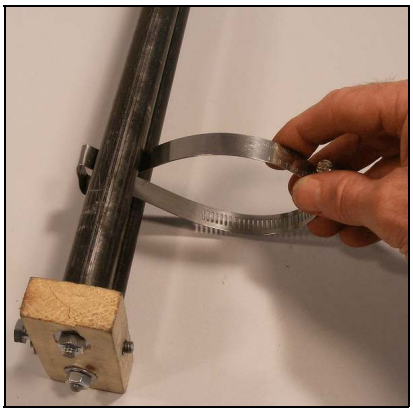
The images on the right show the orientation of the aluminum angle anchor in the band clamp.

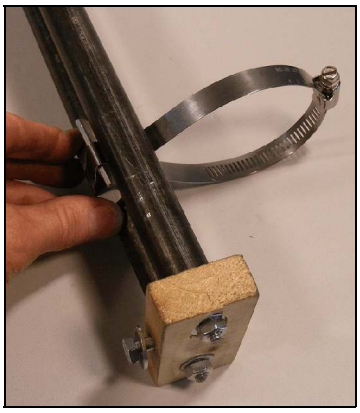
Pliers are used to bend the band clamp to shape. It is then slid between the rails. The clamp is twisted into position, and the aluminum anchor is slid in the clamp's bent section between the pipe rails. Lower images.


Position of angle in band clamp.


Angle held in place by band or strap.


Slide band clamp between pipes.


Twist band clamp into place.

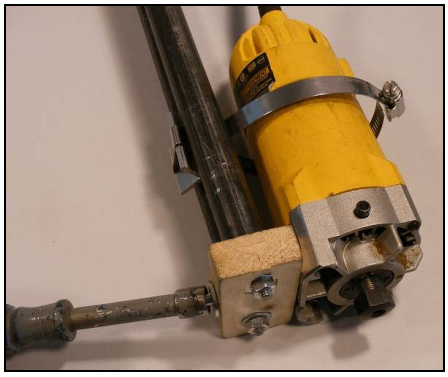

Insert angle in band clamp.

Plumbing tape is easier to bend than the band clamp, and it does not have to be pre-bent before installing it between the rails. Tensioning the plumbing tape against the angle anchor will bend it into shape.

The router is installed after the band clamp or plumbing tape and angle anchor are in place.

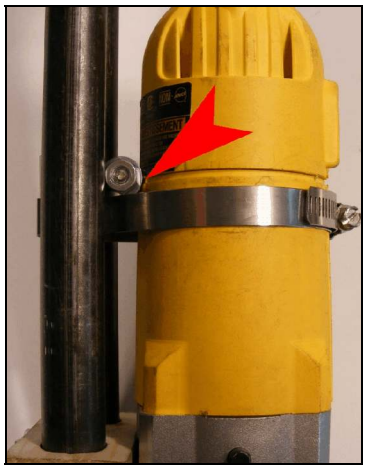
Attach the router to the wooden block with a 1/4-20 x 2 inch bolt. A washer is under the bolt's head.
Tighten the bolt so the router's base is against the wood, but do not completely tighten the bolt.

A cradle that stabilizes the router, and spaces it from the rails, is made from a 1-1/2 inch section of 1/4-20 threaded rod.
A pair of nuts loosely sandwich washers at each end of the threaded rod. Right image.
The washers are not tightly clamped into place, but are allowed to rest at an angle so they will cradle the router's body. Images on next page.


Attach router to base.


Router cradle.

The cradle's washers are angled outward around the router.



Cradle rests in housing junction.

Tighten base and band.

The cradle sits on top of the band clamp. The washers in the cradle rest in the junction between the router's cap and body. Above middle image. The router's plastic is the thickest at this location.

The band clamp is positioned so it supports the cradle. The 2 inch bottom bolt is tightened, and then the band clamp is tightened.

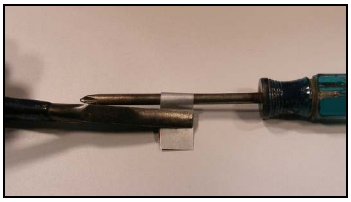
The router should be perpendicular to the table bed. Washers can be used to offset the router from the base. Washers can be used as shims to space the router from the cradle.

Since the Z travel is not very far; generally, if the router appears to be perpendicular, it is true enough for most work.

Plumbing hanger tape clamp.

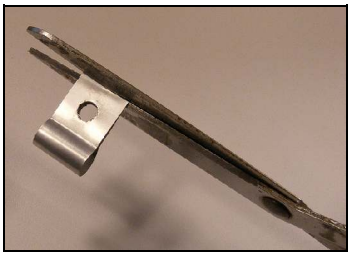
The router's cable can be attached to the top of a tension rod that is inside a Z rail.

A cable clip can be made of plastic or thin aluminum, such as a beverage can. Right images.

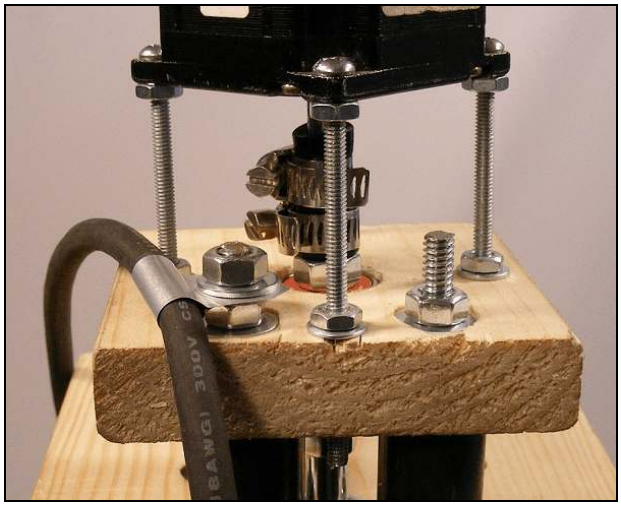


Bend metal around a shaft.

The cable clamp is held on the rod with a second nut and pair of washers.



Trim and drill.



Clamp between nuts and washers.

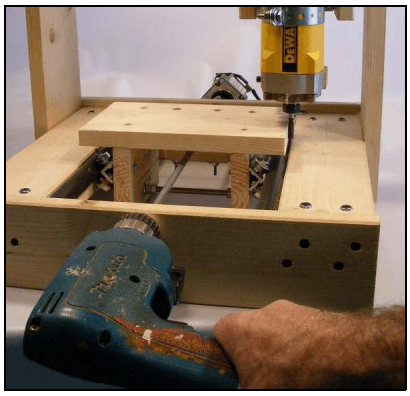
Square Table


Trim table edge.

The table bed is routed on two edges, and checked for square.

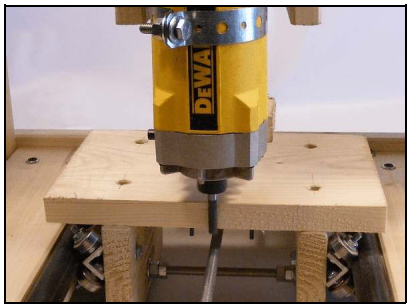
When not square, the gantry is loosened from the table bed frame and shimmed to repair the offset.

The steppers do not have to be powered for this process. The leadscrews are turned one at a time, so a power drill can be used to turn the leadscrews.
Using a drill may be more convenient than turning on the computer, drives and steppers.


Drill used to move axis.

Install a bit in the router, and align the bit and table bed by moving the carriage and table bed so the bit abuts the table's edge.
Move the table bed so the bit is not touching the bed, and turn on the router. With the drill or stepper, move the bed so the router trims the table's edge.

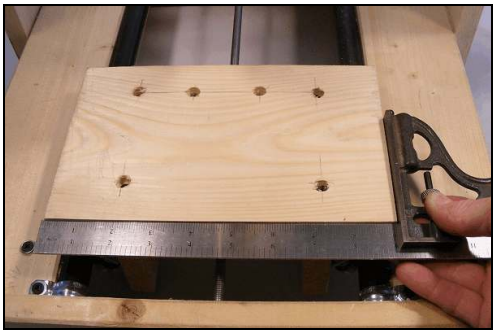
Repeat this process for the front of the table. The gantry's leadscrew will be turned this time.

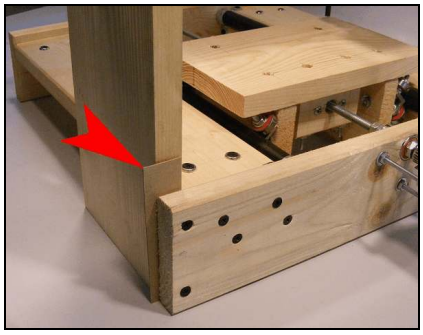

Trimming front edge.

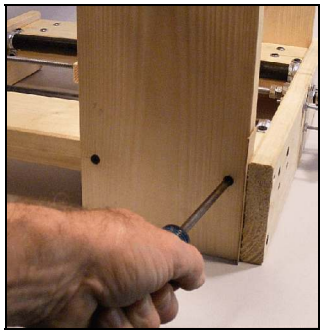
Check the table bed for square by aligning a square along the two trimmed edges. Lower left image.

When the trimmed corner is not square, the gantry to Y table frame screws in one end of the gantry are removed, and a shim is placed between the gantry and the Y stepper end plate.
The screws are then reinstalled. Lower middle image.

The shim can be a piece(s) of paperboard or similar. The shim can be trimmed for appearance when the squaring process is completed.
The front edge of the Y bed is the surface that will be altered by moving the gantry. Put the shim in the end of the gantry that will offset the router in the direction that corrects the existing offset.


Check for square.


Insert shim.


Drive in all screws.

This is a trial and error process that may require repeating of the trim and shim procedure.

Once the trimmed corner is square, the gantry can be permanently glued and screwed into place. The joints are opened just enough to allow glue to be squeezed into them, then all of the gantry end screws are installed and tightened.

Trim Table Top

The table bed's other edges and top can be trimmed once the gantry is permanently attached.
The two remaining edges can be trimmed the same way the first two were routed.
The table's edges can be used to square the stock that will be cut with this machine. Therefore, it is worthwhile to true all of the sides at this time.

A g-code for planing the table top is available on the website. It is linked on the Site Map page.

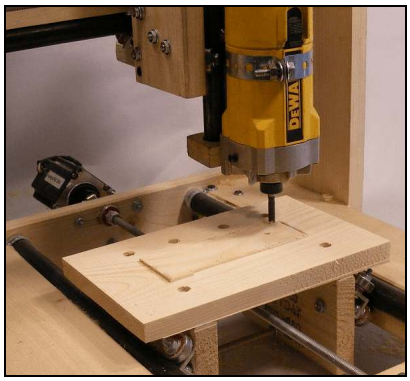
The code is for a 1/4 inch flat end bit, either end-mill or router bit.

The code only cuts in the X and Y direction. The Z axis does not move except for initial and final clearance moves.

Router at origin.

Activate the drives and jog the router around the table top while watching to see which section of the table top is the lowest as compared to the end of the bit.

The bit is lowered so it rests on the lowest section of the table top.
The Z axis is zeroed.
The router bit is jogged to clear the table top, and moved to the front left hand corner of the table.

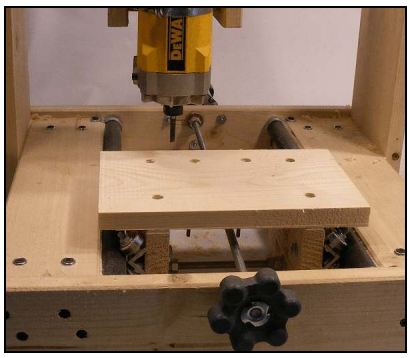


Surfacing top.

The origin, point zero, zero, zero, for this g-code is the outside edge of the table top. Top image.
The cut area is larger than the table top, so the bit may cut air on the first few passes. The pattern is a rectangle that decreases in size as it approaches the center of the top.

The bit removes over half its width per pass. This width of cut with a shallow depth can usually be cut at the fastest speed the steppers can deliver. The g-code is for 40 ipm.
This can be changed by editing the g-code or by changing the feed-rate override.

The machine should be checked for loose hardware. Thread locker is applied to hardware once it is clear that parts are properly aligned and working well.



Top planed.

Stepper Setup and Performance

A note regarding the axis names and orientation:
The X, Y, and Z axes were named in a way that was consistent with Mach software. The names are also consistent with the default orientation of some CAD software. However, these axis letter assignments can be altered. Set them in a way that is intuitive for the work environment.

Steps per Unit

The settings for the stepper will vary depending on the drives, steppers and software used. The documentation from the suppliers should be followed. The information here is an overview of some of the basics as they relate to this machine.

Mach2 or 3 is the recommended software; before the steppers can be run, the software has to be configured.

The values for "Steps per Unit" for Mach are derived as follows:

The steppers from HobbyCNC and Xylotex, like most steppers, move 1.8 degrees per step, which is 200 steps per revolution. This step increment can be made smaller with micro-stepping, which is set with jumpers on the drives.

For the drives used in this shop, Xylotex recommends 1/8 micro-stepping, which means there are 8 steps for every one of the 200 steps the stepper makes per revolution. Therefore, the software has to send 200 x 8 steps = 1600 steps per stepper revolution.

The leadscrews on this machine are 5/16-18 threaded rods, which have 18 threads per inch (tpi), as their name indicates. Therefore, the threaded rod, and thus the stepper, have to turn 18 times to move the axis 1 inch.

In this example with 1/8 micro-stepping, the stepper requires 1600 steps to turn one revolution, and the leadscrew has to turn 18 times to move the axis one inch, so the stepper has to receive 1600 x 18 = 28800 steps to move the axis one inch.
This is the value that is entered into the "Steps per Unit" box in Mach.

The reciprocal of this value is the resolution of the table. This is the smallest distance the table can be commanded to move, which is 1/28800 or 0.000034722 inch.

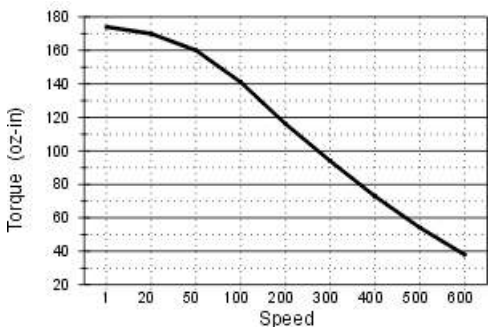
Though the software can send, and the stepper can respond to commands of this resolution, the table cannot engrave the head of a pin because the actual accuracy and tolerances of the leadscrew and leadnut are worse than the software can deliver.

These Step per Unit values are derived the same way for the HobbyCNC drives. The prototypes use ½ step micro-stepping.

The stepper receives 200 x 2 steps per revolution, and the 18 tpi leadscrew gives a Steps per Inch value of 7200, (200 x 2 x 18) and resolution of 0.00013889 inch. Again, this resolution is better than the table's accuracy or tolerance.

Speed and Torque

Steppers deliver their highest torque at low speeds. As shown in the generic graph below, the torque rapidly diminishes as the speed increases. Therefore, it can be difficult for a stepper to move an axis rapidly.



Stepper torque decreases with speed.

With a 18 tpi leadscrew the stepper will have to turn at 900 rpm to give an axis speed of 50 inches per minute. (18 x 50 = 900) This is fast for a stepper, and its torque will be far below its stated output.

Many steppers, when driven with small drives, cannot output enough force to move the table at higher speeds, even though they can turn rapidly with no load.

A prototype of this table uses the HobbyCNC 200 oz.in. system, and is able to rapid over 40 inches per minute (ipm). The 305 oz.in. system performs similarly on this machine. The larger steppers perform better than the 200s on the larger machines. If the steppers are to be recycled into other machines, it is highly recommended to purchase ones with torque over 250 oz.in.

As addressed previously, the faster a stepper turns, the lower its torque. Therefore, it is necessary to adjust the initial settings for the steppers' speeds to a low value, so the steppers will have enough power to turn against the heavier loads of a poorly aligned machine.

The steppers' speeds can be increased after the axes are aligned and running smoothly.

Steppers can be damaged when they are powered while stalled; therefore, it is better to not push them to their stalling point any more than necessary.

The speed of the axis is frequently specified in units per second rather than per minute; so speeds of less than 60 ipm will be in values less than one.
30 ipm will be 0.5 ips, for example.

With the HobbyCNC 200 oz.in. stepper and drive package, an initial value of 0.4 inches per second has proven to be a good starting point.

This gives a speed of 24 ipm (0.4 x 60). Once the machine is tuned this value can be increased. The same initial value worked well for the Xylotex 269 oz.in. system.

The acceleration values in Mach can be in the middle of the range. High acceleration rates can cause the steppers to stall with direction changes.
Extremely low accelerations cause the steppers' motion to be sluggish.

Experiment with the speed and acceleration to find what best suits the machine. Values can be significantly different for each axis. It is a trial and error process.

Acme Upgrade

The machine can be upgraded to use Acme rod. This will approximately double the price of the components, but the quality and speed of the work will improve.

The machine is sized so a standard 3 foot leadscrew can be cut in half to give two 18 inch leadscrews. These leadscrews will be long enough to span the X and Y axes' end plates, but will not be long enough to support knobs. Instead, the knobs can be attached to the steppers.

Upgrading the Z axis is also possible, but the performance improvement for most work is not as substantial as the upgrades on the other two axes.

Two leadscrew sizes that have served well are 3/8-10 two start, which gives five turns per inch, and 3/8-8 four start, which gives two turns per inch. Of course, other thread counts will also work.

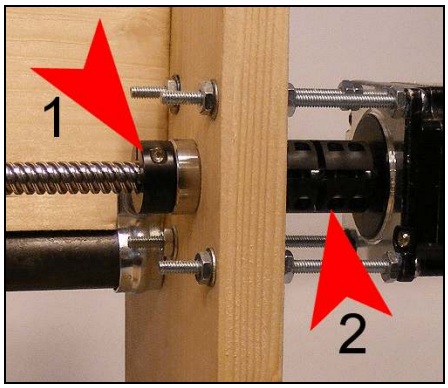
These leadscrews are 3/8 inch diameter and will require 3/8 inside diameter bearings.
3/8 ID by 7/8 OD (Outside Diameter) bearings are a standard size and are available from vxb.com and skatebearings.com among other suppliers.

These bearings will fit in the same recesses that were drilled for the skate bearings. Two bearings are required for each leadscrew.

Collar, shaft, or thread clamps (same product, different names) are used, instead of a pair of nuts, to clamp the inside bearing in place. Arrow 1 in the above right image.

A leadscrew to stepper coupler replaces the hose and #4 clamps that attach the leadscrew to the stepper's shaft. Arrow 2, top image.

Leadnuts, clamps and couplers from dumpstercnc.com have served well.

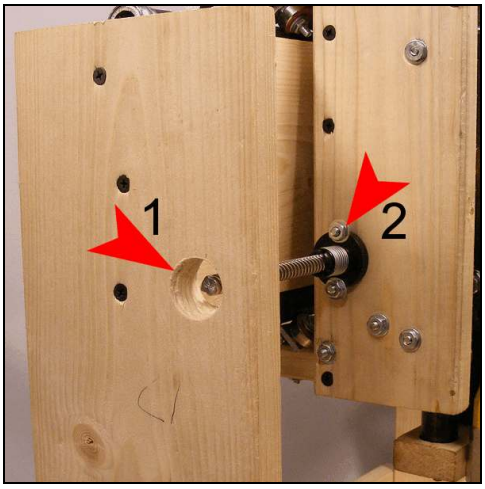


Collar clamp (Arrow 1), and leadscrew to stepper coupler (Arrow 2).

The hose system can be used, but it is challenging to match the larger leadscrew to the 1/4 inch stepper shaft.

These larger diameter leadscrews will not flex as much as the 5/16 inch threaded rods, so they do not need the 5/16 inch diameter hole on the axis end that is opposite the stepper. Image below. This hole can be enlarged to permit more clearance for the leadnut when it abuts the gantry end. (Arrow 1).

The tee nut leadnut will have to be upgraded to one that is sized to fit the Acme leadscrew. Its flange can be notched to fit between the existing machine screws that support the leadnut. Arrow 2 below.



Larger hole in gantry end (Arrow 1) permits more clearance for the leadnut. The leadnut can be notched to fit between the attachment screws. (Arrow 2)