Introduction

"DIY CNC" gives you the complete step-by-step instructions for 12 different CNC projects. Check out these great projects and learn how to make your own CNC mill on a budget. All projects come from Instructables.com, are written by CNC experts, and contain pictures for each step so you can easily make these yourself.

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Laura Khalil

Editor: Outside, Play, Technology, Workshop

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Intro: Use a Treadmill DC Drive Motor and PWM Speed Controller for powering tools

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Step 1: What is a Milling "Blank"? ................................................................................................... 141

When milling a part for a prototype piece of equipment, it is often useful to start with a piece of material that is not much bigger than the part that you are making. This is called a Blank. Using blanks, especially with Computer Numerical Control (CNC) systems, can reduce the amount of time needed to clear excess material during the milling process. .................................................. 141

We describe a method for making plastic milling blanks for CNC milling operations and for making a "Jig" that helps place holes for conveniently mounting the blank onto the milling machine's table. .................................................. 141

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• Coat the inner surface of the mold with a release agent. ............................................................ 142

• Mix 2 part plastic and pour it into the vacuum formed plastic mold. ........................................ 142

http://www.instructables.com/id/DIY-CNC-1/
Step 5: Next Step: Create a Mold for the Blank

There are several ways to do this. We chose to make a vacuum-formed plastic sheet mold. We then poured two-part plastic resin into the vacuum formed mold in order to create the blank for milling.

Using this technique, it is possible to create complex blanks that may have very unique shapes. This makes it possible to decrease the amount of material that needs to be removed by the CNC milling process.

Step 6: Building a Hobby-Vac Vacuum Former:

- Hobby-Vac 12"x18" Do It Yourself Vacuum Forming by D. E. Walsh
- This comes with a large and small platen for vacuum forming small parts and larger trays.
- Build time averages about 2 weeks. Instructions are clear and friendly.
- Requires a vacuum pump.

Step 7: What if I don't want to make a vacuum forming machine?

Try visiting the local dollar store, toy store, or even a grocery market and find something that is about the size that you need, comes packaged in a formed clear plastic shell and use that instead in order to pour your plastic blanks.

Step 8: Where Do I Get Plastic?

- www.warmplastic.com
- Can be ordered in many sizes, colors, and thicknesses.
- Sheets vary in size; up to 4 feet by 8 feet.
- We used 0.04 thickness which is rigid enough to hold the shape and resistant to the amount of heat given off in the exothermic reaction of the plastic resin polymerizing.

Step 9: What is a "Release Agent"?

- This keeps the two-part plastic mixture from sticking to the plastic mold.
- It can be a spray-on product or simply Vaseline wiped on the inner surfaces with a paper towel.
- Make sure to get the release agent into the corners of the mold.

Step 10: Where Do I Get "Two-Part Plastic Resin"?

- www.polytek.com
- EasyFlo 60 1 part A to 1 part B (equal amounts)
- Cures white in ten minutes, will take pigments for color.
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All parts are pine or, if you prefer, MDF wood. Assemble as shown in the CAD model. Drill holes for bolts to slide through snugly. Place the holes to align with the corners of your unique mold for the blanks. ................................. 147

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We have outlined several methods that can be used to create molds for making plastic blanks and a jig for placing fixation points for CNC milling operations. ............................................................... 149

In summary, MDF wood models are created to desired measurements of the milling blank. The wood model is then used to create a vacuum formed mold of the wood model. The mold is used to create the blanks from two part plastic resins. A vacuum degasser may be used to assure absence of bubbles or void spaces in the plastic milling blank. ................................................................. 149

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Follow all safety guidelines, including but not limited to: ................................ 150

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We are sharing our experience, not telling you to do it ........................................ 150

If you choose to try this then - it is at your own risk ! ........................................ 150
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Easy to Build Desk Top 3 Axis CNC Milling Machine

Intro: Easy to Build Desk Top 3 Axis CNC Milling Machine
Here is a way to make a computer controlled milling machine. That puts the real power of a computer control machining into the hands of the average human. Small enough to set on the desk but scalable to any size. As inexpensive as possible without sacrificing accuracy (too much). All most all the parts can be purchased in local retail stores. And above all CHEAP you can be up and running for well under $200. With it you can do 2 Dimensional engraving and PC board etching and 3D milling and modeling in Foam, Wood, Plastic and other soft materials.
Also try watching the YouTube movie at the end (the last frame).

New information on the Motor Driver Circuit is (HERE).

Step 1: The Frame
The frame needs to be a flat base that you can mount everything on horizontally and a goose neck of some kind to hold the Z axis (the up and down part with the motor tool)firmly in place. I used one inch pipe just for fun but as it turned out it was pretty handy too. When I needed to make adjustments I could just tap it with a hammer. As you can see the post that holds the Z axis doesn't have to be in the center. It just needs to be firm and the water pipe does a good job of that. Later, after you are sure all the pipe joints are in the right place, you can add a drop of thread sealer to the joints and it will be a good solid structure.
**Step 2: The X Stage Rails and Motor**

Next it's time to add the rails for the X axis stage. These rails are 3/4 inch U channel aluminum that you can get from the hardware store. Put a washer under each end to space the rail off the pipe just a bit. Don't worry about the rails being perfectly parallel. You'll see why later. Now mount the stepper motor with a bracket like you see here. Connect a length of 1/4 by 20 threaded rod to the motor shaft with a short piece of rubber hose (1/4 inch fuel line). Now your ready to set the movable part of the X axis (the stage).

**Step 3: X it Stage right**

Take a piece of plastic (I used Plexiglas) or metal, something strong and flat and mount a piece of the U channel to it. Now the tricky part. The round thing is a bearing. You can get them out of motors or buy them at a hardware store. Mount it to a short piece of aluminum like so. Then take a 1/4 in. coupling nut (a long nut) and wrap it with aluminum like so (see pic.) The bearing will hold the X stage to the X rail and the coupling nut will allow the motor to run the stage back and forth. It wouldn't hurt to grease the skids a little and the nut too.

Here's a video on making the bearing fixture.
Step 4: The Y stage
The Y stage is just like the X stage but turned 90 degrees. Mount two rails and a motor on the X Stage and then take another piece of flat material and a U channel and make the moving Y stage. Make the little bearing thing and a coupling nut for it too. When your done it should look like this.
Step 5: Zee Z Axis

Again we are going to reproduce the X and Y Stage to create the Z axis stage. Take a flat piece, here I used a piece of white Plexiglas. Mount some rails and a Motor to it. Then make a moving stage piece with a u channel and a roller bearing. We'll do something a little different with the nut (see picture). The four posts you see on the stage will hold the motor tool. Now since this stage is going to move up and down the weight of the motor tool will make it want to come off of the rails so let's add a few more roller bearings to each side to keep it together.
Step 6: Get it together

Now we slap the motor tool into the Z stage. Then its time to mount the stage to the frame. And there you have it. This is the mechanical structure. From here we will need to hook up the stepper motors to a controller and get some software running on the computer but I'm going to save that for future articles.
Step 7: What's it Do

If you were interested in this project it's likely you have already seen what can be done with an 3 axis(XYZ) computer controlled milling machine. What is suprising is what kind of accuracy you can get out of this thing after you tinker with it a little bit. Make sure all the rails are held firm and straight. Tighten the roller bearings so the stage doesn't shift.

I used it to make PC boards. It's real good for engraving name tags and signs. And it's pretty exciting to see it carve a 3D object out of a block of foam or plastic.

WARNING there's a lot to learn about the software. Some venders offer package deals of motors, drivers, and software. That makes it easier but you pay for it. I'll add more to this later. Send me comments and questions.

http://www.instructables.com/id/DIY-CNC-1/
Step 8: Easy Mill the movie
If the literal instructions are confusing try watching the YouTube movie:
http://www.youtube.com/watch?v=6drMZqmyXQc

Also check out the follow up instructions on Stepper Motor Control: Easy Mill Stepper Motor Controller

Step 9: Engraving
Now that I got the machine back together after making the instructable and I did some engraving and made a PC board.

Cutting plastic is no problem but doing the PC board the bit went a little too deep on the left side of the board and took out all the finer traces. This is when you start tweaking on it. Just take some aluminum foil and put it under the rail of the Y axis. So as the stage travels left to right the height of the bit should stay the same. Notice I'm just holding the material down with masking tape. What I like about this thing is, it's easy to fix these kinds of problems because it's all made from simple elements.

Here's the new video:
http://www.youtube.com/watch?v=LcdozYDpzjU

Also check out the follow up instructions on Stepper Motor Control: Easy Mill Stepper Motor Controller

Related Instructables

Hobby cnc by mraspotcnc
Rapid Technique: Preparing Plastic #11:CNC Milling "Blanks" for Parts Used in #11:Prototyping Scientific Equipment by siderits
My 30$ Milling Machine (Photos) by narpas
Make your own cnc controller by charcoal999
Vacuum Table for Mini CNC Milling Machine by Flying_MashedPotato

Mostly self-reproducing 3-axis CNC milling machine(SHELVE PROJECT) by ebidk

How to use a CNC Mill with Google SketchUp by BovineDiozzi

World's Smallest Milling Machine by Technochicken

http://www.instructables.com/id/DIY-CNC-1/
Intro: How to make a mini milling machine- manual or CNC!
I think one of the best things about tools is that they can be used to make more tools! I decided to build a miniature milling machine for machining plastic parts, creating wax patterns and for drilling really small precise holes. I also wanted to design it so that I could convert it to CNC for machining circuit boards and for doing repetitive work.

The finished mill has a 11" x 18" footprint and is about 19" tall. Depending on the motor used it is capable of machining plastic, wax, wood and non ferrous metals. Right now my motor is a bit underpowered due to the power supply I had on hand. It's very quiet- I could use this inside the house at night and not wake up the little ones!

The X axis travel is 6 1/8"
The Y axis travel is 6 1/4"
The Z axis travel is 2 1/4"

If there are any questions about any of the drawings or something just doesn't make sense just ask! You can download larger images so the drawings will be much easier to read- just click on the "i" symbol in the upper left corner. I just added an exploded view sketch that helps show how all the parts fit together.

Follow along and build one for yourself!
1. CNC version

1. manual version

1. exploded view of my mill assembly- I figured a quickie sketch like this would help explain how it all goes together
Step 1: Tools and materials

Tools used:

table saw (a miter saw would also work - they tend to be more accurate for precise cuts)
drill press
router w/ 1/2" straight cutter - needs to be mounted in a router table
jigsaw (or band saw if you're lucky enough to have access to one)
cordless drill
bench plane
bench vise
level
hack saw
assorted files (for cleaning up rough edges)
tap and tap handle (I used a 4mm x .7 tap because I used metric screws but you could also use an 8-32 tap if you want to use 8-32 screws)
#10 countersink bit
wood glue
bar clamps
1 1/4" Forstner bit
5/16" Forstner bit (used for counterbores for 4mm bolts)

Materials/cut list:

3/4" thick Birch plywood was used for the following pieces-
11" x 18" - base plate
12" x 4" - Y axis base plate
8" x 4" - X axis base plate
6" x 2 3/4" - motor mount base
12" x 9" (make four of these) - for the mill column
2 1/2" x 1 7/8" (make three of these) - for the anti backlash screw blocks

3/4" thick MDF (medium density fiberboard) was used for the following pieces-
6" x 6" - mill table
3 7/8" x 1" (make six of these) - rail end blocks

Aluminum channel - 57/64" x 9/16" x 1/16" wall thickness:
12" long (make four) - X and Y axis rails
8" long (make two) - Z axis rails

3/8" thick Delrin was used for the following pieces (Delrin can be purchased from Colorado Plastics):
4" x 3 7/8" (make three of these) - slides
2 1/2" x 3 1/4" (make three of these) - handles
3 1/2" x 3 1/4" (make six of these) - slide retainers
5/16" round Aluminum rod:
1 1 1/2" long (make three) - handles

1/4" round Aluminum rod:
3/4" long (make six) - inserts for anti backlash blocks

1/4"-16 ACME threaded rod: available from McMaster-Carr part# 98935A803
12 3/4" long (make two) - X and Y axis lead screws
8 3/4" long - Z axis lead screw

6 each 1/4"-16 ACME nuts - for anti backlash screw blocks (McMaster part# 94815A007)
3 each 1/2" diameter 1 1/4" long compression spring - for anti backlash screw blocks
3 each 1/4" locking collars - these help hold the ACME screw rod in place (McMaster part# 6432K12)
6 each 1/4" bronze flanged bushings (these fit a 1/4" shaft and fit into a 3/8" bore) - for the rail end blocks (McMaster part# 6338K451)
3 each 1/4" washers (just about any thickness will do) - these are spacers for the handles

3/4" wide Aluminum or brass plate (1/16" thick):
1 7/8" long (make three) - for anti backlash ACME screw retaining plates

1 3/4" (45mm) long bolts w/ washers and nuts:
12 each - I used 4mm hex head bolts for all the bolts but 8-32 bolts will also work
-these go on the ends of the Aluminum channel rails

1" (25mm) long bolts w/ washers and nuts:
4 each - 4mm
-these go in the middle position of the x and Z axis Aluminum channel rails

3/4" (20mm) long bolts:
38 each - 4mm

6 each 4mm x 1/4" (7mm) long set screws - for the handles

8 each 2" long wood screws - for securing the mill column to the base plate and the Z axis base plate

1/2" diameter wood dowel:
4 each 3" long - inserts for mill column
6 each 3/4" long - inserts for rail end blocks

For the motor assembly/spindle I used a 12v electric motor salvaged from my junk box along with a Foredom #44 handpiece. The #44 uses 1/16", 3/32", 1/8" and 1/4" collets (it's also available in metric) so it fits a wide variety of cutting tools. I also have a #30 handpiece which has a standard drill chuck. Both are extremely durable and are very quiet. You could also use a standard Dremel tool if you want an all in one solution.

For the CNC conversion:
6 each 2 1/2" x 2/12" x 3/4" thick Birch plywood pieces - for stepper motor mounts
3 each stepper motors
3 each motor couplers - I made mine myself from old parts I got from a display but the ones I've linked to are identical
12 each #10 1" long wood screws
6 each #10 2" long wood screws
7/8" Forstner bit
CNC stepper motor controller- the HobbyCNC or Linistepper would be my choice

Some notes about using a router table and drilling holes for screws:

When using a router table you always want to cut in a certain direction- the cutting bit should try to force your work into the fence (see drawing.) If you move your work in the opposite direction, the bit will pull your work away from the fence and it will be difficult to get a precise cut.

On many of the drawings I specify a countersink or a counterbore. A counterbore has a flat bottom (it's best cut with a Forstner bit or end mill) and is meant for flat bottomed screws. A countersink is for flush mounting screws with a tapered head, like most wood screws. The other important thing is to always drill a pilot hole first, then a clearance hole and then the counterbore or countersink. If you don't drill a proper clearance hole, the screw will try separate the two parts you're trying to screw together. It'll also make it difficult when cutting threads for machine screws- see the drawing below.

SAFETY NOTE:
Please use care and good judgment when operating power tools. Always keep fingers well away from cutting tools- use a push stick for cutting thin stock on a table saw and router table. Always wear eye and ear protection and a dust mask- especially when cutting MDF as the dust it produces is pretty nasty stuff.
Image Notes
1. eager helper
2. drill press
3. my old table saw I inherited- it's not plugged in when my son is near it due to the lack of a blade guard
4. bench vise

Image Notes
1. remove end cap
2. Foredom #30 handpiece for drilling
Step 2: Design

This mill was designed so that it could be converted to CNC by adding stepper motors and motor mounts in order to make it as versatile as possible. If you only want to mount stepper motors and do not have the need for manual operation then feel free to modify it accordingly.

The design uses an anti backlash system. Backlash is when you turn the handle forward and back and the cross slide doesn't move- it's the bane of many a machinist and it makes it hard to make accurate cuts because you have to compensate for it. It's a bit trickier to build the mill this way compared to using a single ACME nut but it does work very well and it's worth the effort required.

I primarily used Birch plywood and MDF for the construction because it's stable, flat and it works well in this application (it's also what I happened to have on hand!) There are several parts that have wood dowel inserts- this is because when screwing into the end grain of plywood it doesn't hold screws very well at all (ditto for MDF.) The slides are made from Delrin because it works well in this application, it's easy to cut and it holds screws well. I wanted to construct this using materials that could be purchased at local hardware stores. There are a few areas where it can be built differently and I'll note them as I go along.

Here's some sketches of the most critical parts as well as an exploded assembly drawing- the drawing should be used as a general assembly aid (a lot of the bolts are left out of the drawing for clarity.) Many of these dimensions can be modified to suit the parts and materials you might have available. The most important thing is to make everything as absolutely square, straight and flat as possible.
Image Notes
1. exploded view of my mill assembly- I figured a quickie sketch like this would help explain how it all goes together
Step 3: Make the slides
For this step you'll need a router table; if you don't have one you can make one by screwing (or securely clamping) a 5/8" or 3/4" thick piece of MDF to a bench top. Bore a hole in it using a hole saw and mount your router from the underside (see drawing). Use a piece of MDF or plywood to make a fence by clamping it on each side of the table. The 1/2" straight router bit should just barely touch the fence.

Now take the three 4" x 3 7/8" Delrin pieces and cut a shallow track into the bottom of the 4" long end on both sides. The depth of the cut should match the wall thickness of the Aluminum channel exactly.

When assembling the mill, if you find that the slides bind on the Aluminum channel you can go back and adjust the fit by trimming the width of the track you just cut. This can be easily accomplished by loosening the fence, slide it away from the 1/2" router bit and sliding a piece of typing paper between the fence and the bit. Now clamp the fence down and remove the sheet of paper. This will allow you to cut a few thousandths of an inch off the Delrin slide at a time, enabling you to adjust the fit of the parts and get the slide to operate smoothly.
Step 4: Make the end blocks

Take the six pieces of cut MDF blocks (3 7/8" x 1" x 3/4") and drill all the holes in them using a drill press. I drilled them in marked pairs - that way I would be sure they would line up correctly.

Glue 1/2" x 3/4" long wood dowels into the holes on the three pieces. These wood dowels serve as anchors for mounting the stepper motor mounts later on, so if you don't want to make the mill CNC ready you can leave them out. If you make the blocks from Delrin then you don't need to use the dowel inserts since Delrin holds screws just fine.

Tap in the bronze bushings into the 3/8" hole in each block. Check the fit of the ACME rod in each bushing to make sure it rotates freely. The bronze bushing isn't necessary if you make the blocks from Delrin - instead drill a 1/4" hole for the ACME rod (the Delrin acts as the bushing.)
Step 5: Make the anti backlash screw blocks

Take the three pieces of 2 1/2" x 1 7/8" plywood (you could also use Delrin or MDF) and cut them according to the drawing. Drill and counterbore the holes for the mounting bolts. Drill and tap the 1/4" Aluminum rod for the 4mm bolts and insert them into the blocks (make sure you can see the threaded holes.) If you use Delrin to make the parts you can skip the Aluminum inserts and just thread the holes in the blocks for the 4mm bolts that hold the metal plate that retains the ACME nut.

My blocks were cut by hand- and it shows! The best way to cut the 1/2" wide slots for the ACME nuts is to make a jig and cut them using the router table. Clamp the screw blocks in the jig and then run the jig over the router bit to cut the slot. Don’t try to cut the slot to full depth in one pass- just slowly increase the bit height and make multiple cuts until you get the desired depth. Cut the slot for the non spring side first and then flip the piece over to cut the other slot- that way both of the ACME nuts are guaranteed to be in perfect alignment.

Now make some 3/4" x 1 7/8" retaining plates for the front by drilling holes for the mounting bolts and a 5/16" hole so the ACME rod can slide through.

Check the fit of the parts by assembling it as shown in the drawing. The spring should be 1 1/4" long ( or close to that) before being compressed.
Step 6: Make the rails

Take the cut Aluminum channel and drill three 4mm holes in each one. One hole 1/2" from each end and one hole in the center along its length. If you use a center drill first then the drill bit won't move around on you when you try drilling the holes.

Deburr the holes using a deburring tool- this will get rid of any rough edges left by drilling. You could also use a file but it's not quite as clean.
1. center drill: makes drilling holes in metal exactly where you want them much easier.

1. deburring tool
Step 7: Make the mill column
To make the mill column take the four pieces of plywood that measure 9" x 12" and glue them together using wood glue and clamps. After the glue has dried overnight, check that it is square and that the ends are flat. If not, you can use a bench plane to flatten the ends.

Now I used a 1 1/4" Forstner bit to cut the radius on the inside edge and then cut the inside with my trusty jigsaw. Four 1/2" holes are then drilled and wood dowels are glued in.

The column then gets glued and screwed to the back center of the 18" x 11" plywood base using 2" long #10 wood screws. I always countersink the screw heads- do this using a #10 countersink.

If you don't want to go to the trouble of making a laminated plywood column you can make one from 1 1/2" plumbing pipe (see drawing.) You might have to shim the flanges to get it to sit square and level.

Image Notes
1. bench plane- great for making really flat surfaces
Image Notes
1. 1 1/4" Forstner bit

Image Notes
1. 2" long #10 wood screw- I dig these star heads because they don't strip out like regular Phillips heads
Step 8: Make the Z axis

Begin by screwing (using 2” long wood screws and countersinking the holes) and gluing the 8” by 4’ piece of plywood to the mill column. Make sure it is square/level relative to the mill base.

Now clamp the rails to the plywood base—use the cut Delrin slide as a spacer. Remove the Delrin slide and insert the end blocks. Slide the ACME rod through the blocks to make sure everything is lined up correctly and then drill through the holes in the rails. Insert four long bolts through the ends of the rails and secure them with nuts. Now insert a shorter bolt from the back of the plywood base through the center rail hole and secure it with a nut.
Step 9: Make the X axis and Y axis

These are done just like the Z axis. Make sure the X axis rails are mounted square to the milling column. The Y axis rails are mounted to the 12” x 4” plywood piece. The center bolts on the Y axis need to be counter bored so they sit flush with the bottom of the plywood base, so use the 3/4” long bolts.
Step 10: Assemble the slides

Mount the anti backlash blocks in the center underside of the Delrin slides. Do this by using the 3/4” long bolts and drilling and tapping holes in the Delrin slides.

Now mount the 3 1/2” long by 3/4” Delrin slide retainers by drilling and tapping holes and then screwing them to the slides with 3/4” long bolts.

Mount the Y axis slide to the underside of the 6” x 6” MDF piece.

Mount the X axis slide to the bottom of the of the Y axis plywood base plate (the part that has the Y axis rails mounted to it.) It is VERY important to get this mounted centered and square.

File a 1/2” flat spot into one end of each ACME rod- this is for mounting the handles. Now assemble the anti backlash assembly. The side of the assembly that has the retaining plate faces toward the side of the mill where your turning handles will go.

Image Notes
1. 4mm x .7 tap
Image Notes
1. Delrin slide retainer block (two mounted to underside of each slide)

Image Notes
1. Counter bore bolts so they sit flush
2. This end of the rod faces toward the front of the mill
3. X axis slide

Image Notes
1. 6"x6" MDF top
2. Y axis slide

Image Notes
1. Y axis base
2. X axis slide
Step 11: Mount the slides to the rails
Cut the ACME rods using a hacksaw; make sure to clean up the ends of the threads where you cut the rod. Use some wood blocks or a cloth wrapped around the thread when holding the ACME rod in a vise for cutting so you don't damage the threads. File a flat spot onto the last 1/2" of the ACME rod; this is so you can mount the handles (or stepper motors) later.

Mount the slides by removing each of the end rail blocks. Slide the slides onto the rails and fit the ACME rod into the bushing in the opposite rail block. Slip the retaining collar over the ACME rod. Now slide the end rail block into place and secure it with the bolts that were removed.

Mount the 6" x 2 3/4" plywood motor base plate to the Z axis slide using 3/4" long bolts. Make sure it is square!
**Step 12: Make the handles**
Drill a 1/4" hole into the center of each of the 2 1/2" long Delrin pieces. Drill a 5/16" hole toward the end and drill and tap a hole for a set screw for each hole you just drilled. Insert a 5/16" Aluminum rod into the outer hole and secure it with the set screw. Slide a 1/4" washer over the ACME rod and then slide the handle onto the ACME rod and secure it with a set screw.

**Image Notes**
1. set screw

**Step 13: Mount a motor! (or a spindle and motor)**
I used an old Aluminum block I had in my scrap box to mount the Foredom handpiece. The handpiece has a 1" OD and the block I had was for holding bicycle fork steerer tubes during cutting so it was a perfect fit. You could also use a hardwood block with a hole bored in it with a Forstner bit. The holes in the center of the block are for tightening/loosening the collet.

I drilled a couple of holes in the block and mounted it to the Z axis plate with two bolts. The motor mount was a piece of bent steel that came from an electrical box. The motor is connected to the handpiece with a small timing belt that came from an old copying machine, but I've found that large "O" rings do a good job as well- so do vacuum cleaner drive belts. The end cap of the handpiece is removed and a timing belt pulley is fitted to the handpiece shaft- the shaft is 1/4" diameter. I'm currently working on speed control for the motor and will post an update when that's finished.

I found a similar motor to the one I'm using here. It's a 12v motor like the kind used in a cordless drill. They tend to be very durable and have a wide voltage range. Miniature timing belts and pulleys are available here.

The other option is to simply mount a Dremel tool- no need to worry about belt tension!

Mount some rubber feet to the bottom of the mill and you're done!

I did add some stick on metal ruler scales to the Aluminum channel for each axis- it makes it really easy to get rough measurements. I also made a dial indicator holder that is positionable so I can get really precise measurements from each axis. The indicator in the photo measures in .0001" increments.

I'll be posting the CNC conversion soon along with several handy tools like an indexing fixture and milling vise so stay tuned....
1. Foredom #44 handpiece

1. Remove end cap
2. Foredom #30 handpiece for drilling
Image Notes
1. rubber feet
Step 14: CNC conversion

For converting the mill to CNC you need to make some stepper motor mounts and motor couplers. I made each motor mount from two 2 1/2" square 3/4" thick plywood blocks that are glued together (you could also use Delrin and make it as one piece.)

The mounts are very simple- just two 7/8" holes bored through them using a Forstner bit -one (on the end view of the drawing) is for the motor coupler to slide through and the other is so you can tighten the set screws on the motor coupler after the motor is mounted. There are four holes for mounting the motor and an additional two holes for screwing the motor mount to the mill.

The motor coupler is just a 5/8" diameter Aluminum rod with a 1/4" bore through it and a couple of set screws to fasten it to the stepper motor shaft and the ACME rod lead screw. Note that the dimension shown on the drawing for the length of the motor coupler is incorrect- it should be 1 1/4" long. You can buy the motor couplers here if you don't want to make them yourself.

The mounts are designed to accept a standard sized NEMA 23 stepper motor. These are very common and are easily obtained. I bought mine surplus for $15 each (I don't remember where). The stepper motors shown are:
Superior Electric Slo-Syn
Model #M061-FD02
35oz in.
5v 1A
200 steps per revolution

I haven't yet decided what CNC controller I'll be using but I'm leaning toward either the Linistepper or the HobbyCNC ProDriver.

Both controllers are capable of driving a fourth axis (something I plan to add later on) and have had very positive reviews. The Linistepper is an open source controller and there are a couple of different versions of it floating around.

As soon as I can afford a controller I'll have a video of it making some cool parts!
Intro: $20 CNC Machine
I got inspired for this instructable when I viewed the Easy To Build Stepper Controller instructable. When I read the instructable I knew I could make a decent looking and functioning cnc machine for under 20 dollars with a recycled twist. Not to mention I did this in under a week.

I expect you to have basic knowledge on power tools and hand tools and of course this instructable requires you to have a rotary tool such as a dremel. Even if you don't have knowledge on power tools or hand tools I advise you to try this instructable because you will learn a lot about hand and power tools and you can build this for less then 20 dollars so if you mess up it's no biggie and it would not cost to much to replace a part.

Let's Build!

Update 02/01/10

Hi everyone just thought I would give you an update on this instructable since I've been getting a lot of emails and messages and such.

I'm getting really close to completing the electronics for the CNC, as stated in a comment the steppers I found in the printer were bi-polar stepper motors which the circuit would cost quite a bit more if you went this route. If you were lucky to find some Unipolar stepper motors then you could build the electronics for under 3 bucks however unipolar motors have less torque. I will be selling CNC kits soon and they will be of better build quality as well as a cheap price tag because I know how it is to be on a budget and not have the tools I need to create simple things and even complex things and this world needs more DIY builders.

The CNC kits will be available roughly 1 to 2 weeks after the electronics Instructable has been released their will actually be a video showing this CNC working when the electronics Instructable is completed}
Step 1: Find recycled material

Now this is the most enjoyable part of building the CNC machine which is trying to find garbage that people want to throw away.

Here's what you need to locate

Flat bed scanner

Old printer

These two items are going to have your juicy stepper motors and the beautiful harden steel rods, that's not the only thing you can get out of these green machines.

You will find gears, bushings, cold cathodes, capacitors, buttons, parallel ports and there is so much more.
Step 2: Tools
Now I tried to build this with the bare necessities so I could show you that it is possible to make a cnc machine with very little.

Required Tools:
- Drill
- Screwdrivers
- Tap and Die set
- Rotary tool
- Hack saw
- Vise or some form of clamping device
- Pliers
- Drill bits
- File
- Center punch

Recommended Tools:

http://www.instructables.com/id/DIY-CNC-1/
Band saw
Table saw
Lathe
Bench grinder
Bolt cutters

Image Notes
1. Hack saw
2. Drill
3. Vise
4. 3ft aluminum rod

**Step 3: Linear slides of fun**
The center core of your CNC machine is your tables so read carefully and follow the instructable.

**Required materials**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Type</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>2&quot;x6&quot;x1/2&quot; Expanded PVC</td>
<td>2.00</td>
</tr>
<tr>
<td>2</td>
<td>2&quot;x4&quot;x1/2&quot; Expanded PVC</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>10&quot; 3/8&quot; Aluminum rod</td>
<td>0.75</td>
</tr>
<tr>
<td>2</td>
<td>12&quot; 3/8 Aluminum rod</td>
<td>0.75</td>
</tr>
<tr>
<td>2</td>
<td>8&quot; 3/8&quot; Aluminum rod</td>
<td>0.50</td>
</tr>
<tr>
<td>1</td>
<td>11 1/4&quot; 5/8&quot;-24 threaded rod</td>
<td>1.00</td>
</tr>
<tr>
<td>1</td>
<td>9 1/4&quot; 5/8&quot;-24 threaded rod</td>
<td>0.75</td>
</tr>
<tr>
<td>1</td>
<td>7 1/4&quot; 5/8&quot;-24 threaded rod</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Now this is just the run down of everything I of course cut everything up, you can purchase everything you see here from your local hardware store and plastic store for really cheap.

**First step**

Stack 2 of the expanded pvc pieces that are the same size and drill a whole in the center and two holes each three quarters of an inch from the edge from the center line.

Now cut your aluminum rods to size and stick them through, now you should have a comparable piece down below

Repeat for all Axis
1. Expanded PVC

1. This is what it should look like after you are done

1. Holes for the aluminum rod
2. Hole for motor

1. X and Y axis

1. Z axis

http://www.instructables.com/id/DIY-CNC-1/
**Step 4: X,Y,Z tables for your brunch**

Alright now here comes the most time consuming part making the tables for the slides but once they are made it really feels like the project is taking off.

**Required Materials**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Type</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6”x12”x1/4&quot; Acrylic</td>
<td>Scrap</td>
</tr>
<tr>
<td>1</td>
<td>6”x10”x1/4&quot; Acrylic</td>
<td>Scrap</td>
</tr>
<tr>
<td>1</td>
<td>5 1/2”x5”x1/4” Acrylic</td>
<td>Scrap</td>
</tr>
<tr>
<td>15</td>
<td>1 1/2”x1 3/4”x1/2” Acrylic</td>
<td>Scrap</td>
</tr>
</tbody>
</table>

Now what you are going to want to do is stack 4 pieces of the 1 1/2”x1 3/4”x1/2” and drill dead center with a 3/8 drill bit.

After you have done so feed 2 pieces on each rod and line them up and place your sheet on top and flip it over now glue.

Repeat for each axis.

For your Y axis now would be a good time to drill your holes so you can mount things you wish to cut.

---

**Image Notes**

1. 1 1/2”x1 3/4”x1/2” Square blocks

2. Square block ready to be glued.
3. Use acrylic glue for maximum strength and clean look.

4. You should end up with something like this. Repeat this step to make all three axis.
Step 5: Motor mount time

Now depending on where you get your motor from they are all going to be different so they will require special mounts.

I recommend printer stepper motors because they are easy to mount but scanner steppers motors will work just fine.

Now in step three you should have drilled the motor hole and now all you have to do is mount it in.

The coupler that attaches from your stepper to your threaded rod is going to be different based on stepper you have.

I made one out of aluminum but you can make one out of plastic just as long as it is wide enough.

All you have to do is drill in the center of a little piece of rod to the size of the stepper then on the other side drill 5/16 for the threaded rod. After that tap the 5/16 side and glue.

1. Grid paper is a good way to get your holes in parallel.
Step 6: Thread me please

Now once you have made your coupler it's time to attach the threaded rod and glue a threaded coupler to one of the 1 1/2"x1 3/4"x1/2" square blocks. You have to make sure that the center on the threaded coupler matches the center of the threaded rod. After you should get something like down below.

Required Materials

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Type</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5/8&quot;-24x1&quot; threaded coupler</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Repeat for each axis.

Image Notes

1. Just a piece of rod I used to mark the center

Step 7: Gluing time

So now you should have all three axis completed and now it's time to line them up and glue.

The base I used was a 20"x12"x1/4" piece of white acrylic I found at the plastic store. You could use smaller but I wouldn't recommend it.

Once you have found a base, glue your x axis to it and then your y axis to your x axis acrylic top, then you should have something like down below.

use acrylic glue
for this step

it will glue expanded pvc as well if your wondering

After that Glue your z axis to a piece of 8"x4"x1/4" acrylic sheet.

Required materials:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Type</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20&quot;x12&quot;x1/4&quot; Acrylic sheet scrap</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8&quot;x4&quot;x1/4&quot; Acrylic sheet scrap</td>
<td></td>
</tr>
</tbody>
</table>

http://www.instructables.com/id/DIY-CNC-1/
Image Notes
1. You should have something that looks like this
2. Base I used

Image Notes
1. Glue here using acrylic glue
2. Glue all the expanded pvc to the acrylic sheet but make sure it's parallel

Step 8: Where's the Z axis :(
Don't worry I didn't forget about that

Moving along

Now we want to add a mount for are rotary tool to the acrylic sheet on the z axis

I used a pipe holder and a screw clamp, you can buy both these items at a local hardware store for really cheap.

You have to cut a little lip to attach to the acrylic sheet because the pipe mount isn't going to be flat once you slide the rotary tool in because it expands.

Place the pipe mount on top of the acrylic lip and glue.

Required Materials

Quantity Type Cost
1 Pipe mount 0.40
1 Screw clamp Free
Step 9: A piece from the heaven's

Now that you made your z axis rotary mount it's time to set up the posts and the acrylic sheet that connects them.

You need a square hole in the center of the 10"x16"x5/16" acrylic sheet to feed your z axis through.

After you have cut that out it's time to attach a thick piece of a acrylic to support the z axis on.

After you have done that you should attach you z axis to it and make sure the acrylic piece is sticking out at least 1/16" off the edge so you can have a flat side.

Required materials:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Type</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10&quot;x16&quot;x5/16&quot; Acrylic Sheet Scrap</td>
<td>Scrap</td>
</tr>
<tr>
<td>1</td>
<td>1/2&quot;x5&quot;x1&quot; Acrylic Sheet Scrap (aka thick piece)</td>
<td>Scrap</td>
</tr>
</tbody>
</table>
Step 10: Tall posts oh my!
Now it's time to glue the 1 1/2"x16"x1" posts to the z axis acrylic top and then after you're done with that, you then glue it to the base.

Required Materials:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Type</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1 1/2&quot;x16&quot;x1&quot; Scrap</td>
<td></td>
</tr>
</tbody>
</table>

Step 11: Are we done yet!
The answer is no but we do happen to be mechanical done now because of the short amount of time I had I could not add the electronics part to this instructable, so I am going dedicate an entire instructable just to the electronics part some time this week as well as a video.

So turn that frown upside down

Word of advise this is quite a bit of work even though it may not look like it so by the time you have this finished the electronics instructable will be beyond finished.

I will most likely add it on Tuesday or Wednesday of this week.

Part list:

<table>
<thead>
<tr>
<th>Quantity</th>
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</tr>
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</table>

http://www.instructables.com/id/DIY-CNC-1/
4 2"x6"x1/2" Expanded PVC 2.00
2 2"x4"x1/2" Expanded PVC 1.00
2 10" 3/8" Aluminum rod 0.75
2 12" 3/8 Aluminum rod 0.75
2 8" 3/8" Aluminum rod 0.50
1 11 1/4" 5/8"-40 threaded rod 1.00
1 9 1/4" 5/8"-40 threaded rod 0.50
1 7 1/4" 5/8"-40 threaded rod 0.25
1 6"x12"x1/4" Acrylic sheet Scrap
1 6"x10"1/4" Acrylic sheet Scrap
1 5 1/2"x5"x1/4" Acrylic sheet Scrap
15 1 1/2"x1 3/4"x1/2" Acrylic sheet Scrap
3 5/8"-24x1" threaded coupler 0.60
1 20"x12"x1/4" Acrylic sheet scrap
1 8"x4"x1/4" Acrylic sheet scrap
1 Pipe mount 0.40
1 Screw clamp Free
4 1 1/2"x16"x1" Scrap
? Scrap from Tap Plastics 12.00

**Totals: 19.50**

I got all my plastic from tap plastics scrap bin and I got the rest of the pieces from home depot and a local metal supply shop.

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**Image Notes**
1. Almost all done!

**Image Notes**
1. Electronics Instructable soon to come!

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**Step 12: Recommendations**

Now the stepper motors you find in a printer would do just fine but after a while I would highly recommend to upgrade to some bigger stepper motors.

As for the expanded pvc I would replace that with Acrylic but do to the fact that I had a budget and the short amount of time I had no choice but to go with expanded pvc but I would really recommend you use acrylic.
How to Make a Three Axis CNC Machine (Cheaply and Easily)

by oomlout on June 29, 2007

Intro: How to Make a Three Axis CNC Machine (Cheaply and Easily)
The idea behind this Instructable was to fulfill my desire for a desktop sized CNC machine. While it would have been nice to purchase an off the shelf unit the issue of price as well as size proved prohibitive. With this in mind I endeavored to design and build a three axis CNC machine with the following factors in mind:

-Use Simple tools (needs only a drill press, band saw, and hand tools)
-Low Cost (this kind of got away from me however with everything bought off the shelf the cost for all parts is under $600 (significant savings could be made by skillfully sourcing some pieces))
-Small footprint (30” x 25” footprint)
-Usable working envelope (10” X-axis, 14” Y-Axis, 4” Z-Axis)
-Relatively fast cut rate (60” per minute)
-Small part count (fewer than 30 unique parts)
-Easy to source parts (all parts available from 4 sources (Home Depot + 3 online sources)
-Ability to cut ply-wood (Successful)

Lets get started...

UPDATE: - Coming soon the ability to order pre-cut MDF pieces from oomlout

Step 1: Others Who Have Finished
A salute to those who have laboured through to this point (and to demonstrate that it is reproducible) Here are some pictures of other peoples machines.

Photo 1 - Chris and his friend put together this unit; laser cutting the parts out of half inch acrylic. Not only does it look super it must weigh a ton. But kudos, anyone who's worked with acrylic knows laser cutting it is great but it is a very very unfriendly material to drill and there is a lot of side drilling in this design. Good job guys, check out more details (and photos including some testing with circuit boards) on Chris's blog rainbowlazer.com. I particularly like his work with making 3-d objects out of 2d cuts (here).

Photo 2 - Sam McCaskill has finished his desktop CNC machine and it's looking really really nice. Super impressively he also resisted the urge to cheat and cut all his pieces by hand. I'm really impressed.

Photo 3 - Angry Monk's - With MDF pieces cut on a laser cutter and drive converted from toothed belts to threaded rod

Photo 4 - Bret Golab's - Bret has completed his and gone through the extra step of getting it setup to work with Linux CNC (a task I attempted and was foiled by complexity). If you're interested in his settings you can send him a message (Instructable ID: bretlyssii ). Great job Bret!

(If you have built one and would like it featured here, please send me a PM and we can arrange for the sending of photos)
Step 2: Specs.
I'm afraid I don't have the space (or the expertise for that matter) to go into the fundamentals of CNC here but there is one website in particular I found quite useful in my research.

CNCZone.com - A discussion forum which has a DIY machine section which is a wealth of knowledge (direct link)

Machine Details:
Cutting Head: Dremel or Dremel Type Tool

Axis Details:
X Axis
travel: 14”
Drive: Toothed Timing Belt
Speed: 60” min
Acceleration: 1” per second2
Resolution: 1/2000”
Pulses Per inch: 2001

Y Axis
Travel: 10”
Drive: Toothed Timing Belt
Speed: 60” min
Acceleration: 1” per second2
Resolution: 1/2000”
Pulses Per inch: 2001
Z Axis (up down)
Travel: 4"
Drive: Threaded Rod
Acceleration: .2" per second^2
Speed: 12" min
Resolution: 1/8000"
Pulses Per Inch: 8000

**Step 3: Required Tools**
The goal was to try and keep the tools required within the realm of an average handyman's shop.

**Power Tools:**
- Band Saw or Scroll Saw
- Drill Press (drill bits 1/4", 5/16", 7/16", 5/8", 7/8", 8mm also Q (5/16” closest imperial drill bit)
- Printer (seemed like the right category)
- Dremel or Similar Tool (to attach to the finished machine)

**Hand Tools:**
- Rubber Mallet (to provide "persuasion" when necessary)
- Hex Keys (5/64", 1/16")
- Screw Driver
- Glue Stick (UHU) or spray adhesive
- Adjustable Wrench (or 7/16" socket and ratchet)
Step 4: Required Parts
The attached PDF (CNC-Part-Summary.pdf) provides detailed cost and sourcing information for each and every required part. Listed here is only a summary.

Sheet Stock --- $20
-a 48" x 48" piece of 1/2" thick MDF (any 1/2" sheet stock can be used I have plans to make my next version out of UHMW but cost was prohibitive this time around)
-a 5"x5" piece of 3/4" thick MDF (this is used to make spacers so any piece of 3/4" stock found around the shop could be used)

Motors and Controllers --- $255
-An entire instructable could be written on choosing a controller and motors. In short what is required is a controller capable of three axes of control (with pulsed step and direction inputs) and motors with about 100 oz/in holding torque. I sourced mine from http://hobbycnc.com they have worked well and the kit was quite easy to solder. (direct link)

Hardware--- $275
-These parts can be acquired from three places. The conventional items can be acquired at Home Depot, the specialty drive products are easy to find at any industrial supplier, I used McMaster Carr (http://www.mcmaster.com) (I chose them because they have a nice online store), and finally because of the large number of bearings required I found the best price from an online seller (http://vxb.com) which sells 100 for $40 (leaves quite a few left over for other projects) (direct link)

Software --- (free)
-What is required is a program to draw your designs (I use CorelDraw), and a programme capable of interpreting these files into pulses to be sent to your controller. I'm currently using a trial version of Mach3 (http://www.machsupport.com) but have plans to convert to LinuxCNC (An open source machine controller which uses linux) (http://www.linuxcnc.org)

Router Head--- (extra)
-I attached a dremel type cutting tool to my machine however if you are more interested in additive construction (like fab@home or RepRap) you may wish to look into their deposition tools.

Details
-the metric components and especially the cross nuts aren't very popular and I had to visit several Home Depots in my area before I had enough.
-I couldn't find a way to link to parts directly on the McMaster Carr site. To find them go to www.mcmaster.com and search for the part #

![Three Axis CNC Machine Part Summary](http://www.instructables.com/id/DIY-CNC-1/)
Step 5: Printing Pattern

I had some experience Scroll Sawing pieces so I choose to use a glue on pattern method. What is required is to print out the PDF pattern files onto tiled pages, then glue on each pattern, and cutout each piece.

File Name and Material:

Summary: CNC-Cut-Summary.pdf
- 0.5" MDF (35 8.5"x11" tiled pages): CNC-0.5MDF-CutLayout-(Rev3).pdf
- 0.75" MDF: CNC-0.75MDF-CutLayout-(Rev2).pdf
- 0.75" Aluminum Tube: CNC-0.75Alum-CutLayout-(Rev3).pdf
- 0.5" MDF (1 48"x48" page): CNC-(One 48x48 Page) 05-MDF-CutPattern.pdf

(note: I've added a DXF version of the 0.5" MDF pattern to this step (DXF-05-MDF-SimpleDXF.dxf) I have removed the cross drilled holes and writing from this file to make it a manageable size, if anyone would like any of the drawings in a different format or including different information please just drop me a line and I'll do what I can)

(note: I've included the original CorelDraw format drawings in a zip file (CNC-CorelDrawFormat-CutPatterns(Rev2).zip) for anyone who wishes to do some editing)

(UPDATE: There is now a choice in patterns for the 0.5" MDF layer, you can download one file (CNC-0.5MDF-CutLayout-(Rev3).pdf ) with 35 8.5"x11" pages tiled, or you can download one file (CNC-(One 48x48 Page) 05-MDF-CutPattern.pdf) which has the entire layout on one 48"x48" page to print on a large format printer or tile yourself)

(Step by step)
1. Download the three layout pdf files
2. Open each in Adobe Reader
3. Goto the Print Dialog
4. (IMPORTANT) in the page scaling dialog select "none"
5. Check to make sure the file didn’t accidentally get scaled to do this measure the printed ruler on page one of each pattern (make sure it matches up with a ruler you trust) (I didn’t do this the first time and accidentally printed out a copy at 90% size more on this later)
Three Axis CNC Machine Cut Summary

File Downloads

- [C:\Documents and Settings\Aaron\My Documents\Plotter Stuff\00-Active\Instructable Files\CNC-Cut-Summary.pdf](C:\Documents and Settings\Aaron\My Documents\Plotter Stuff\00-Active\Instructable Files\CNC-Cut-Summary.pdf) (263 KB)
  [NOTE: When saving, if you see .tmp as the file ext, rename it to 'C:\Documents and Settings\Aaron\My Documents\Plotter Stuff\00-Active\Instructable Files\CNC-Cut-Summary.pdf']

  [NOTE: When saving, if you see .tmp as the file ext, rename it to 'CNC-05-MDF-CutPattern(Rev3).pdf']

- [CNC-075-MDF-(Rev2)CutPattern...pdf](CNC-075-MDF-(Rev2)CutPattern...pdf) (13 KB)
  [NOTE: When saving, if you see .tmp as the file ext, rename it to 'CNC-075-MDF-(Rev2)CutPattern...pdf']

- [CNC-075-Aluminum-CutPattern(Rev3).pdf](CNC-075-Aluminum-CutPattern(Rev3).pdf) (18 KB)
  [NOTE: When saving, if you see .tmp as the file ext, rename it to 'CNC-075-Aluminum-CutPattern(Rev3).pdf']

http://www.instructables.com/id/DIY-CNC-1/
Step 6: Gluing Down the Pattern

Next step is to glue the pattern to the MDF stock and aluminum tubing.

1. Glue the tiled pages to your sheet stock (MDF) ensuring the edges match up.
2. For the aluminum tube the pattern must be glued to two sides. If the tube is laying flat on a table and you glue the side A patterns to the top side B can be glued on either of the side faces.

Tips:
- Use lots of glue
- Have something nearby to help push down each piece
- Patience
(if anyone else has tips on doing this I would love to hear them)

Step 7: Cutout Pieces

Not too much to say for this step simply cut around each outline.
Step 8: Cheating
I must apologize at this stage I succumb to the desire to cheat. As mentioned earlier I accidentally printed out my initial pattern at 90% size. Unfortunately I did not realize this until this stage. So left with a 90% scale set of pieces and having moved across country I was now within reach of a full size CNC router table. I gave in and cut my pieces using this machine. However it was unable to do the drilling of holes so back to the real steps (this is why all the pieces from here on out do not have paper patterns glued on them)

Step 9: Hole Drilling
I have not counted but this project requires a lot of holes. The holes which are drilled into the edge of the material are particularly important so just take your time, you’ll appreciate it later when you need to use the rubber mallet only sparingly.

The areas with holes drilled overlapping are an attempt to create grooves if you have a table router that would work much better for this.

Step 10: Assembling
If you’ve made it this far I must offer my congratulations and suggest it only gets better from here. Looking at the pile of pieces picturing how it manages to become a machine may be a tad abstract so I tried my best to create instructions as close to those produced by LEGO. (downloadable in the attached pdf CNC-Assembly-Instructions.pdf). But in the interest of amusing along the way here is a timelapse of me putting my machine together.
Step 11: Software, Wiring and Configuring

Almost there. All that is required is to wire up your motors and controller following their instructions, and to set up your control software using the included instructions and the machine specific details included here in step 2.
Step 12: Finished

There you have it hopefully you are finished and ready to go into production. I hope I have not left out any crucial details but if you think of something you'd like to know which I have omitted please just ask. Finally to demonstrate that it all works a video of my machine cutting out a pattern in pink foam.
Related Instructables

3 Axis CNC Router - 60”x60”x5” - JunkBot by russeanderson

The DIYLILCNC: Open-Source Plans For a Low-Cost, Easy-to-Build CNC Mill. (v1.0.2) by DIYLILCNC

Make a CNC Hot Wire Foam Cutter from parts available at your local hardware store by tbarnea

Tiny Wanderer - A Table Top Robot by dallaspersonalerobot

Homebrew Laser Cutter made by Zach Radding by TimAnderson

Open Manufacturing - (How to Build 30 (SERB) Kits) by oomirout

DIY prototypes (robots or art design), with homemade pieces (recycling guide) Part One by aisteir

Fireball V90 CNC Router Assembly (video) by abbtech
Intro: Use a Treadmill DC Drive Motor and PWM Speed Controller for powering tools

Power tools such as Metal cutting mills and lathes, Drill presses, bandsaws, sanders and more may require .5HP to 2HP motors with the ability to fine tune the speed while maintaining torque.

Coincidentally most Treadmills use a 80-260 VDC motor with a suitable HP rating and a PWM motor speed controller to allow the user to change the belt speed and keep a good constant speed and torque while running on it.

There are Commercial DC Motor/PWM controllers available or you can build the PWM circuit from scratch and buy all the components seperately but you will spend a lot of time and money either way. All the parts you need are on the treadmill.

Tear your own apart or get one on Ebay.

(shameless self-promotion below)

Motor/controller combos on Ebay

Safety and Disclaimers- You should have some knowledge of electricity and the dangers of household current and know your abilities/abilities. Serious injury may occur to you or others from use/misuse of these motor set-up. If you are in doubt DO NOT ATTEMPT. IT CAN KILL YOU. Any Crazy Ideas found here REQUIRE your testing. Your appilication and use of any ideas here are all on you and you agree I cannot be held liable. You equipment should have On/Off safety switches, Fuse protection, ground wires on your machine as required and your power source should have ground fault interrupters, circuit breakers,properly grounded sockets and cords and always unplug equipment before tinkering and any other safety practise I am forgetting to mention.

Step 1: Motor Vid

Testing the motor/controller
**Step 2: The PWM circuit board**

For a complicated description of a treadmill PWM (Pulse-Width-Modulation) controller you can visit http://www.freepatentsonline.com/6731082.html or You can visit wikipedia for a better definition of PWM.


But basically (as best I can understand) it’s an efficient speed controlling circuit that pulses the Voltage and the width of the signal to the motor off and on thousands of times per second. This transfers more power to the load and wastes less power to heat than a resistive type speed controller.

PWM style controller Trim Pots- located near one of the edges of the board. Each Set for specific motor

**MIN** (Minimum speed-Touch if you dare) adjusting MIN Trimpot may affect MAX, may be necessary to adjust both until desired levels are achieved

**MAX** (Maximum speed-Touch if you dare) Note that MAX adjustment may affect MIN

**IR COMP** (Inrush compensation-Don't touch) Improves load regulation by providing minimal speed fluctuation due to changing loads. If the load presented to the motor does not vary substantially, the IR adjustment set at a minimum level. Excessive IR comp will cause control to become unstable causing motor cogging.

**CL** (Current Limiting-Don't touch) The CL Trimpot sets the current which limits the maximum current to the motor. Also limits the AC line inrush current to a safe level during startup.

**ACCEL** (Acceleration Time Period, 0-full speed in seconds) I've never seen one on a treadmill circuit card, only on commercial PWM DC motor controllers. There must be something on the treadmill board that sets the time value..resistor perhaps?
Step 3: The speed Pot

PWM circuits uses a Pot (Potentiometer) to adjust the speed from 0 RPM to Max RPM. The Potentiometer can be of the rotary type or linear sliding type. The potentiometer is usually rated 5 or 10K Ohms. Typically 0 Ohms is no movement and 10K Ohms is full speed (unless you have your Pot High and Low wires swapped...then it’s visa versa). Keep in mind the motor may not even begin moving till 2 or 3 K Ohms (actual value varies) and you can’t really start the pot at 2 or 3K Ohm position either because the treadmill motor controller requires 0 Ohms on start-up (Kind of annoying).

The Pot talks to the circuit board through 3 terminals usually marked High, Wiper and Low (or H, W, L).

Some controllers use a digital console to change the motor speed. You don’t want to scroll through programmable selections, exercise routines and heart beat monitors just to change the motor speed on your lathe.

Solution: Throw it away and replace it with an appropriate Pot (usually 5 or 10K Ohm Pot). The digital console interfaces the PWM Circuit board the same way that The speed Pot does, through those 3 terminals (on some marked G OH or W L H and colored black, white and red or S1, S2, S3, colored Blue, Grey, Orange.

You should also use a switch for ON and OFF. The Pot is for speed control once the machine is running.
Step 4: Types of Treadmill Motors

I have seen 3 types of motors.

**DC Permanent Magnet with PWM controller** (Great for torque at all speeds). 2 wires to the motor (Usually).

**DC motor with Armature-voltage DC Motor Control**. (Great for torque at all speeds). 4 wires to the motor. 2 run to the shunt-field current, 2 run to the armature. Vary the voltage applied to the armature, vary the speed. Not all 4 wire motors are Armature Voltage controlled. Some have 2 wires that are part of a thermal protective circuit. The ones I have seen are usually both blue.

**AC motors**. (Probably not any better than the AC motor you’re thinking of replacing). Motors are running at a constant. Incorporates a special sliding pulley. Changing the belt speed is done manually-controlled with a cable that changes the size of the pulley's diameter. Larger motor pulley diameter faster belt speed, smaller pulley slower belt speed (I think).

The DC motors vary in size but most are Permanent Magnet, have brushes, a flywheel, and have either tapped holes or a bracket or flange welded to the case for mounting. They typically can range from 80-120VDC but as high as 260VDC. The HP's 1/2 to 3.5HP (treadmill duty rating), Upper end RPM 2500-6000, 5-20 Amps.

The Max RPM isn’t as critical when you can adjust to any RPM within the range and keep a near constant torque.

You can reverse the direction on the DC motors by reversing the polarity. Simply swap the 2 motor wires (usually Black & White or Black & Red) at the terminals on the PWM circuit card. Remember if you reverse the direction of the motor you can’t use the flywheel as it is. Because of left hand threads it could come off. Drill tap and set-screw the flywheel to the shaft.
Step 5: Drive Pulleys and Belts
Most treadmill motor flywheels serve also as the pulley. They fit a fancy flat belt with 5-10 "v" grooves. The driven pulley that mates with this belt originally drove the large roller that the treadmill belt rode on. Reusing the plastic roller pulley is near impossible. Very few motors actually come with the common Automotive 4L style belt pulley.
Solution: Remove flywheel and replace with normal V-belt pulley. *If the flywheel you take off had fins for cooling the motor, replace it with either a blade mounted to the shaft or an externally powered fan*

Taking the flywheel off can be a pain. The flywheel are left-hand 4m thread and can really be cinched down or corroded onto the shaft. Chuck the flywheel end in a vise and turn the shaft on the opposing end Clock-wise and the flywheel may come off.

Some Motors don't have 2 shafts. The shaft on the brush side is usually hidden under the bearing housing. For the stubborn or single shaft motors I use a hacksaw and run the motor on low speed and use it like a metal lathe and saw the pulley through once or twice. It always comes off easily when you turn the nut into 3 thinner nuts rather than one wide nut. Just make sure you don’t cut into the motor shaft. Eyeball it close and then test it by turning it with a pair of vise grips until you are through the threaded portion.

Or.... If you don’t mind the flywheel...
You can use the motor(at a very low speed) as a metal lathe and carve a suitable groove to fit the belt of your choice. It can be a bit tricky (dangerous) as your cutting tool is not fixed. ** USE eye protection, gloves, faceshield etc.**
A rat tail file will work for a round belt or a small bastard file can carve a v shaped groove for the common automotive style belt.

Remember again- If you reverse the direction of the motor you can't use the flywheel as it is. Because of left hand threads it could come off. Drill tap and set-screw it.

Step 6: More Idiosyncrasies
There are some small but solvable problems using these set-ups. I think a lot of these issues could be fixed with trim pot settings but the exact amount of adjustment and the values for each vary too much, are vague and unpublished or unknown to the average person. If you come up with better solutions PLEASE let me know so I can update them.

problem 1) Treadmill motors have a 3-4 pound fywheel. Engineers calculate the energy stored by spinning this heavy flywheel to obtain Horsepower ratings referred to as “Treadmill Duty Horsepower”. Any quick changes in speed aren’t noticed because of the kinetic energy still stored in the flywheel. Sometimes you can hear the motor totally turn off till the flywheel spoools down and balances the motors RPM with the respective setting on the rheostat. If the load is restored or the speed setting raised above the motor’s present speed, the motor turns right back on. Solution: remove the flywheel. Some of that kinetic energy will be stored in the piece of equipment you are powering but if not then some horsepower could be lost.

problem 2) When starting up a treadmill you wouldn’t want it to start up at full speed while you are on it. If the rheostat is not set to the lower end of the resistance value the circuit will not start. Now you have the Motor/controller combo on your drill press or mill and it won’t start because the rheostat is not set in the start position. Solution: Turn the rheostat to the start position before turning on.

http://www.instructables.com/id/DIY-CNC-1/
Step 7: My Treadmill Powered Tools
This is my Drill press converted to a mill. I got it at the junkyard for $10. It had a bad AC motor. The Crossfeed table is from Enco and the new motor is off of a treadmill also from the junkyard. The motor and belts drive it just like the original motor did. It drills and mills fine. The treadmill motor mount was identical to the original AC motor mount. I experimented with the original 2 belts but quickly got rid of the extra belt and step pulley and went with one belt. There was no need for moving belts up and down the step pulley anymore. The motor keeps good torque at all speeds.

(Future pics of Sewing machine mod will be here)
The machine is the 1940 style heavy duty leather machine and had its own 4 ft bench and a 50 LB friction clutch motor hooked up to a treadle. The machine and bench just would not fit in my garage. am fitting it with one of these set-ups and have tested it enough to know it will work. The foot control is off of a newer sewing machine that used an AC motor speed control circuit also utilizing a Pot. I tore out the rest of the circuit and replaced the Pot with the 10K Ohm Pot my treadmill motor speed control needed. Now I can operate the sewing machine in my living room like a normal portable machine. It has as much torque as the original clutch motor and will sew right up your arm.

Step 8: Motor Mount Styles
This is 4 of the styles I have found. All pictured are DC motors. All except the last one are the permanent magnet type. The lower left motor image has a mount almost identical to the mounts on the AC motors found on drillpresses and such.
Step 9: Foot Speed Control
This is a sewing machine foot control that I modified to run a motor set-up I plan on powering an old industrial sewing machine with. The circuit inside was originally for controlling an AC motor so it is only good for mounting your potentiometer. Remove all the circuitry of the original controller (i.e. resistors, pot SCR’s and such) and mount your speed Pot. It takes some adjustment of the placement but it can be done. I can now control the treadmill motor with my foot from a few RPM to full 4000 RPM.
Step 10: Schematics/Pics
This is some Schematics and Pics I have collected. Most Treadmills have one taped to the plastic belly panel. If you have a schematic you would like to contribute email me. The PDF’s download very slow but the detail is worth the wait so be patient. Just right click it and open in another window and check out the rest of the instructable while it downloads.

File Downloads

Step 11: Reader Submitted Contraptions
Ball Pitching Machine
http://www.youtube.com/watch?v=oEUYlI-SYGg
CO2 laser that cuts sheet metal
by owhite on May 2, 2007

Author: owhite  author's website
just trying to make sense of this world.

Intro: CO2 laser that cuts sheet metal
PLEASE NOTE: I'm really not competing to win the laser, a t-shirt would be fine, thanks.
I saw the competition and thought it would be fun to show off my system.

INTRODUCTION. The general idea of this CO2 laser system is that a beam is directed down to a part for cutting. The part sits on a computer controlled platform which moves the piece around the stationary laser beam. Cutting is achieved by passing the beam through a focusing lens. A focused beam exits through the bottom of a cutting head nozzle. Gas, such as oxygen, is fed into the side of the chamber below the focusing lens. This gas exits the nozzle along with the beam and the laser beam/oxygen combination serves to vaporize the steel for cutting.

Click here to see it cut

One thing that I discovered when making this system is that purchasing the laser was the easy part; many other systems are required to be on-line in order to achieve anything useful with the laser. To give you an idea, this is a comprehensive diagram describing the basic components of a CNC laser cutting system.

This is a picture organizing many of these components around the central control unit and includes other sub components such as the motors, encoders, solenoids and flow sensors.

Assume for now that you have a really great laser, and these main components are handled:

- Laser head and power supply
- Optics
- Control unit
- CNC table and power supply.
- Computer
- Cooling systems

What other systems have to be on-line in order to have a cutting operation?

Electrical
Two 110VAC 20 amp lines were run to operate ancillary equipment, a 220VAC 20 amp line services the laser power supply, a 220VAC 20 amp line services the chiller outside of my house, and another 110VAC 15 amp line runs room lighting.

It was also useful to make boxes like this that have 110VAC entering into them and also had relays system that could be driven by TTL levels to run various appliances like ventilation.

Ventilation
A ventilation system has yet to be installed in the work area. This will be required to remove fumes and reduce smoke that will contaminate the optics inside the beam delivery system. The laser has the capability to cut a number of different materials like wood and plastic. Ventilation will be essential to remove the fumes produced by these materials.

Gas Lines
The laser cutting system can use either oxygen or nitrogen depending on the cutting application. This required that a couple tanks get installed and I ended up mounting the tanks up off the wall. This is to conserve floor space so I can cut larger sheets of metal. The brackets came from the welding supplier. The plastic chameleon has a couple magnets embedded in it for sticking to the tank.

Here's a pic of the gas set up. Here is another .

Support Arm
The laser head needs to be suspended about 48 inches away from the nearest wall. Another design criteria was that it has to be able to change the height of the laser along the z-axis. A CAD drawing was put together, and I bought a pile of channel iron, angle iron, and flat stock then went to work with my chopsaw. Note the lag bolts attaching the angle iron to wall and floor.

Here's the support .

http://www.instructables.com/id/DIY-CNC-1/
**Step 1: The Laser Head**

This be that laser. My system is based the Coherent G-100, an RF excited sealed industrial CO2 pulsed laser. It consists of 100 watt laser resonator and solid state RF amplifier integrated into an all aluminum enclosure. The RF amplifier provides pulsed RF power to the laser to ionize the CO2 gas mixture in the tube. A modulation signal applied to the laser head controls the output pulse width and period. The amplifier produces 3000 watts of RF power.

- Average power range 10-100 watts.
- Peak effective power: 250 watts.
- Input power: 48 volts DC at 50 amps.
- Weight: 35 pounds.
- Cooling requirements: 2500 watts, water based.
- Documentation
- Original price: $27,000.
- The Coherent web site.

DC Power Supply. The power supply was specifically designed for the G-100. It is air-cooled and digitally controlled. The supply produces 48VDC at 50 amps and requires 220VAC input.

Control systems. The G-100 has a DB25 connector that supplies control and input modulation signals to the RF amplifier and supplies status information from the amplifier. This allows monitoring of the temperature, duty cycle, and supports digital control of the overall power output of the laser.
Step 2: Robotic CNC Table

I purchased a large CNC table on ebay for $500.

The table was probably made in the 90s. It has a total of 18 inch movement in X and Y directions. The lead screws have a .25inch pitch. The motors that came with the table were too old to be used, and some new servos were retrofitted.

The servos also came from on ebay.

Their specs are the following:

37.51 Oz-In/A  
25.0-30.5 V/KRpm  
Motor Terminal Resistance .75-1.02 Ohms @ 4A.  
Maximum Terminal Voltage 60V  
Maximum Continuous Speed 2100 RPM (No Load)  
Maximum Peak Torque 1500 Oz-In.  
Maximum Peak Current 44.5A  
Maximum Continuous Stall Torque At Max Motor Temp 300 Oz-In.  
Maximum Continuous Current 8.9A

US digital motor encoders were used to detect the position of the motor relative to turns of the lead screw.

The new motors were so large that they dont fit the nema 34 sized system on my table.

At Stock Drive Products, they have piles of cad drawings, pdf files specifying pulleys and belts, and a straight-forward ordering system. I had to make an educated guess about the length of the belts, so using the data from the sdp site I put the geometry of the motors, pulleys and ballscrews in autocad and figured out the number of teeth required for the correct length belt.

After getting the anticipated position of the motor the motor mounts were designed and plans were sent off to a machinist:

...who made the parts out 3/8th inch aluminum plate.

The CNC table also needed to have a rack added that would support parts that are getting cut by the laser. The rack has to be level, because the distance from the laser that can develop the power density to cut metal can only vary by a less than a millimeter. The first table was machined aluminum, very flat, and served as a good platform for the rack. The rack was made of 3/4 inch aluminum bar stock. Its held together with threaded rod. Aluminum tubes were cut 1 3/4 inch for spacers.

I tried putting neodymium ring magnets attached with small bolts in on each bar.

The neodymium rings came from ebay. If you search on neodymium you'll get a million hits. Nice stuff, but you cant machine it, so the ring variety was purchased for easy bolting.

Next generation table

I went to a newer version of the table that supports parts to be cut by the laser more effectively. It was constructed with 12 power hack saw blades. The dimensions of the blades are 24 inches long, two inches wide and 1/16th of an inch thick. They have 4 teeth per inch. The table was constructed by running two foot long, 1/4 inch threaded rod through the holes at the end of the blades. One and a half inch long spacers were placed between each blade.

The only other construction item was the brackets that were placed in the assembly to bolt the blade-unit to my cnc table. The brackets were cut by my table and folded into the a C-shape. Its nice to have a system that can help build itself.

The main picture is the table made of the blades. Here is another, holding up a piece of stainless steel. The t-shaped brackets staying flat on the table have bolts that project down and wing nuts bring up a part below the table to hold down the steel.

In my previous set up, when the laser passed over the part getting cut in the areas where the bars contacted the part, it would splash in funny ways producing problematic cuts. In the new system the point of contact to the part is relatively small, when the laser passes over where the supporting table there's no splashing. The tips of the points on the blades are machined well enough they form a nice flat surface. Once assembled together with the threaded rod they are very ridged and dont flex in left to right or up and down directions. The blades came from ebay and cost about $100 total.
Step 3: Motor power supply

The laser has a CNC table that moves parts around a stationary beam source.

A table of this size required building fairly large power supply to drive the table’s servos. This documentation describing power supply formulary says that two servos requiring 10A should never exceed $2 \times 10 \times 67\%$, or 13.4A.

The manufacturer Plitron sells toroidal transformers. They have some useful technical notes. To calculate the desired transformer voltage I used the formula: $(68\text{VDC}/1.4) = 48.6\text{ VAC}$. However, when I constructed my power supply I used a formula supplied by Plitron which uses a slightly different method of:

$$(68\text{VDC} + 2) \times 0.8 = 56\text{ VAC}.$$ 

Using this required that I make the modification described below. But since I went with a 55VAC toroid I went with a 13.4A * 55VAC = 743 VA rated toroid transformer. I purchased plitron transformer 117042201, with two 55v secondaries @ 9A each, $139.73. See plitron's toroidal ratings.

At this amperage and using the formula $(80000 * I) / V$ I estimate I would need around $(80000 * 18) / 68 = 21167\text{ uF}$ filter capacitor. I purchased five Model# 3VTLM153M80V, 15000uF, 80V electrolytic caps on ebay and I'll wire two in parallel. I also purchased 4, 25 Amp 200 Volt bridge rectifiers, $4 each.

CAUTION: the capacitors in the supply store a lethal charge after powering up. The resulting discharge has the potential to be very unsafe. This is typically experienced when you’re just hooking the thing up to the rest of circuit and comes in the form of a firecracker-sized explosion. This is primarily a problem with the power supply is not hooked up to anything and its best to keep the output terminals shunted when not in use. Fortunately the manufacturer of the Gecko drives provisioned for removing the energy stored in the caps and the overall is system is much safer when the Geckos are connected to the supply. Knowledgeable designers should consider adding circuitry that will safely discharge across a power resistor; although I have not been able to get advice on exactly what that circuitry would look like.

The supply employs a full wave bridge circuit and put into a canibalized Sun harddrive enclosure. Its a nice box that comes with fans and a 5VDC power supply. Most wiring was done with 14 guage wire, terminals, and screw-down terminal blocks. After completion I looked at the voltage on my oscilloscope and there was absolutely no ripple.

Over-voltage repair

The plitron transformer produced too much voltage. I used the formula from their site. I recommend the formula for the transformer rating of:

$$\text{VDC} = 1.4 \times \text{VAC}$$

The voltage is 79Vdc. Lowering the voltage of the transformer required that I remove some wraps from the Plitron torroid. I drilled out the epoxy core on the drill press in about ten minutes. The heat shrinkable wrapping around the windings completely prevented the epoxy from entering any windings. After chipping out the remaining epoxy block I removed the heat shrink wrap. The secondaries wires were very accessible and I didn't have any problem unwinding them.

I went with about 5 windings first prior to testing. I carefully checked for shorts between any of the exposed wires. (Its a bit of an act of faith that the enamel around the wires will prevent any shorting but it does the job.) After checking as much as I could, I hooked up the transformer and measured the voltage. The first time the voltage wasnt even close. I unwrapped some more, eventually got to the right voltage, trimmed the secondary wires, soldered new connectors and put heat shrink tubing around solder joints.

Heatshrinkable sheet was wrapped around the donut. I didnt like that result but left the sheet on, and followed up with lots of wraps of electrical tape. I popped the transformer back in the power supply enclosure and I'm operating at the right voltage.
Step 4: Laser Optics
Sheet metal cutting requires a power density of 106 watts/in\(^2\) (source: Mike Klos @ laser mechanisms)

Converting to millimeters, that's 1550 watts/mm\(^2\). (using equation: 1in\(^2\) = 645mm\(^2\))

A 100 watt laser can achieve a power density of 1550 watts/mm\(^2\) in a spot size that is 0.6452mm\(^2\)

A spot size that is 0.6452mm\(^2\) has a diameter of of .28mm or 280 micron (using area = \(\pi \times (d/2)^2\))

280 micron! If I can deliver 100 watts to a spot of 280 micron, I should be able to cut metal. That's too easy.

Why? Well, how big a diameter can I expect with my optics? The information on my beam diameter varies. I have read it goes anywhere from 1.6 to 2.3 mm.

At 1.6mm, if I have a 3x beam expander I get 4.8 mm, which will be 103 micron using a 1.5 inch focal length

(equation: diameter = .013 \(\times\) M\(^2\) \(\times\) (fl/D) where M\(^2\) is equal to 1, and D is diameter of incoming beam. See this site .

If I substitute in an M\(^2\) of 1.5, I still get a diameter of 150 micron. So according to calculations I should be able to deliver a power density needed is 106 watts per square inch.

Note: I'd like hear from anyone who could verify that 106 watts per inch is the power density I need.

Note: the reason I bought the microscope was to be able to measure in micron -- hopefully I can use it to check my beam diameter

Romos gave me some excellent feedback on my post about beam sizes. He points out that the expected beam size can be taken from this table for the G100:

Distance From Laser (mm) vs Beam Diameter (mm)

0 mm distance = 1.9 mm beam diameter

http://www.instructables.com/id/DIY-CNC-1/
The beam delivery system is composed of a bend mirror, a processing head, a cut quality enhancer and a circular polarizer, and a beam expander. In order to attach the cut quality enhancer to the G-100 two adaptors were machined out of aluminum (1, 2). The cut quality enhancer improves the shape of the G-100 beam, and the circular polarizer prevents the beam from reflecting back into the laser head. Both parts came from Laser Mechanisms. The cutting head was manufactured by Haas LTI.

The principal of the processing head is that the beam enters the top of the head and is directed to a focusing lens that is found in the center of the cutting head cavity. A focused beam exits through the bottom of the cutting head nozzle. Gas, such as oxygen, is fed into the side of the chamber below the focusing lens. This gas exits the nozzle along with the beam and the laser beam/oxygen combination serves to vaporize the steel for cutting.

The optics for the laser

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Alignment

Originally I thought this was going to be voodoo engineering because you can't see the beam of the laser. It turns out that it's not that hard. First set up a system to mark circles or edges of your beam path with cross hairs in the center of scotch tape.

The place your targets on the beam path. If the item that gets the tape can be threaded into place it makes it easy to mount the target.

Using this system, I started with a target on the cut quality enhancer, and then moved on to the elbow that points the beam towards the floor. The elbow has Allen head screws that allow you to micro-adjust the mirrors in the beam. This took a little while to figure out the impact of changing these screws and where the beam lands, so for a while I would take to shots on one piece of paper, and view the where the beam moved after making a change. After I got the hang of this, I went back to the targeting system to adjust the beam as best I could to be on center.

The cutting head has a nozzle on it with a port that is roughly half a millimeter in diameter. If the beam is not exactly on center, it gets reflected off the side when it comes out of the nozzle and forms a characteristic pattern that looks like this.

Another alignment method I used to cure this problem was to remove the nozzle, and shine a short pulse on thermally sensitive paper. The issue is to carefully adjust the beam so that it produces the same spot shape with and without the nozzle to ensure it is going directly through the port of the cutting head. A friend also recommended that acrylic works as an alternative to the thermal paper.

Height adjustment

Here is a nice picture of laser beam height adjustment. The issue is that the beam forms a waist and the most power of the laser occurs at the minimum waist diameter. The sweet spot of the beam waist can be placed in path of the beam by adjusting the height of the cutting nozzle.

To find the best height for minimum beam diameter, I used the thermally sensitive paper and looked at the beam diameter as a function of height. The markings on the card are based on 100ths of an inch are relative; they do not reflect the actual distance of the focusing lens to the paper. What you can see from this experiment is that the beam size gets smaller down to a distance of 650ths of an inch and then starts to increase in size.

I would not claim that is a good method to determine the beam diameter. I don't know if there is a way to determine what the beam size is, however, it was still interesting to look at the spot under the 100x microscope.

This is a picture of my smallest possible spot on the thermal paper. The microscope was focussed on the stainless steel below the paper. You can see burr edges around the hole. The burns are not a result of reflection as shown here, at least they don't occur like this repeatedly. It seems more like the results of a heat flare coming off of the beam.

This is the underside of 1/8th inch thick plywood which was cut at 10% power levels on the laser. The kerf width is roughly 200 micron as well.
Image Notes
1. cut quality enhancer
2. bend mirror
3. collimator
4. cutting head

http://www.instructables.com/id/DIY-CNC-1/
**Step 5: Laser Controller**

Blessed are those that use Eagle Schematic software.

The Gecko drives and the USC board are nice, but the laser controller also has some custom electronics that measure the states of laser itself, generate a pulse width modulated signal, and report an E-stop to the Universal Stepper Controller. The schematic of the custom electronics was generated using [schematic software](http://www.cadsoftusa.com/). The laser measurement was based on circuitry specified by the laser manufacturer.

The states of the laser were fed into a "Just A Minute" or JAM circuit ([original schematic](http://www.instructables.com/id/DIY-CNC-1/)). The JAM circuit was originally designed for a game show situation, where multiple contestants can hit a switch, when the switch is thrown a light goes on indicating who hit the button, and the rest of the contestants are locked out. Perfect for my application, because if any of multiple states go low I want to register which system went low, lock out other inputs, and then flip the E-stop toggle of the USC board. The custom board also has a PWM circuit which is based on a programmable timer that feeds into a binary counter and magnitude comparator combination.

There's also a section on the circuit that debounces the push of a button and then toggles a D-type flip flop. This receives power from an unswitched power supply, when the user hits the pushbutton it turns on a solid state relay that powers up the remaining circuit.

The schematic epitomizes the I/O problem posed by the laser controller. There are over 120 different lines from connectors going to limit switches, encoders, geckos and the USC board. All lines were led into one of four 30 pin female headers. This was good way to go because it reduced any soldering or other types of direct connections between components -- basically all connections between components were handled by linking between header pins using wire wrap.

This has several advantages: 1) it is an overall reduction in soldering -- soldering is fine but its harder to disconnect -- connections are made by crimping wires onto pins and then inserted into the header 2) The "logic" of how lines are linked is managed in software as described in the next section -- this avoids mechanically looking at a header block from the geckos and deciding which wires have to be soldered to the pins leading to the encoders. 3) Overall, it reduces the spagetti of the circuit. Dont get me wrong, the spagetti is still there, but its centralized into four main headers. Readers may not want to go with this strategy, but one thing I strongly recommend is to avoid making hardwired connections between components. Be sure everything is connected by easily disconnected plug ends -- hardwired leads soldered directly between components make it really hard to pull the components out of the box when problems arise.

**View circuit...**

**Wire wrap is a beatiful thing.**

Eagle supports exporting the schematic as a net list and a pin list. These files were used as input to a perl program which was also given the locations of all the parts on a wire wrap board, which then listed all the wire wrap connections required to make the board. The program also creates a drawing that shows the location of the chips on the wire wrap board.

There are significant advantages to mapping out the entire network of connections in a net work connection file. The main thing is that its faster. You arent looking at much except the names of the pins on the wirewrap board, wiring those pins together, and then checking for continuity with an audible tester. This is in contrast to a situation where you have your components on one side of the board, you're looking at those, looking at a circuit diagram, then flipping the board over, picturing the location of the IC pins in your mind that are now on the other side of the board, and then connecting things together. I've now gotten into the habit of always translating the circuit I'm working on into pin to pin connections. The other advantage I see with having a listing of wire wrap connections is if I experience problems with the circuit in the future -- imagine just having a circuit diagram and a completed wire wrap board in your hands. Debugging the circuit -- looking for breaks, testing chips -- is very time consuming. With a list of wire wrap connections you can order the list to give all the connections for one single IC, and rapidly check those connections.

The wire wrap was performed using a slit-n-wrap tool purchased from Digi-key; a few points about this process:

- If you haven't done slit-n-wrap, dont compare it to other methods. Slit-n-wrap takes a little getting used to, but you can end up making a pretty high quality product. Frankly I thought it was fun.
- Dont use pre-stripped wire wrap tools because they only allow you to make two connections. Slit-n-wraps let you make as many connections as you want on one wire.
- Get an audible continuity checker. You must check for continuity -- when it works wirewrap is a very solid connection but around 10 percent of the connections will fail and have to be redone. The audible continuity checker is a lot faster.
- Being able to rapidly unwrap wirewrap is essential. Radio shack part number 276-1570 is a cheap wire wrap tool that absolutely should not be used do wire wrap with slit-n-wrap wire, however; it is a great device for unwrapping. Digiskey also sells unwrap tools but they are over-priced. Unwrapping using the radio shack tool is a matter of pushing the tool over the wirewrap post, bearing down on the wrapped wire, and turning in the opposite direction. This loosens the wire enough to then be pulled off with your fingers.
- I purchased my wire wrap boards on ebay by searching on "AUGAT" "WIREWRAP" and or "WIRE WRAP". Augat wire wrap boards are absolutely the best. Their original cost is astronomical but fortunately many have been appearing on ebay for garage-sale prices.

My board had over 400 connection points and I would definitely use wire-wrap if I had do it again. On the other hand, now that I debugged my circuit I could just have a board shop make a PCB for around $100. :-) The [http://www.cadsoftusa.com/](http://www.cadsoftusa.com/) website has links to places that make PCBs.
Thinking outside of the box included thinking how to work outside of the box.

Previous motor controllers that I’ve made have had one serious flaw -- all the components were mounted directly into their enclosure. This made circuit repair, as well as installation and removal of all components very inconvenient. For this controller, I started by mounting all the components on a plywood board. The board has rubber feet and makes it much easier to service all the parts on my bench. The board sits on a recycled computer case, which also has a hole on the side for a fan. The fan points directly over the gecko motor drivers. This laser cut connector plate was made by first designing the plate using dimensions of connectors found in documentation obtained from digikey. The resulting DXF file was sent to Arts who produced the plate by laser cutting 1/8 inch thick plywood. Ironic that I am out-sourcing to other laser shops to do something I hope to eventually do in my own basement. The wires leading to the connector plate form something that I refer to as the neural network, an extensive collection of wires and connectors that hook to all the internal components. Once the neural net is connected to the internal components the plate faces outside of the enclosure, and is slightly recessed to allow all the cabling connectors to be protected from getting banged around.

Assembled system...

Installation

I ordered a PCB from fab express. The board cost only $65.

This board was mounted on the outside of the enclosure.

The strategy of this PCB is that it has an AVR chip right on it, this allows me to set in two different power settings manually. There is an input to the board that selects these two preset values, and based on the values five outputs are pushed onto another chip on the wire wrap board that handles selecting the pulse width set to the laser. The completed controller box was closed up and put on the shelf.

On shelf

If you look at the diagram you can see there a lot of inputs and outputs to the controller. This creates a problem because you end up with a lot of cables to manage. I have a friend who used to wire phone closets. He suggested doin’ it like the phone company and making spools made of posts projecting off the wall. This was very helpful because it keeps the excess wound up and the cables stay off the floor. Its also nice because there will be some excess length to the cables which will be helpful in a situation where some of the hardware gets moved to a new location. The cable expert and I lay over 100 feet of between the controller to the CNC table.

The cabling...

Observe the loops of wire going around these spools in the picture above. The controller joins some other components on the shelves. That was pretty much the complete layout of the system, the following is a video showing the motion control system.
File Downloads

- controller.pdf (212 KB)  
  [NOTE: When saving, if you see .tmp as the file ext, rename it to 'controller.pdf']

- jam_buzzer.pdf (12 KB)  
  [NOTE: When saving, if you see .tmp as the file ext, rename it to 'jam_buzzer.pdf']

- CD4541.pdf (83 KB)  
  [NOTE: When saving, if you see .tmp as the file ext, rename it to 'CD4541.pdf']

http://www.instructables.com/id/DIY-CNC-1/
Step 6: FAQ

I want to make a metal cutting system too. What would you have done differently? Are there ways that I could save time by buying OEM components?

Well there are some things that I would have done differently to be sure, but I don’t think it would mean that would have saved time. The main reason is cost. There aren’t any systems that I know of that are in my price range. Another way to say it is, most OEM solutions are incredibly expensive.

Most of the mechanical parts of the system like the physical CNC table, the chiller, the frame supporting the laser were very easy. This is fun and not very time-consuming. Perhaps the biggest technical hurdle was that I put my laser support system together using a welder which some people may not have.

The optics were pretty much bolt-together parts and I don’t think there would have been much time to save there. There are some optics that are specifically designed for the laser itself which would allow you to just take the optics out of the box, connect to the system, and you are ready to go. I was lucky to get my optics from eBay and other sources for fairly cheap, but it was not an instant solution. I would still go with the used parts solution again.

Electronics. Now, this was hard for me. You need to have motor drivers, some laser controls, limit switches and emergency stops. Putting this all together under one integrated system was a very large amount of work. I don’t know of a commercial system that works for my laser, even an expensive one, so I had to make all that circuitry myself. I used a lot of TTL logic, and to be certain I would never do that again.

So one thing I definitely would do differently is this. I would use microcontrollers. I would have liked to have all inputs and outputs of electronic/electric connections going into a board handling TTL signals, relays, and connections for external limit switches, and then put the logic of the overall system together with microcontroller software.

On the other hand, if you want to save some time it would be best to find an alternative to making the electronics yourself.

House wiring. There was a lot of wiring I had to do myself, which was fun but also a lot of work. You could definitely save time (not money) to have someone else do that.

There are examples on eBay of complete laser cutters with enough power to cut metal. They are very expensive, and also require wiring ventilation and cooling pretty much similar to what it would be like if you had a shop with a really large milling machine. But that still might be a way to be cutting metal without taking a lot of your time.

So the short answer to your question is this: unless you want to spend $50,000 I think you’d have to do most of it yourself.

Can I cut brass?

No. I can’t either. The industry would love to cut brass and they ain’t figured it out either. I gather it’s a problem due to the heat transmission of brass and copper. It spreads out its heat over the area of the cut too effectively. If you can’t concentrate the heat on a particular area, the metal doesn’t get obliterated. Steel is a lovely and cooperative metal.

I have a glass laser that delivers 100 watts of power, can I cut steel too?

Probably not. It’s really hard to tell what power my laser actually delivers. The ambiguity is because the product literature says that they modulate the output. The laser sends out higher bursts of energy that probably exceed 100 watts. The total delivery of power integrated over time is 100 watts. But according to the manual, they claim that by peaking the delivery over short bursts that it actually develops intermittent delivery of 250 watts. I don’t know if its really doing that -- I do know that other lasers (e.g., YAG) also work on the principle of quick bursts that deliver much higher power. If you have a sealed glass laser, it delivers continuously, and it doesn’t do this burst trick that the Coherent does. That’s not to say you can’t get some cutting power. Maybe you could cut stuff that’s 0.005 inches, or better. The key, as you may very well know, is to think about your optics. If you really want to explore the issue you have to read and understand: http://www.nilco.com/laser_intro/optics.html your goal is to get a tight beam, and a DOF that is thicker than the object that you want to cut. If I was in your shoes one place I’d do some research is to find out what power density is required to cut metal. I was told over the phone by Coherent guy (hey better than an incoherent one) that it is 106 watts/in² for steel. But there’s a chance that he’s wrong. Once I think I know, is that I can control my power output with electronics going to the laser. When I take that down to 50% of the max, it still cuts, maybe not as well but it still cuts. It suggests to me there is still hope for the glass tube guys.

What else do I need to cut?

You must have a functioning cutting head, that delivers oxygen that flows through the nozzle. You also need a CNC table running the part around underneath the nozzle.

How much did it cost?

Its rude question but...total estimated cost is about $15k or so. The laser itself was $6500. I bought a CNC table for $500, and the optics were another $2500. A chiller from eBay cost me $500. There were lots of other incidental costs like a lot of electronics, motors, motor controllers, 220 volt wiring, cooling and ventilation. The biggest operational cost is oxygen. A tank of oxygen is $55 and can easily be used up in a weekend. The operational cost of electricity is negligible. The stainless is pretty cheap, around $1 a pound.

Then there’s time. The project took 2 years, but if I had to do it again it could get done in about 6-12 months.

I was thinking earlier today about all these CNC machines when all of a sudden I looked over at my printer and realised that with a few modifications it might be made into a basic CNC.

I don’t think this approach works. The problem is lateral thrust.

If your printer is buzzing along, try putting your hand in the way of the movement, you’ll see that even a bit of resistance will prevent most of the electromechanical gizmos from moving. Now think about instead of that printer head on a little gantry system, you’ve substituted in a cutting tool like a small dremel.

You can imagine that you’d have problems with the printer mechanics moving a cutting tool in wood, but you also have problems just with forward inertia. If the heavy cutting tool is moving in one direction, reversing that movement quickly won’t happen perfectly, it will try to reverse, some belt or gear or stepper will slip a little. (If you clamp your fingers on small steppers when they are moving, they just stop.)

Since most systems of that kind lack feedback about the exact position of the gantry after that slip happens you don’t have a good relationship between what the computer is treating as an x-y position, and what’s actually happening on the printer. This’ll screw ya up.

but, some cutting tools offer little or resistance, like a laser beam being moved around by flying optics, or really really really fast cutting tools (like a high speed bit in a dental drill), so then all you have to do is deal with the forward-reverse inertia problem. There are other applications, like if you’re spraying paint or something, that would also have no resistance. Also if you’re cutting something really soft, but be advised I used to have a balsa wood cutter and there ain’t no way a printer could handle pushing a bit through that with any accuracy.

http://www.instructables.com/id/DIY-CNC-1/
so for cutting tools, you want to have something stronger than a printer. be advised though, if you want to make something it just aint that hard. there's steppers and pulleys and belts and drivers and premade systems galore, just gotta make a little investment. search ebay using the term "linear actuator" or "xy table" or "cnc table", at least some of those searches will show something cheap. 

the other way to think of it is go ahead and buy a plotter on ebay and hack it up, they have all the parts in there. you either hack the existing driver, or get a cheap motor driver board and connect the motors to that. its incredibly instructive to see how a system works. it wont handle moving a cutting tool but its still very instructive. I started by getting a laboratory robot that moved around small liquids, was really good for showing basic principles.

so it just boils down to how much lateral force a cutting tool needs, and the forces involved when redirecting movement of the cutting tool. my guess is that in most cases you could just clamp your finger down on the motors that are moving your printer and you could stop the movement. to be sure, the older printers and the larger format plotters might have a chance. the other option would be to use the mechanical parts from an old system and swap in bigger steppers.

Can your laser cut thru your finger. That'll leave a mark.
No. This laser cant cut through a whole finger. One reason is that co2 lasers cant penetrate through water, which is what meat mostly is made of. The other reason is because of divergence, the power density of the beam drops off very very quickly as it leaves the cutting nozzle. Its the molecular equivalent of shooting at a target with a shotgun that's a mile away.

I have succeeded in cutting a disk of approximately 1/4 diameter off the tip of my finger though. Hurts like heck but it cuts while it cauterizes, so there's no bleeding.

Step 7: Gallery
These are various items I have made with the laser.
Related Instructables

- **Homebrew Laser Cutter** made by Zach Radding
- **3 Axis CNC Router - 60"x60"x5"** - JunkBot by russaanderson
- **How to Make a Three Axis CNC Machine (Cheaply and Easily)** by oomlout
- **Laser cutter, start slicing stuff for under 50 dollars** by lamedust
- **New 007 Laser Weapon - Revealed!** by Kipkay
- **Laser Pointer Scissors** by you in the yellow
- **Build a CNC Router from Scratch (Part 2): Complete Video Tutorial** by phooddaniel
- **Laser Cut Cake!!** by colin

**Intro:** Make your own cnc controller
Build your own CNC controller for next to nothing from rubbish
You can build your own CNC controller for a HM30 or Junior mill. The CNC controller is able to move the table at a max rate of about 200-300 mm/minute. The controller is built basically from parts from a fisher and pykel washing machine from the tip. Three motors are required.

http://www.instructables.com/id/DIY-CNC-1/
Step 1: Connecting stepper motor to milling machine
Finding the stepper motors
The motors from a fisher and pykel washing machine are removed along with the control board. Three motors are required.
Connecting the stepper motors to the HM30 machine
The hole at the end of the plastic housing the motor spindle, slips over the end of the x,y axis on the mill table. The spindle is shortened and drilled to allow the shaft from the table to slide into the shaft from the washing machine. A tapered pin and hole, hold the two together.

Step 2: The stepper motor Controller
The motor is basically a three phase stepper motor. Good luck finding a driver for it.
A driver can be made by using the FETs from the washing machine controller.
A PICAxe chip (see Oatley electronics) is programed to take the step and direction pulse's and energise three outputs for the three coils (5 input/outputs fits on the PICXE08 model, this is programmed with free software on the serial port of the PC).
The three outputs are used to drive a darlington pair in the chip ULN2003 (drives up to 8 outputs), this in turn drives our FETs from the washing machine.
Step 3: PICAXE Code for control

Below is the code that is downloaded into the picaxe chip it will do half stepping, that is energises two coils then drops one, then energises the next etc. This proved to give the most power to the stepper.

Note: because the darlington pair effectively earth's the signal going to the fets the all the outputs in here are inverted (0->1 and 1->0). This sets every thing straight.

'BASIC converted from flowchart:
'C:\PROGRAM FILES\PROGRAMMING EDITOR\DRIVER AS FLOW CHART.CAD
'Converted on 27/1/07 at 13:24:23

```basic
main:
symbol pos = b0 REM current position
let pos = 0
dirs = %00000111 REM set three outputs

WAIT_ZERO: if pin4=1 then WAIT_ZERO REM **** wait for step pulse to zero for next pulse
rem debug b0

WAIT_ONE: if pin4=0 then WAIT_ONE REM **** wait for step pulse to ONE for next pulse

CHECK_DIR: if pin3=1 then CW
  goto CCW

CW: branch pos,(coil12,coil2,coil23,coil3,coil31,coil1) REM **** move one step cw

CCW: branch pos,(coil31,coil1,coil12,coil2,coil23,coil3) REM **** move one step ccw
REM **** energise correct coil and set position ****
coil1:
  let pins = %00000110 rem 001
  let pos = 0
  goto WAIT_ZERO
coil12:
  let pins = %00000100 rem 011
  let pos = 1
  goto WAIT_ZERO
coil2:
  let pins = %00000101 rem 010
  let pos = 2
  goto WAIT_ZERO
coil23:
  let pins = %00000001 rem 110
  let pos = 3
  goto WAIT_ZERO
coil3:
  let pins = %00000011 rem 100
  let pos = 4
  goto WAIT_ZERO
coil31:
  let pins = %00000010 rem 101
  let pos = 5
  goto WAIT_ZERO
```

http://www.instructables.com/id/DIY-CNC-1/
**Step 4: Constant current supply**
The coils are low resistance and we wish to use as large a voltage as we can (allows faster stepping with higher voltage), but we must limit the current 2 Amps for the Z, Y and 4 Amps for the X axis (overhanging axis requires more power).

Again FETs are used, plus a large heat sink and a fan. The cooling is not required for 24 Volts but once we get up to sixty volts it is required.

![Circuit Diagram](image)

**Step 5: More Voltage for faster Movements**
Up to about 70 mm/min 24 Volts is fine but faster than that requires more voltage. To get a reliable 200 mm/min (for Aluminium) 60 volts is used (just use your arc welder output rectified).

With my program (QUICKCNC) I have enabled outputs on the parallel port that go active when a faster speed is required (otherwise FETs heat up too much on slow speed for the constant current)

![Image of setup](image)
Step 6: Software

Having looked for easy to use software on the net that is quick and simple that would work on an old computer, I gave up and wrote my own. This was not a quick task and I would not recommend it.

I did not want to buy a new computer just to run my mill (old computers I can get for about five dollars at the tip shop).

All the software programs either

Required XP software with fast processor

Did just the design then required G-code conversion followed by something to interpret the G-Code, and a simulator to check the G-Code.

Very rarely on the software did all three marry up, and cutting a couple of recesses and holes, curves lines, all with offsets and just have them cut any checking.

That said there is free software out there - Master Utilities (but for some reason when I tried to go over 70 mm/min it would not work, on my program it would). Also Mach software but XP is required

Also I did not have ball screws and fancy lead screws and I found that even if I accounted for backlash in the program the backlash was not always the same.

So I added a couple of input contacts that are activated from a sliding rod that give feedback as to when the table is moving, and it virtually gives me no error (step size is 0.0179mm).

Try it, use it (else give me feedback).

Step 7: Putting it all together

The diagram below shows the connections between the individual elements.
Low Cost Hobby Servo XY Table
by CarlS on August 26, 2008

Intro: Low Cost Hobby Servo XY Table
For this project, we wanted to build a lower cost, lower precision XY table for an installation at TeleToyland. The goal is to allow web users to draw shapes in a sand box, so we wanted a simple XY table that is easy to control from a web application. Since we already have the Web to Hobby Servo connection working well for other installations, using a hobby servo was the desired approach. Most homebrew CNC XY tables use motors like steppers and acme screw drives, but we don't need that much precision, and they are a bit slower than we’d like. The Hobby Servo approach also gives us absolute position control, and helps keep the cost down too - using industrial servos would be great, but a lot more expensive. We were also looking for a lower cost way to do the linear glides - trying to avoid costly linear bearings etc.

(Note, we have a newer version of this project at this Instructable)

You can try this project out live at the site

The Challenge
So, the challenge is taking a hobby servo and getting 2-3 feet of linear motion out of it. ServoCity is working on servo linear actuators, but we’d prefer lower power, lower cost, and longer reach that they currently offer (though new ones may be pending). We also built a basic SCARA type arrangement with 3” lazy susans, servos, and counter weights. This works OK, but the workspace was limited, and due to the polar approach with hobby servos, the resolution is uneven - higher nearer the servos. This may not be a huge problem, but the approach shown here yields the same precision over the entire workspace. We could also consider a hybrid - using one rotational arm with a liner slider on it - the math would be easy in that it would use polar coordinates directly. We could also reverse the two - use on linear slider and add a rotating arm to it. A project for another day!

Using Hobby Servos
With a Hobby Servo, you typically get just 90 or 180 degrees of rotation, so the trick is getting that to work over a longer span - 2-3 feet. We could modify a servo for continuous rotation, but then you lose the positioning capability and we’d like to keep the internal PID circuitry and potentiometer approach. If you use the internal potentiometer and add a big servo horn, you could get a wider range of travel. With a circular horn, the distance traveled is Pi * Diameter of the horn / 2 - that last divide by two is to account for the max 180 degree of travel (we’ll get into that later). So, for a 2’ travel, you’d need a servo horn with a diameter of over 15”! We could use that approach with a lazy susan type of setup, but the momentum in moving that much material puts a huge mechanical strain on the servos (the same issue we had with the SCARA prototype). Another approach is to gear up the output, so you get more motion on the output. We didn’t dig into this, and there may be issues with the power required to move those gears, and in addition, using gears is a bit ticker mechanically - we came up with a much simpler approach.

So, for our system, we pulled the potentiometer out of the servo case, and replaced it with a 10-turn potentiometer. So, right away, you can multiply the distance traveled by 10, so for the above case, it takes the horn diameter for a 2’ travel from 15” to 1.5” - much more reasonable!

In terms of coupling the output we could drive a threaded shaft with a follower nut (ACME threading seems to be preferred). This appears to be the most common drive mechanism for homebrew XY Tables - due to it's power and precision. It does result in slower travel, though, and again, a lot of gearing to get the potentiometer to move at the right speed to cover the span of travel.

What we opted for was a very simple timing belt approach where the servo drives a timing belt pulley, and the 10-turn potentiometer is connected directly to the shaft. With this very simple arrangement, then, we get 2-3’ of travel in a few seconds with no complex mechanics. You could scale this approach up by gearing down the drive or potentiometer to the limits of the mechanics of a hobby servo.

http://www.instructables.com/id/DIY-CNC-1/
Step 1: Materials
Timing Belt Pulleys and Belts

Timing belts are strong, flexible, and lose almost no movement to slippage. We used XL timing belts with 0.2" pitch - 77" long (and 3/8" wide to match the pulleys). This seems to work fine - we thought about testing the MXL belts with a 0.08" pitch, but didn't see the need since there was no noticeable play in the system for our purposes, and there was a wider belt selection. We used a fairly large timing belt pulley since that has a big impact on the final distance (the circumference) - it's about 1.5" in diameter - the largest we easily found with the 1/4" shaft size we were using. With a bigger pulley, the range would increase, but the system is ultimately limited by the precision of the potentiometer, so a much bigger belt may not work as well - certainly less positioning precision. We used 1/4" shafts throughout for simplicity - the same as the ten-turn potentiometer shaft.

We got our timing belts and pulleys from McMaster-Carr (but they are available elsewhere):
part # 6484K454 Trapezoidal Tooth Neoprene Timing Belt .200" Pitch, Trade Sz 770XL, 77" Outer Circle, 3/8" Wide
part # 57105K21 Acetal Pulley for XL-Series Timing-Belt for 1/4" & 3/8" Belt Width, 1.63" OD, 22 Teeth

Bearings and Collars

For the timing belt pulley bearings, make sure to get the extended inner ring ones so they don't rub against the shaft collars. You could also use regular ones with small washers on the inner ring. We used flanged ones to make mounting easier.

We got our timing belts and pulleys from McMaster-Carr (but they are available elsewhere):
part # 6462K12 Type 303 SS Set Screw Shaft Collar 1/4" Bore, 1/2" Outside Diameter, 9/32" Width
part # 57155K337 Miniature Precision SS Ball Bearing - ABEC-5 Flanged Shield, Extended Inner Ring, .25" ID, .5" OD

After building these, we noticed that Home Depot has ball bearings for patio doors, and these may work almost as well at a much lower price. Rather than mounting the bearing in a hole, you could put a couple bolts right through the outer plastic ring and bolt it right to an L bracket.

Potentiometer

Most servos use a 5K potentiometer, so we got one of those. The 1/4" shaft couplers for the potentiometer to the drive shaft connection are available at many places (McMaster-Carr, ServoCity, and Jameco all have them). The potentiometer could be connected to the shaft on the other side of the timing belt pulley from the servo, but in our case we extended it to the same side of the other pulley just as a simple means to keep the mechanics on one side of the device.

We got our potentiometers at Jameco: part # 183548 - they have a tolerance of +/- 5%
We also saw some at Digi-Key with +/- 0.2% - part # M-22E10-0502K-ND - we may try these at some point to see if they have any finer resolution.

Note: with heavy use on the site, the potentiometers started wearing and freezing up, so we have ordered ETI Systems MH22B series hybrid potentiometers (Mouser #882-MH22B-10-5K). Hybrid potentiometers use a layer of conductive plastic over the wire windings, so they are potentially more accurate and they last a lot longer - 10 million turns vs. 1 million turns for the wirewound ones. It's possible the issue is in the slight wobble of the shafts. so we used a piece of plastic tubing to connect them rather than the rigid shaft couplers - will see how that works.

Servos and Servo Hubs

We started with fairly standard servos - Hitec HS-425BBs (57 oz. in. and 0.16 sec to 60 degrees @6v). In testing, we had a standard servo driving a shorter timing belt, and got about 1.5' of movement in about 4 seconds. Not bad, and the servo was powerful enough to move it. But we opted for more speed, and upgraded to higher speed servos - Hitec HS-6965HBs (111 oz. in. and 0.08 sec to 60 degrees @6v). The newer ones were twice as fast, and much more powerful as a bonus, though that wasn't required. They are also digital, so they are programmable and all, but they do whine a lot more due to the higher frequency motor control.

(June 2009) See notes on the servo and last page, but for the X axis, we are currently using a Pololu 3A Motor Controller with Feedback and a 12VDC 250RPM DC Gearhead Motor. The board from Pololu works just like a servo control board, and we already have the external potentiometer.

To connect the servos to the shafts, we used Servo to Shaft Couplers from ServoCity (http://www.servocity.com/html/servo_to_shaft_couplers.html) - part # HSA250. As far as we know, those couplers are fairly unique to Servo City.

Drawer Glides and Misc Hardware

Mechanically, this is a simple system - we used wood and various metals in the prototypes, and they all worked fine.

For the linear motion, we used Accuride full extension drawer glides from Home Depot. We bolted pairs of them (top to bottom) to give a longer travel. You can buy longer...
drawer glides, but they get expensive fast, so bolting two together works well at a low cost. One disadvantage with drawer glides is that they extend out past the machine when in use. Also, with two shorter glides screwed together, they tend to dip slightly when fully extended. We used 24” ones for the parallel glides and 20” ones for the single track. Both were fine since we had about 38” of travel. We may switch to linear bearings and shafts at some point if we can find lower cost ones.

We got the 1/4” steel shaft (zinc plated), the 1x4 and 1x6 wood and various aluminum and steel angles from Home Depot. All of the small bolts used in the project were #6 size, and the wood was screwed with drywall screws and pan head screws. We also used some electrical conduit boxes for the plastic shape (see below), but this is totally optional.

**Step 2: Timing Belt Pulley Assemblies**

The first thing we did was build the timing belt pulley assemblies. There are a lot of possible ways to do this, but basically, we used a collar-bearing-bracket-pulley-bracket-bearing-collar setup. We made several metal L brackets - just drilled a 1/2” hole in them for the ball bearings to fit in to. Then we saw some electrical conduit boxes at Home Depot and used them to make U shaped bracket. Both approaches are fine. It helps to have some shorter 1/4 rods to test these out - we used 2.5” pieces for ours. The final assembly has one 3’, 1/4” rod connecting the two sides to prevent racking.

**Image Notes**

1. Shaft Collar
2. Ball Bearing
3. Timing Belt Pulley
4. Ball Bearing
5. Shaft Collar
Step 3: X Stage Frame and Drawer Glides

We built the frame from 1x4 and 1x6 pine - we used the fancy grade to limit the amount of warping etc. The length of the 1x6s was 40” to allow for the length of the belt plus a little extra room. The 1x4s were 38” long, but it looks like they could be 40” too. Maybe someday... Screw the 1x4s on top of the 1x6s with a couple drywall screws in each corner. If the screws get in the way when mounting the pulleys later, you can move them. The 1x6s are on top to allow the most room for the mechanics. Make sure to make the frame nice and square - measuring the diagonals works pretty well. Once the frame was complete, we mounted the timing belt pulleys and timing belts. We used a timing belt on the opposite side to help prevent racking as it moves, and it turned out that we only needed one shaft to go across, though we had originally used a long shaft on both ends.

Once we had that working and tested (OK, we cheated and did step 6 first :-)), we added the two drawer glide combos. As described in Step 1, each one was two drawer glides attached top to bottom to give a longer extension with less expensive glides. The ones we had allowed you to remove the top glide (of three), making mounting much easier. We used 6-32 screws and cut off any excess with a Dremel tool.

Image Notes
1. These kinds of brackets would work fine too.

Image Notes
1. We eventually removed this shaft since it wasn't needed with the timing belts.
2. hobby servo
3. external 5K ohm potentiometer
4. servo tester
Step 4: Y Stage

To the top of the two drawer glides, mount a small filler block (we used some scrap 1” thick wood, which allowed the Y stage to clear the X stage belt), then the Y stage board - we used the 1x4 for that since a thinner board gives you a bit more work space. When mounting the filler blocks, it was handy that the top slide had a plastic release catch so we could pull the glide off, attach the block, then slide it back in again.

Mount two more timing belt pulleys and a timing belt on this stage, leaving room for the drawer glides on one side.

Image Notes
1. We eventually got rid of this shaft - with the timing belts it wasn't needed.

http://www.instructables.com/id/DIY-CNC-1/
2. Two drawer slides connected together. We originally tried top-to-top (pictured here), but changed it top-to-bottom - it was stronger that way.
**Step 5: Clamp the Timing Belts to the Stages**

To attach the X stage, we used an aluminum plate (about 1"x3") under the Y stage board with two screws on each side of the timing belt. We drilled two holes in the X stage to get our 3" driver bit in there - put in two screws, then slide the assembly up a bit and add two more screws. For the Y stage, we made two aluminum plates (one about 1"x3", and the other about 1"x1") to connect the belt to the stage. In each case, you are just trying to clamp (or pinch) the belt to the mechanism.

**Image Notes**

1. a small square plate below this one clamps the belt tightly

**Image Notes**

1. a plate screwed from below
Step 6: Modify the Servos for Continuous Rotation and Remove the Potentiometer

We won’t go into too much detail on hacking a servo for continuous rotation - there are plenty of sites on the web, and Instructables too. Some servos are easier, and if it looks tricky, ServoCity sells modified servos with the potentiometer outside already. For the HS-6965HBs, we pulled the gears, then popped the motor down by wedging a tiny screwdriver between the motor gear and the housing to force it down. We then removed the pot and pulled the wires out through a small hole we drilled in the case. We have no idea if this is the proper way to do it. The HS-425BBs we originally used were even easier since the circuit board comes right out.

In both cases, we also cut off the limiting tab on the main gear. We used a Dremel tool for this - but we had to clean it well after that.

(June 2009) Note that for the Y axis (the one on top), the servo motor is working fine, but for the X axis, we have had some issues. So the current system is using a Pololu 3A Motor Controller with Feedback and a 12VDC 250RPM DC Gearhead Motor. The board from Pololu works just like a servo control board, and we already have the external potentiometer. The motor is much more robust, and has been working well. One minor issue is that the PID algorithm sometimes overshoots a bit, but it’s not too much, and the board allows you to set the PID constants - just need time for fiddling. :-) You can also use a servo board and adapt it for the same use - we’ll look into that sometime too.
Step 7: Mount the Servos and Potentiometers, and Calibrate

We made L brackets from aluminum to hold the potentiometers and servos in place. At this point, we were just hacking out brackets that fit each situation. They don't need to be very strong - just want to reduce any movement, and they aren't under a lot of pressure. In all cases, using fewer screws and keeping it loose is better since the shaft will not be perfect, and the servos and potentiometer actually move around a bit. We didn't try it (yet), but on some XY tables, we have seen some plastic or rubber hose used to couple the motors to the shaft to allow for movement.

Note: we did eventually have issues with the potentiometers, and have replaced them with longer-life hybrid ones and also have now used (2-3" pieces of) plastic tubing to mount them to the shaft. In addition, we moved the shaft that connects the two sides to the other side, and now have the X axis potentiometer sharing a short shaft with the X axis servo. (see last picture)

Leave the potentiometer and servo couplers loose, move the stage to approximately the center of travel and drive the servos to the center position (using a servo tester, an R/C transmitter or serial servo control board like the Lynxmotion SSC-32). Then turn the potentiometer until the servo stops, looking for the point where the servo slows down and switches direction. Once you find that point, then lock the set screws down. Note that servo testers and R/C radios may go 90 degrees, while SSCs usually can drive servos to 180 degrees. This is important to get the full range of motion - will use more of the potentiometer range.

We didn't worry too much about having it exactly in the middle since we are driving them by computer and needed to set the servo commands for the min and max position anyway.
Step 8: Conclusions, Notes, Room for Improvement

That’s about it. For TeleToyland, we used some PHP scripts to command the servos via an Internet to serial connection to the SSC-32 board, which the servos plugged right in to. If there is enough interest, we may do a separate Instructable on that setup.

Both axes have issues with not quite centering due to the potentiometers - causing the the digital servos to whine a lot at rest. For occasional use, it’s probably fine. For TeleToyland, we used a separate servo powered switch to just turn them off when not in use. We may get a digital servo programmer to see if narrowing the dead band will help. Higher quality potentiometers may help, but we may also be reaching a practical resolution limit in this approach.

(June 2009) For the linear slides, we used drawer glides. These are working fine so far, but they do stick out when the XY table is in the home position. So, we are thinking about using 16mm Linear glides from www.vxb.com - that seems like the lowest cost ones around.

(June 2009) Note that for the Y axis (the one on top), the servo motor is working fine, but for the X axis, we have had some issues. So the current system is using a Pololu 3A Motor Controller with Feedback and a 12VDC 250RPM DC Gearhead Motor. The board from Pololu works just like a servo control board, and we already have the external potentiometer. The motor is much more robust, and has been working well. One minor issue is that the PID algorithm sometimes overshoots a bit, but it’s not too much, and the board allows you to set the PID constants - just need time for fiddling. :-) You can also use a servo board and adapt it for the same use - we’ll look into that sometime too.

Other Uses

This is an interesting approach, and might make an excellent arm configuration for a mobile robot. The Leaf Project members are interested in arms, and this could be used for part of it. You could even add a counterweight on the belt opposite the end effector so that the arm would balance automatically - as the hand moves out, the counter-weight would move back. Adding a second linear system behind it would allow the weight of the object picked up to be balanced too.

The following sites provided some of the inspiration for this project:

Easy to Build Desk Top 3 Axis CNC Milling Machine Tom McW ire
Improving Servo Positioning Accuracy David P. Anderson
ServoCity Servo Power Gearboxes

We didn’t use this, but it looks interesting - a timing belt pulley for MXL belts (0.08” pitch) for Hitec servos

We found this after building ours - uses gears in a similar way, and the drawer glides are similar:

Autonomous Foosball Table.

http://www.instructables.com/id/DIY-CNC-1/
You can drive this project live at TeleToyland.

http://www.instructables.com/id/DIY-CNC-1/
The DIYLILCNC project is a set of plans for an inexpensive, fully functional 3-axis CNC mill that can be built by an individual with basic shop skills and tool access.

The DIYLILCNC project was started at the School of the Art Institute of Chicago in 2007 by Taylor Hokanson and Chris Reilly.

Intro: The DIYLILCNC: Open-Source Plans For a Low-Cost, Easy-to-Build CNC Mill. (v1.0.2)

CNC devices are used to fabricate physical objects with a high degree of precision. Some CNC devices, including the DIYLILCNC, feature a gantry-mounted cutting tool (like a router) that can move in two or more directions. The operation of the tool is controlled by a computer, which is tasked with translating a digital design into actual tool movement.

The DIYLILCNC can be built for around $700. This cost includes all the stock hardware and sheet material used in construction. CAD files for custom laser-cut parts are distributed along with the plans. Anyone with access to a laser cutter can use these files to fabricate all the panel parts necessary for construction; those without ready laser-cutter access can use local or online laser-cutting services. Some users have even adapted the files to be cut using another CNC mill.

Plans and instructions for building the DIYLILCNC are distributed freely and intended for wide distribution and modification with few restrictions. The plans are formatted to facilitate easy fabrication, especially for beginners. The DIYLILCNC can be built by an individual, a student group, or a class. Besides being immensely fun, building the DIYLILCNC is a great way to learn about motion control and CAD/CAM/CAE.

Specs
- Cutting bed size: ~12” x 14” x 2”
- Spindle speed: 0-35,000 RPM
- Total cost for hardware, sheet material, motors and driver board: ~$700
- Tested cut materials: foam, hardwood, acrylic, MDF, thin copper sheet

Licensing

The plans and source files for this project are released under a Creative Commons Attribution Share-Alike license. This license lets others remix, tweak, and build upon our work and the work of previous authors, even for commercial reasons, as long as they credit all authors/contributors appropriately and license their new creations under identical terms. This license is often compared to open source software licenses. All new works based on the information presented below must carry the same license.

Attribution

Authors’ names and sponsor institutions referenced below must be attributed in any future modification or redistribution of these plans.

This project is a fusion of two instruction sets published by Stuart McFarlane/Oomlout: CNC1/desktop CNC router (2007) provided the basic design for a functioning CNC mill; How to Make Anything (Using Acrylic and Machine Screws) (2009) details a solution for constructing 90° joints in laser-cuts stock using simple hardware.

The plans and source files presented below were adapted and expanded by: Chris Reilly (www.rainbowlazer.com, www.chris-reilly.org) and Taylor Hokanson (www.taylorhokanson.com) with generous support in the form of funding and facilities from the School of the Art Institute of Chicago (SAIC).
Step 1: Download the Plans.

Visit http://diylilcnc.org/downloads and get the CAD Files & Assembly Instructions for version 1.0.2.

Step 2: Order Parts and Hardware.

Use the parts list on pages 19-22 of the instruction PDF to order all the parts, hardware and stock you'll need. The MDF and some hardware can probably be sourced at lower prices from a local hardware store.

The parts costs for these plans include all of the hardware, stock and electrical components needed to build the mill/gantry, driver board and driver board enclosure. The total cost does not take into account the cost of the controller PC, nor does it account for the cost of laser cutting services, should you need to use them. Prices listed were accurate at the time of publication, but may currently be higher (or lower).

In addition to the parts on the list, you'll have to acquire a PC that can be used to run the controller software (see page 62 of the instruction PDF for specs).
Step 3: Hand-Cut a Few Parts

Some parts of the DIYLILCNC must be fabricated by hand. These are mostly done with easy table-saw or chop-saw cuts.

Pages 23-26 of the instruction PDF cover the details.
Step 4: Laser-Cut (or CNC) Gantry Panels.

Use the .dxf file included in the CAD Files & Assembly Instructions for version 1.0.2 to generate your gantry panels from the 1/4” Masonite/MDF stock.

Beware, as not all 1/4” stock is exactly 0.25”-- we found materials to range in thickness anywhere from 0.2”-0.25”, and this can make a big difference when trying to fit parts together. Measure stock thickness with calipers before you cut your parts!

Too-thick parts can sometimes be sanded to fit together; alternately, you can visit the DIYLILCNC downloads page for an Illustrator symbol file that links all the connection patterns to central symbol shapes--just change the depth of the symbols, and the new thickness settings will cascade out to all the cut patterns in the file.

If you don't have access to a laser cutter, you can use online service bureaus like Ponoko, or look for local providers at a site like ThomasNet. Several cities now have a TechShop, sort of like a Gold's Gym for CNC fabrication. Additionally, many colleges and universities are now acquiring laser cutting equipment, and college students (or professors, for that matter) can easily be paid off in beer and pizza!
**Step 5: Assemble the Hardware.**
Follow the detailed assembly instructions, starting on page 35 of the instruction PDF.

**Step 6: Set Up a Computer.**
Find a computer with a parallel port, then install EMC Linux. Plug in your configuration settings and you’re ready to roll!

Don’t have a computer with a parallel port? Here’s a detailed walk-through of setting up a $175 PC, including software installation and EMC setup.
Step 7: Make Something!

For a detailed list of free/cheap design software for CNC milling, see this link. CNC fabrication can be very simple or very complicated depending on what you're doing. Don't be afraid to ask questions at the DIYLILCNC forum, or at local hacker spaces near you.

http://www.instructables.com/id/DIY-CNC-1/
Related Instructables

- CNC Stomp Pad Project | CNC Programming | G-Code Programming | CNC Plasma Cutting by ivanirons
- Rapid Technique: Preparing Plastic #11: CNC Milling "Blanks" for Parts Used in #11: Prototyping Scientific Equipment by siderits
- How to use a CNC Mill with Google SketchUp by BovineDiozzi
- Vacuum Table for Mini CNC Milling Machine by Flying_MashedPotato
- Send an NC file to your HURCO mill by geo
- Mostly self-reproducing 3-axis CNC milling machine (SHELVE PROJECT) by ebidk
- Hobby CNC by mraspotcnc
- DIY CNC by csshop

http://www.instructables.com/id/DIY-CNC-1/
How to wire an arduino-based 3-axis CNC machine

by aggrav8d on June 15, 2010

I've seen a number of tutorials about how to build the platform for a 3-axis CNC milling machine. I have not seen anyone tackle the tricky subject of the electronics. Here now is my attempt to do so.
**Step 1: Parts**
You'll need:
- an arduino. I chose duemilanova. (depends on the board you get)
- 3 stepper motors. I chose NEMA 17s. ($15/ea)
- 3 EasyDrivers from Sparkfun. ($15/ea)
- some Cat5 ($2?)
- a 5V power supply for the steppers ($5?)
- a soldering iron
- some electrical tape
- an optional female plug is not a bad idea (<$1)

*TIP:* Don't get a 6ft or 10ft Cat5 cable. Buy your cat5 by the foot from any computer or electronics store. That stuff has one wire inside instead of lots of little fibers. Little fibers are a huge pain to work with.

**Step 2: Wire the stepper motor to the EasyDriver**
Now we'll wire up each of the EasyDrivers.

Remove some of the interior wire from the Cat5 and strip the ends. For each servo you will need two normal pairs of white/colored and one oddball of a white and two colored. In all, you’ll have to strip 14 ends.

PCB soldering is easy, once you get used to it. There are many other tutorials that cover the subjct. Follow the image as indicated. Your color combinations for the servo may be different. I had to google for a long time to find this page with the color codes for my model.

*TIP:* “Do NOT connect or disconnect a motor while the driver is energized. This will cause permanent damage.” -- Sparkfun

Next we'll wire the power sources and the arduino.

**Step 3: Soldering and wiring.**
I've done this all in one step, but feel free to wire each EasyDriver one at a time, check that it works, and then unplug it from the power and do the next one.

All 3 GND wires from the EasyDrivers are soldered to a single line, which goes to GND on the arduino.

All the positive leads from the stepper power are soldered to a single line.

All the negative leads from the stepper power are soldered to a single line.

*TIP:* Remember to put the plug cover on the wire BEFORE you solder everything together. Then slide the cover down and over the soldering.

*TIP:* Don't forget to have everything disconnected while you solder!

Solder the positive and female lines to the female plug.

Double check you didn't wire the board power to the stepper power. That would be bad.

Do you have a multimeter? This would be a good time to check your connections.

Plug in the power. The +5v light in the corner of each board should light up.

Now the wiring is done, time to test it with some code.
Step 4: Testing one stepper

UPDATE: I've been playing with my steppers and I wrote this little piece of code to play with just a single stepper.
Change the DIR/STEP pins as you see fit. If you put the stepper on a hollow flat surface like a desk top it will sound like a tiny formula 1 race car.

```c
// for duemilanove atmega328 arduino board + easydriver stepper controller
// dan@marginallyclever.com 2010-06-15
#define DIR1_PIN (12)
#define STEP1_PIN (13)
#define DELAY (1600/10)
#define BAUD (9600)

void setup() {
  Serial.begin(BAUD);
  pinMode(DIR1_PIN, OUTPUT);
  pinMode(STEP1_PIN, OUTPUT);
}

void loop() {
  int i,j=DELAY;
  digitalWrite(DIR1_PIN, LOW); // Set the direction.
  delayMicroseconds(DELAY);
  Serial.println(">>");
  for (i = 0; i<3400; i++) // Iterate for 4000 microsteps.
  {
    digitalWrite(STEP1_PIN, LOW); // This LOW to HIGH change is what creates the
    digitalWrite(STEP1_PIN, HIGH); // "Rising Edge" so the easydriver knows to when to step.
    delayMicroseconds(j); // This delay time is close to top speed for this
    j+=1;
  } // particular motor. Any faster the motor stalls.
  digitalWrite(DIR1_PIN, HIGH); // Change direction.
  delayMicroseconds(DELAY);
  Serial.println("<<");
  for (i = 0; i<3400; i++) // Iterate for 4000 microsteps
  {
    digitalWrite(STEP1_PIN, LOW); // This LOW to HIGH change is what creates the
    digitalWrite(STEP1_PIN, HIGH); // "Rising Edge" so the easydriver knows to when to step.
    delayMicroseconds(j); // This delay time is close to top speed for this
    j+=1;
  } // particular motor. Any faster the motor stalls.
}
Step 5: Sample arduino code
// for duemilanove atmega328 arduino board + easydriver stepper controller
// dan@marginallyclever.com 2010-06-15
#define DIR1_PIN 4
#define STEP1_PIN 5
#define DIR2_PIN 6
#define STEP2_PIN 7
#define DIR3_PIN 8
#define STEP3_PIN 9
#define DELAY 150

void setup() {  
  Serial.begin(9600);  
  pinMode(DIR1_PIN,OUTPUT);  
  pinMode(STEP1_PIN,OUTPUT);  
  pinMode(DIR2_PIN,OUTPUT);  
  pinMode(STEP2_PIN,OUTPUT);  
  pinMode(DIR3_PIN,OUTPUT);  
  pinMode(STEP3_PIN,OUTPUT);  
}

void loop() {  
  int i;  
  digitalWrite(DIR1_PIN, LOW); // Set the direction.  
  digitalWrite(DIR2_PIN, LOW); // Set the direction.  
  digitalWrite(DIR3_PIN, LOW); // Set the direction.  
  delay(DELAY);  
  Serial.println(">>");  
  for (i = 0; i<6800; i++) // Iterate for 4000 microsteps.  
  {  
    digitalWrite(STEP1_PIN, LOW); // This LOW to HIGH change is what creates the  
    digitalWrite(STEP1_PIN, HIGH); // "Rising Edge" so the easydriver knows to when to step.  
    if((i%2)==0)  
      digitalWrite(STEP2_PIN, LOW); // This LOW to HIGH change is what creates the  
      digitalWrite(STEP2_PIN, HIGH); // "Rising Edge" so the easydriver knows to when to step.  
    }  
    if((i%4)==0)  
      digitalWrite(STEP3_PIN, LOW); // This LOW to HIGH change is what creates the  
      digitalWrite(STEP3_PIN, HIGH); // "Rising Edge" so the easydriver knows to when to step.  
  }  
  delayMicroseconds(DELAY); // This delay time is close to top speed for this  
  digitalWrite(DIR1_PIN, HIGH); // Change direction.  
  digitalWrite(DIR2_PIN, HIGH); // Change direction.  
  digitalWrite(DIR3_PIN, HIGH); // Change direction.  
  delay(DELAY);  
  Serial.println("<<");
for (i = 0; i<6800; i++) // Iterate for 4000 microsteps
{
digitalWrite(STEP1_PIN, LOW); // This LOW to HIGH change is what creates the
digitalWrite(STEP1_PIN, HIGH); // "Rising Edge" so the easydriver knows to when to step.
if((i%2)==0) {
digitalWrite(STEP2_PIN, LOW); // This LOW to HIGH change is what creates the
digitalWrite(STEP2_PIN, HIGH); // "Rising Edge" so the easydriver knows to when to step.
}
if((i%4)==0) {
digitalWrite(STEP3_PIN, LOW); // This LOW to HIGH change is what creates the
digitalWrite(STEP3_PIN, HIGH); // "Rising Edge" so the easydriver knows to when to step.
}
delayMicroseconds(DELAY); // This delay time is close to top speed for this
} // particular motor. Any faster the motor stalls.

Step 6: In conclusion
If everything worked right, you should have three steppers each moving at different speeds back and forth. There should be a light on each EasyDriver showing that it has power. If you have a light and no movement, You might not have a good connection to your arduino.

So what next?
Now that you have three motors working through the arduino you can use the serial interface to tell the arduino what you want the steppers to do. By changing the different motors in the right pattern you can interpret G-CODE and start cutting patterns. The biggest choice you face is what to cut!

Thanks for reading!
Dan
Image Notes
1. Congratulations! You earned it.

Related Instructables

DIY CNC by csshop
DIY CNC - Software by csshop
XY-Plotter by bdeakyne
Pocket laser engraver. by Groover
SADbot: the Seasonally Affected Drawing robot by dustynrobots
Vacuum Table for Mini CNC Milling Machine by Flying_MashedPotato
Internet Arduino Controlled T-Slot XY Table by CarlS
How to Build an Arduino Powered Chess Playing Robot by mJustic
Make a CNC Hot Wire Foam Cutter from parts available at your local hardware store
by tbarnea on July 12, 2008

Intro: Make a CNC Hot Wire Foam Cutter from parts available at your local hardware store
Make a CNC Hot Wire Foam Cutter from parts available at your local hardware store like HomeDepot. This machine can be used to cut wings for RC planes, surfboards, crown molding, packaging foam and lots more

The original design was built in order to cut RC wings (even tapered wings - where one side is different then the other side)
Polystyrene (EPS and XPS) will cut using a hot wire - other foams - like polyurethane should only be cut with a blade or saw.
When cutting, be careful !!! - wire will get hot, and some people may be allergic to the EPS fumes - always work in a well ventilated area.

Step 1: Over View
Most parts can be found in your local hardware store, like Home Depot..
The first prototype was made out of wood, but didn't look "professional" enough, so I decided to go with a more robust design made of steel.

The design can be modified to almost any size. Keep in mind that for longer travel you will need a longer lead screw.
The problem with a long lead screw is that because it its own mass, it will "wobble" in higher speeds.
One way to overcome this problem is to move to a larger diameter lead screw.
Another way is to move to a chain or belt driven design. Belt driven machines are usually 8' and longer but require the use of micro-stepping. An example of a machine larger then 8 foot would be a surfboard foam cutter.
Some surfboards are up to 12 feet in length, the only way to cut these boards would be a belt driven or chain driven mechanism
I will try to cover this topic in the future with a sample machine and pictures...

We started out building a machine to cut wing cores, but soon after we discovered a huge interest in the machine for other industries - like moldings, architectures, surfboards, Logos, props, packaging Willow Sills, Casings, Wainscoat , Fascia, Crown, Parapets, Wallcaps, Pediments, Quatrefoils, Columns

www.8linx.com
Step 2: The Y axis - Vertical axis (step #1)

If you are building the CNC foam cutter for RC wings, then you would probably need 10” max travel on the Y towers.

If building a hot wire CNC foam cutter for props, crowns, moldings
You would probably want to go with a 4’ x 4’ (X x Y)
EPS Foam billets are usually 3’ x 4’ x 8” or 4’ x 4’ x 8’

XPS foam comes in sheets of about 4’ x 8’ x (1” or 2” or 3” thick)

If building a CNC foam cutter to cut Polyurethane foam - FORGET IT
Polyurethane foam should not be cut with hot wire, but a blade or a saw
There are CNC foam cutters for Polyurethane that work similar to a band saw
But use a abrasive wire instead of a saw - click here for more information

In this section we will build the two Y posts or towers (Y axis).
The posts can be found at the fence section at Home Depot
You can replace these posts by any other post as long as you are able to keep them from vibrating during the cut.
Any vibration of the posts will result in vibrations on the wire resulting in “waves” or not smooth cut of the foam.

The following can be found in the drawer section, you will need two 16” drawer slides
The Home Depot Catalog number for 24” slides made by Liberty 7-81266-18070-4
www.8linx.com
Step 3: The Y axis - Vertical axis (step #2)
The above picture is of the 2”x4FT Post with foot - that’s the Home Depot name
Cat num: 204-008 Home Depot num: 6-39426-48607-7

measure 6” from the base, and screw in (or use a rivet gun) the slide to the post

Make two of these units - one for the left side of the machine and one for the right side of the machine.

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Step 4: The X axis - Horizontal Axis (step #1)
This U shaped part (the X axis carriage) will hold the Y axis stud.
Here is the Home Depot Catalog number for the part below:
"Half Base" made by Company named Simpson
Catalog number : C751-973
Home Depot num: 044315-10350
these parts were punched and then bent, when we decided to make our own parts we had them laser cut and bent - then powder coated

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Step 5: The X axis - Horizontal Axis (step #2)
Drill the 3 holes on the slides (24” slides), and mount the U shaped carriage onto the two slides using rivets or screws.
You will need two of these units, one for the right side of the machine and one for the left side of the machine.

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**Step 6: The X axis - Horizontal Axis (step #3)**

At this point we have an Y axis carriage which is mounted on the X axis carriage. We used large 5/8" screws to hold the post in place on top of the U shaped X carriage.

Now make the 2nd one - again you will have a total of two units.

[www.8linx.com](http://www.8linx.com)

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**Step 7: The Lead Screw (step#1)**

Using parts from Home Depot, I could only find threaded rods, I later found online, stainless steel threaded rods.

For this section, I used a lathe and a set of tap and die. There may be ways around, but I chose to go the safe route.

We later had ACME nuts made just for us - if you are interested in purchasing ACME nuts Please visit our online store at [http://www.8linx.com/cnc/online_store.htm](http://www.8linx.com/cnc/online_store.htm)

There are a few differences between threaded rods and ACMEs. Usually ACME have a lower inch per turn.

A later design, we used ACME screws that can be found on ENCO - search [www.use-enco.com](http://www.use-enco.com) for ACME threaded - here is the exact link

[Threaded rods](http://www.8linx.com)

[www.8linx.com](http://www.8linx.com)
Step 8: The Lead Screw (step#2)
If you use a 1/2-10 ACME screw and ACME Nut that means that the ACME screw will turn 10 times and during this time it will advance 1 inch. If you use 3/4-6 ACME rods and ACME nut - this means the ACME screw will turn 6 times and during this time it will advance 1 inch.
When calculating the steps-per inch on a machine you need to know the ACME value and the stepper motor steps.
For example: using 1/2-10 ACME with a stepper motor driver at 1/2 step - to calculate the steps per inch follow these steps: 10 turns per inch times 200 (which is the usually stepper motor steps per turn) times 2 (this is the half step of the stepper motor driver) the total comes to 4000. This means that the resolution of your machine will be 4000 steps per inch.

If you decided to go with the ENCO threaded rods, you can buy from them the ACME nut as well. Here is the link: ACME Nuts

www.8linx.com
**Step 9: ACME Screw (step #3)**
A simple way to connect between the motor shaft and the threaded rod, is a plastic tube.
A better way is to make this "Coupler" out of rubber - this will help in case the motor shaft and the threaded rod are not aligned.
We later moved to ACME screws that can be found on www.use-enco.com. These ACME screws come is 3' and 6' lengths. Since their diameter is 1/2" and the motor shaft is 1/4" you will have to machine these ACME rods to 1/4" diameter. Use your lathe of stop by at a machine shop and they can do it for you.

www.8linx.com

![ACME Screw Image]

**Step 10: ACME Screw (step #4)**
Now, make another one just like it, but mirrored.
The last picture on this page shows that the two "T" brackets are facing each other, this is where the hot wire will connect. For those who wish to mass produce wings, simply add one or even two more "T" brackets and you can cut 3 cores at a time.

www.8linx.com

![ACME Screw Image]

**Step 11: The Software**
There are a few software out there that will run the machine - some need special hardware - we spent months testing and evaluating many of these software and hardware.

1. FoamWorks software will work with the electronics in the package below - has CAD capabilities as well
2. GMFC - needs a timer module - without the timer the package below will not work
3. Mach3 is a generic CNC router software will work with the package below, but you need to be able to generate 4 axis g code.
4. KCAM - same as above - generic CNC router software - will do nice PCB boards as well
5. DeskCNC - is an additional hardware board that connects to the PC via the serial port and its output is the electronics package below, not very easy to put together but doable.

Online store
All of the software above other then DeskCNC require you to have a printer port on the PC

If you are going to cut wings or simple shapes we would recommend the use of Foamworks
If you want to cut complicated shapes and multiple shapes we would recommend DeskCNC or Mach3. We currently use AutoCAD to draw the shapes, then convert them into G code using DeskCNC, and the last step is to run the machine using Mach3.

Here are some tutorials for all 3 software packages - we have spent many hours creating them, and they are free of charge to use or distribute !!

www.8linx.com
Step 12: The Electronics

The electronics is the only part that is "kinda" hard to find.

You can search eBay and look for "4 axis stepper motor driver".

Then you will have to find 4 stepper that will match the drivers - pay attention to the type of driver you are getting. Some will work with Bipolar motors and some will work with Unipolar motors.

The last step is to find a power supply. The power supply should be around 24V 5A, but its best to get all of the electronics from one source.

If you can't find anything on eBay try this

The Electronic box works together with the software you choose.

Make sure that the electronics you select can be programmed to accept pulse and direction for each of the 4 axis.

Mach3, KCAM and Foamworks will all work fine.

Mach3 will only drive the electronics. Foamworks will also generate a file called "DAT" file, and with this file it will also control the electronics.

Sounds complicated, but take a look at all these web sites and after a while things will start making sense.

Mach3 - www.artofcnc.ca
Foamworks - www.foamwork.net
Step 13: The Stepper Motors

Bipolar motors
There are only two coils, and current must be sent through a coil first in one direction and then in the other direction; thus the name bipolar. Bipolar motors need more than 4 transistors to operate them, but they are also more powerful than a unipolar motor of the same weight. To be able to send current in both directions, engineers can use an H-bridge to control each coil or a step motor driver chip.

Unipolar motors
In a unipolar stepper motor, there are four separate electromagnets. To turn the motor, first coil "1" is given current, then it's turned off and coil 2 is given current, then coil 3, then 4, and then 1 again in a repeating pattern. Current is only sent through the coils in one direction; thus the name unipolar.

A unipolar stepper motor will have 5 or 6 wires coming out of it. Four of those wires are each connected to one end of one coil. The extra wire (or 2) is called "common." To operate the motor, the "common" wire(s) is(are) connected to the supply voltage, and the other four wires are connected to ground through transistors, so the transistors control whether current flows or not.

A microcontroller or stepper motor controller is used to activate the transistors in the right order. This ease of operation makes unipolar motors popular with hobbyists; they are probably the cheapest way to get precise angular movements.

(For the experimenter, one way to distinguish common wire from a coil-end wire is by measuring the resistance. Resistance between common wire and coil-end wire is always half of what it is between coil-end and coil-end wires. This is due to the fact that there is actually twice the length of coil between the ends and only half from center (common wire) to the end.)

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Step 14: Finalizing the machine (step #1)

Clamp down both axis, one shown in the picture on the 1st slide.
I use strong spring to keep the cutting wire tight. The spring also keeps the wire tight when cutting a tapered wing.
You can get the spring in your local Home Depot. On some designs I have seen people using a bow instead of the spring design. I got better results with the spring, but feel free to experiment

Here is a setup which I also use on my foam cutting bow. The router speed control can handle up to 15A And the power supply can supply up to 3.5A which is more then enough current for a 30" wire. (about 1.5A) The low voltage power supply is used to isolate the main voltage (110V) from the cutting wire.

Another way to go would be to use an isolation variac - here is a good choice for one
http://www.action-electronics.com variac.htm
make sure to get the isolation version !!!

www.8linx.com
Step 15: Finalizing the machine (step #2)
The router speed control can be purchased at www.harborfreight.com for about $20
The router speed controller connects to the mains voltage and its output goes to a transformer (should be isolated)
These transformers can be found in surplus stores like www.allelectronics.com

Another way to go is to use an insulated variac - this is better since it provides isolation from the main power.
You can find this variac at http://www.action-electronics.com/variac.htm
Almost all variacs are NOT isolated, and by being not isolated, the user may get "zapped" if not careful. Use caution when powering the hot wire, try to stay at low voltage (below 50V), in some cases you may need to go beyond 50V - in case you have a long wire. make sure never to touch the wire or the springs.

A hot wire CNC foam cutters as its name - cuts the foam by melting it before having contact with the foam EPS foam - expanded polystyrene at 1LB density can be cut at speeds from 10 to 20 inch per min XPS foam - XPS foam has an innate combination of properties that make it one of the most efficient insulating materials available. The closed-cell structure, responsible for the foam’s excellent moisture resistance, also contributes to its high compressive strength and superior thermal performance. Extruded polystyrene foams may need to cut at a slower speeds, from my experience, when cutting XPS foam, I use a thinner wire - about 0.4mm. XPS cut are generally smoother then EPS foams.

Another kind of foam is EPP foam (the kind they make the Zagi wing flyer) - EPP (Expanded Polypropylene) EPP foam doesn't dent or break. It has a "spongy" quality to it, so on impact it compresses and pops back to shape

Hot wire:
We started out using stainless steel wire as our hot wire, this will work well, but the wire will not last long and can break under too much tension. If cutting a 2LB foam for a large project, wire breaking during the cut can cause a lot of $$ At a later stage we moved to Nichrome wire. Nichrome wire will last longer and will not break even when red hot. Keep in mind that the wire will tend to stretch when heated, so a spring is needed to keep it from sagging

The software I use is foamworks (www.foamwork.net)
This software is the most popular foam cutting controller software, and also not too expensive (about $50) It will control up to 4 motors and let you cut tapered wings and other shapes, take a close look at the site There is a lot of useful information there, and even a link where people

www.8linx.com
Step 16: Videos
Cutting multiple shapes out of one 4’ x 4’ x 8’ block of EPS foam

http://www.instructables.com/id/DIY-CNC-1/
Step 17: What's next?
We plan on building a CNC plasma cutter and explaining how to - step by step.

Related Instructables

Chunky Jigsaw Puzzles by hive76
Insulating Laptop Pad by Bats22
WWI Trench Model by William930
Foamboat construction by unclesam
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Simple methods for molding fiberglass and carbon fiber by Honus
A new twist to the hot wire foam cutter by dave spencer
Rapid Technique: Preparing Plastic CNC Milling "Blanks" for Parts Used in Prototyping Scientific Equipment
by siderits on January 11, 2010

Intro: Rapid Technique: Preparing Plastic CNC Milling "Blanks" for Parts Used in Prototyping Scientific Equipment
Rapid Technique: Preparing Plastic CNC Milling "Blanks" for Parts Used in Prototyping Scientific Equipment
Richard H. Siderits MD
A. Maskey

Step 1: What is a Milling "Blank"?
When milling a part for a prototype piece of equipment, it is often useful to start with a piece of material that is not much bigger than the part that you are making. This is called a Blank. Using blanks, especially with Computer Numerical Control (CNC) systems, can reduce the amount of time needed to clear excess material during the milling process.
We describe a method for making plastic milling blanks for CNC milling operations and for making a "Jig" that helps place holes for conveniently mounting the blank onto the milling machine's table.
Step 2: Basic Approach: Make Mold Blanks
- Make a model of the desired shape for the plastic blank. Use MDF type wood.
- Vacuum form a mold onto the MDF wood model.
- Trim the vacuum formed mold.
- Coat the inner surface of the mold with a release agent.
- Mix 2 part plastic and pour it into the vacuum formed plastic mold.
- Extract the blank from the mold (“de-mold”).
- Attach blank to CNC Milling machine.
- Additional technique:

Making a "Fixing-Jig"

Step 3: First: What is MDF Wood?
- Medium-density fibreboard (MDF).
- Engineered wood.
- Mixed with wax, resin at high temperature and pressure.
- Stronger and denser than plywood.
- Contains: urea-formaldehyde so it may irritate lungs and eyes - Wear mask when cutting or sanding.
Step 4: Making the Model:
- Cut MDF wood to size of required "blank".
- Cut edges of wood at a 15 degree angle to help the mold pop off.
- Sand the edges smooth with sand paper.
- Remember to use the measurements on the top (smaller) half of the model as the minimum area for your milling blank.

Step 5: Next Step: Create a Mold for the Blank
There are several ways to do this. We chose to make a vacuum-formed plastic sheet mold. We then poured two-part plastic resin into the vacuum formed mold in order to create the blank for milling. Using this technique, it is possible to create complex blanks that may have very unique shapes. This makes it possible to decrease the amount of material that needs to be removed by the CNC milling process.
The platform that we use is a Home hobby vacuum forming unit that was easy to build and very inexpensive.
Step 6: Building a Hobby-Vac Vacuum Former:
- **Hobby-Vac 12”x18”**
- *Do It Yourself Vacuum Forming* by D. E. Walsh
  - This comes with a large and small platen for vacuum forming small parts and larger trays.
  - Build time averages about 2 weeks. Instructions are clear and friendly.
  - Requires a vacuum pump.


Step 7: What if I don’t want to make a vacuum forming machine?
Try visiting the local dollar store, toy store, or even a grocery market and find something that is about the size that you need, comes packaged in a formed clear plastic shell and use that instead in order to pour your plastic blanks.
Step 8: Where Do I Get Plastic?

- www.warmplastic.com
- Can be ordered in many sizes, colors, and thicknesses.
- Sheets vary in size; up to 4 feet by 8 feet.
- We used 0.04 thickness which is rigid enough to hold the shape and resistant to the amount of heat given off in the exothermic reaction of the plastic resin polymerizing.

Step 9: What is a "Release Agent"?

- This keeps the two-part plastic mixture from sticking to the plastic mold.
- It can be a spray-on product or simply Vaseline wiped on the inner surfaces with a paper towel.
- Make sure to get the release agent into the corners of the mold.
Step 10: Where Do I Get "Two-Part Plastic Resin"?

- www.polytek.com

- EasyFlo 60
  1 part A to 1 part B
  (equal amounts)

- Cures white in ten minutes, will take pigments for color.

- Hard as machinable wax

Water thin and fairly inexpensive

Step 11: Vacuum Forming

Top Left: Vacuum forming “Platen”, Top middle: MDF wood models under vacuum formed plastic molds. Top right: Clear plastic vacuum formed molds for blanks. Bottom left and right: Cutting out molds to cast the blanks for CNC milling.
Step 12: Examples
MDF wood models, vacuum formed molds, and white plastic blank with fixation holes for mounting on CNC milling table.

Step 13: Making the "Fixing Jig": Materials

- Two 3/4" x 5 1/2" x 11"
  Top and Bottom
- Three 5 1/2" x 2" x 3/4"
  Dividers and Side Supports
- Two 3/4" x 3/4"
  Alignment Ridges
- Two 5 1/2" x 2.0" x 3/4"
  Standoffs for Top
- Carriage bolts 3" x 0.25"

All parts are pine or, if you prefer, MDF wood. Assemble as shown in the CAD model. Drill holes for bolts to slide through snugly. Place the holes to align with the corners of your unique mold for the blanks.
**Making the "Fixing Jig": Materials**

- Two 3/4" x 5 1/2" x 11" Top and Bottom
- Three 5 1/2" x 2" x 3/4" Dividers and Side Supports
- Two 3/4" x 3/4" Alignment Ridges
- Two 5 1/2" x 2.0" x 3/4" Standoffs for Top
- Carriage bolts 3" x 0.25"

All parts are pine or, if you prefer, MDF wood. Assemble as shown in the CAD model. Drill holes for bolts to slide through snugly. Place the holes to align with the corners of your unique mold for the blanks.

### Step 14: Example of Fixing-Jig
Top and Bottom Half of Fixing-Jig with a Mold and Blank

### Step 15: Separation of Mold and Plastic Blank
Separate top and bottom half. Note mold and plastic blank have separated. Alignment bolts will unscrew to remove.
Step 16: Releasing the Blank
Turn bolt with a wrench to release blank, leaving behind holes to affix the blank onto the milling table.

Step 17: CNC Milling a Plastic Blank
MAXNC 10-CL CNC Milling a Plastic Blank

Step 18: Project Summary:
When prototyping parts for experimental scientific equipment, it is often useful to have custom plastic blanks that are suitable for use in CNC milling operations.

We have outlined several methods that can be used to create molds for making plastic blanks and a jig for placing fixation points for CNC milling operations.
In summary, MDF wood models are created to desired measurements of the milling blank. The wood model is then used to create a vacuum formed mold of the wood model. The mold is used to create the blanks from two part plastic resins. A vacuum degasser may be used to assure absence of bubbles or void spaces in the plastic milling blank.
Project Summary:
When prototyping parts for experimental scientific equipment, it is often useful to have custom plastic blanks that are suitable for use in CNC milling operations.

We have outlined several methods that can be used to create molds for making plastic blanks and a jig for placing fixation points for CNC milling operations. In summary, MDF wood models are created to desired measurements of the milling blank. The wood model is then used to create a vacuum formed mold of the wood model. The mold is used to create the blanks from two part plastic resins. A vacuum degasser may be used to assure absence of bubbles or void spaces in the plastic milling blank.

Step 19: Disclaimer:
Follow all safety guidelines, including but not limited to:

1) Using two part plastic polymers and vacuum formers.
2) Powertools that you never read the instructions for.
3) All tools that you never learned to use properly.
3) Anything that heats up, pinches, cuts, squeezes or causes traumatic, caustic or thermal injury.

We are sharing our experience, not telling you to do it.

If you choose to try this then - it is at your own risk!

No really, we’re not kidding about this.
Step 20: Project Details
Facility: RWJUHH Investigational Pathology Division and Center for Parabiotics Research
Section: Special Projects

Application: CNC Milling - Preparing Plastic Blanks

Technique: Rapid Prototyping in laboratory science

Title: "Rapid Technique: Preparing Plastic CNC Milling "Blanks" for Parts Used in Prototyping Scientific Equipment"

Project Team: R. Siderits and A. Maskey

Step 21: The End, Thank You
The End...
Thanks!

The End...
Thanks!
Related Instructables

- Venturi Vacuum Degassing Apparatus for use in Rapid Biomedical Part Prototyping by siderits
- Mostly self-reproducing 3-axis CNC milling machine (SHELVE PROJECT) by ebidk
- Poor Man's (not so rapid) Prototyping Method for the Fabber-less by xeijix
- make plastic 3D models from CAD designs using an automated "milling machine" by leevork
- Vacuum Table for Mini CNC Milling Machine by Flying_MashedPotato
- How to make a mini milling machine-manual or CNC! by Honus
- Make your own cnc controller by charcoal999
- Mini CNC router, complete plans and instructions by berbefarac