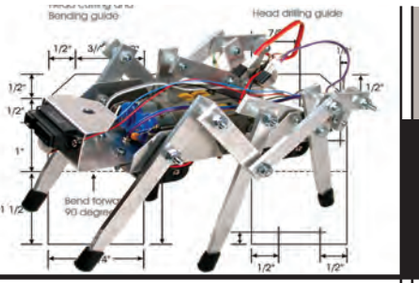
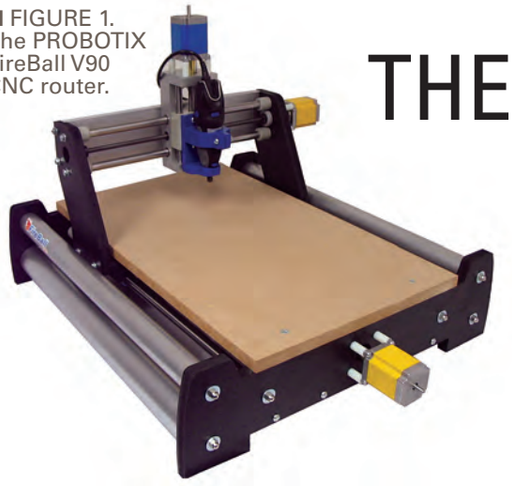


■ BY VERN GRANER

THE PROBOTIX FIREBALL V90 CNC ROUTER



■ FIGURE 1. The PROBOTIX FireBall V90 CNC router.

IN THIS MONTH'S ISSUE, WE CONSTRUCT THE PROBOTIX FireBall V90 CNC router from a kit and then put it through its paces.

TEA. EARL GREY. HOT.

Jean Luc Picard of *Star Trek* fame had high tech replication gadgets at his disposal. In his Utopian sci-fi future, these devices would be so common that they were used for such mundane tasks as making a cup of tea in the captain's quarters. Although we have a long way to go before we can expect any item we ask for to pop into existence from a wall-mounted gadget, some intrepid folks are diligently working in that direction, starting with automating the creation of parts.

When building things both robotic and mundane, I've found myself sanding, cutting, shaping, bending, and otherwise changing the physical shape of some item used in a project. In many cases, creating exact duplicates of a part is critical to making something that balances or requires matching or aligned holes. Creating these things by hand can be rather time-consuming. It sure would be nice if I could just draw what I needed and then have a device that would cut the part for me. Though not exactly up to the "replicator" on *Star Trek*, if automatic part-making sounds interesting to you, then a CNC machine is a pretty good place to start.

I SEE, CNC!

CNC or Computer Numeric Control is an acronym that refers to a tool that can cut or shape by using computer generated instructions (see the sidebar for a bit of history). Most CNC machines have a number of axes and a tool of some sort that can be guided by a computer to very precisely remove material. Originally created in the 1940s for the automation of large-scale manufacturing (Figure 2), CNC has become more capable over the years and has made its way down to small desk top fabrication systems. Though some small-project CNC systems are available to the hobbyist, most are in the multi-thousand dollar range so they haven't seen much widespread adoption in the humble homebrew market. Until someone can get the price down to sub-thousand dollar levels, we probably aren't going to see many of these tools on a typical hobby workbench.

■ FIGURE 2. A CNC turning center in the FAME Lab in the Leonhard Building at Penn State. (c) 2005 Nathaniel C. Sheetz.

BRINGING DOWN THE PRICE

I was having lunch with long-time Robot Group member and good friend Paul Atkinson at Pok-e-Jo's BBQ restaurant here in Austin, TX where we were munching BBQ and talking tech while the electric train circled the dining room (see The TrainSaver, *Nuts & Volts*, July '06). Paul mentioned that he had recently read about a new CNC machine from PROBOTIX that seemed to have finally managed to break the $1,000

■ FIGURE 3. The 56 pound shipping box from PROBOTIX.

■ FIGURE 4. Nested packages inside the shipping box.

hobbyist CNC router. A bit of investigation showed PROBOTIX offered the FireBall V90 CNC router for $599 plus another $309 for an entry-level motor kit that included the stepper motors, the power supply, and the motor controllers. Add in shipping, and you can have a complete CNC router kit on your doorstep for less than a kilo-buck! All you have to provide is the home computer (with a parallel port) to run the software and a Dremel® moto-tool to use for cutting.

I sent an initial inquiry to John Hansford over at FireBall CNC to get some information on the availability of the product and to see if they would be interested in having their CNC router covered in *Nuts & Volts*. John seemed excited about the prospect and put me in touch with Len Shelton over at PROBOTIX. Before I knew it, Len had my order finalized and just a few days later I had one big (heavy) box on my doorstep. Looks like it was time for me to dip a toe into the waters of CNC fabrication, but first I had to build the machine itself.

IT'S HERE!

Amazingly, I received the Fireball CNC in a single box (Figure 3). It weighed in at 56 pounds and was extremely well packed (seemed like the person who did the packing must be pretty good at Tetris!). Overall, the box measured 27" by 16.5" by 8.5" leaving me wondering how they could fit everything in there. I checked the packing list/invoice and it appeared that everything was on the list.

Inside I found two smaller boxes and lots of things wrapped up in brown paper (Figure 4). It still didn't look like there were enough pieces to build a machine but, by the time I finished unwrapping everything, the parts were all accounted for. When I said everything was well packed, I wasn't kidding!

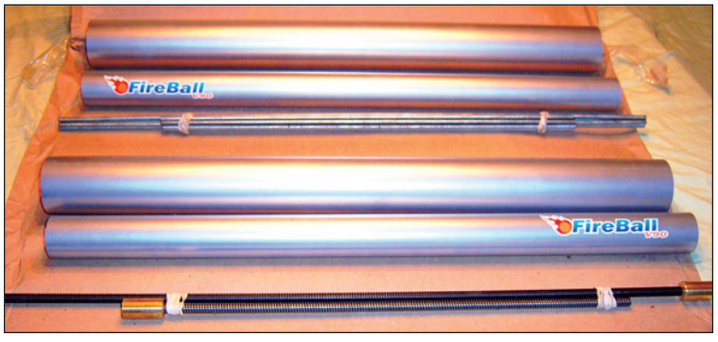
I found that the large side tubes contained the smaller side tubes which contained the lead screws and motor couplers and the threaded frame tension rods (Figure 5). Not only was this a nice use of space, but it was also a very effective way to protect the delicate parts while in transit.

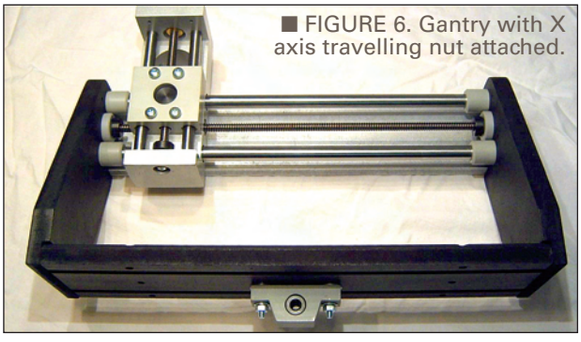
After carefully emptying the large box and laying out all the components on the kitchen table, I went to both the Fireball CNC and PROBOTIX websites to look for instructions or pictures to help me with the assembly. I identified all of the major parts and located a couple of tools to help in the process. The primary tools were a 7/16 inch nut driver, a Phillips screwdriver, and a set of Allen wrenches (hex keys).

After identifying the major parts, I cleaned the protective wax from the precision ground and hardened Thomson shaft with some acetone. I then installed the smallest set of rods transverse to the Z axis. I installed the Z axis and rods between the gantry uprights and added the gantry back and base. Next, I added the X drive nut to the bottom of the gantry base. This was starting to look like a CNC machine already (Figure 6).

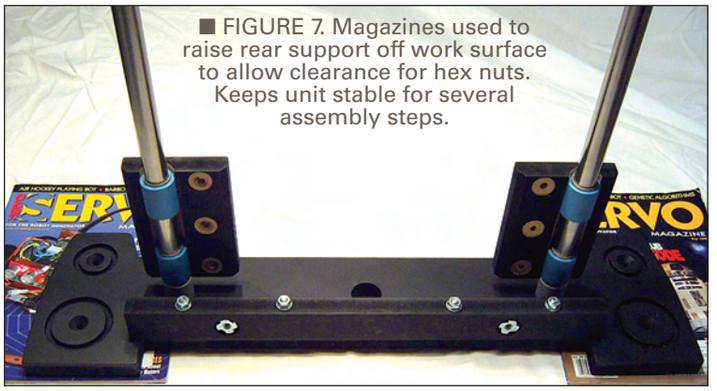
The next step requires a couple of magazines to hold the frame end plate off the work surface (Figure 7). The frame is assembled vertically to

■ FIGURE 5. Painted support tubes containing Acme lead screws (with brass couplers) and threaded tension rods (top).

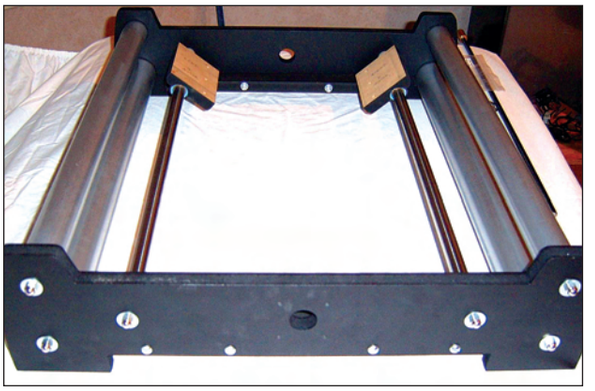




■ FIGURE 6. Gantry with X axis travelling nut attached.



■ FIGURE 7. Magazines used to raise rear support off work surface to allow clearance for hex nuts. Keeps unit stable for several assembly steps.



■ FIGURE 8. Front support attached to tension rods (inside silver tubes) via acorn nuts and washers.

make it easier to install the threaded rods which tension the frame ends and hold the base together. The magazines provide clearance for the nuts on the end of the threaded rods. The holes that these threaded rods go into are surrounded by a slightly cone shaped recess which helps to guide the rods into and through the appropriate holes.

The precision-ground shafts are put into the gray bushings and the end tubes are put in place. The bushing plates that later connect to the gantry base are added next. (Make sure you install these the right way around as it is tedious to turn them around later.) Finally, the other frame end plate is added and held in place with washers and nuts added loosely (Figure 8).

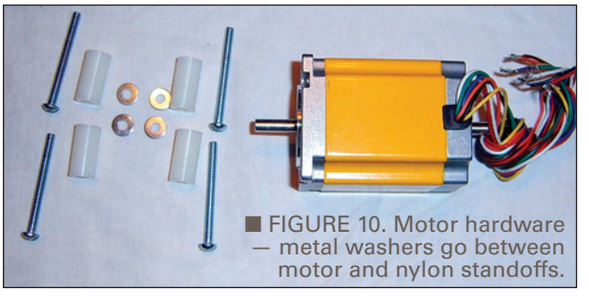
At this point, the frame can be put flat on the work surface and the gantry is loosely bolted to the gantry bushing plates. Alignment of the unit takes place at this point (before the lead screws are added). By moving the gantry and Z axis assembly back and forth with a finger while carefully snugging up the existing bolts, you can tell if things are in alignment by how easily things slide on the Thomson shafts. Once you have the alignment feeling right, you can tighten the bolts about a half turn past finger tight.

Now that we have the table done, it's time to add the lead screws that the motors will use to control the motions. There are several washers and locking collars which were in small, well labeled bags (Figure 9). It is important to put these parts on in the correct order. *(Note: The Z axis assembly already has its rods and lead screw installed, so we are only dealing with the X and Y axis here.)* Once the lead screws are installed, I again turned them by hand to make sure there was no binding anywhere across the range of motion for both the X and Y axes.

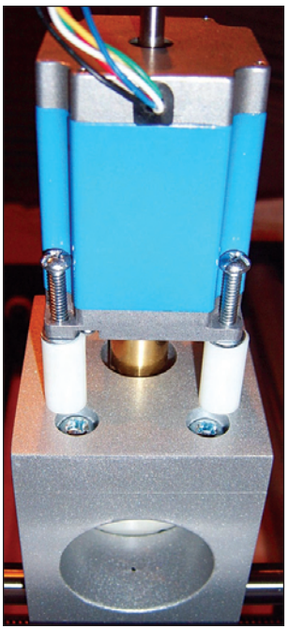
AND NOW, FOR SOME ELECTRONICS!

At this point, the complete $599 FireBall V90 CNC router is assembled. It's now time to move on to the electronics package. In the standard motor package, the blue motor goes on the Z axis and the yellow motors go on the X and Y axes. Someone was thinking ahead when they thought of color-coding the motors! A quick tip: Before mounting the motors, you may want to consider grinding a flat on the shafts. This will allow the coupler set-screws to make a better seat.

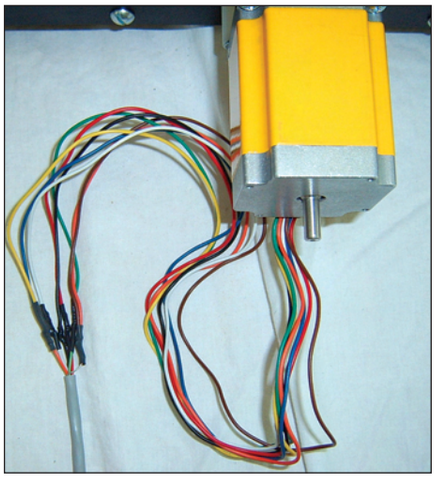
■ FIGURE 9. Starting at top center and going clockwise: table supports, tool holder, Z axis assembly, hookup wire, fuses, fuse holders, power cord, lead screw bearings and clamps, and assorted bags of hardware.



■ FIGURE 10. Motor hardware — metal washers go between motor and nylon standoffs.

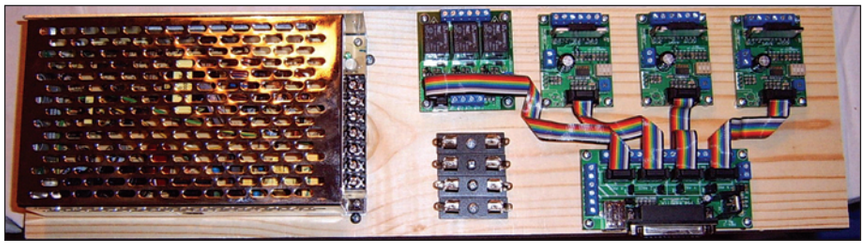


■ FIGURE 11. Z axis motor in place — ready to tighten screws.



■ FIGURE 12. Stepper leads attached to cable with solder and heat shrink. I did this slightly different than PROBOTIX since I used orange and shield as V+ conductors (they only use orange in the gray cable).

The motors are mounted using nylon stand-offs (Figure 10), and bolted to the top of the Z assembly (Figure 11) and to the gantry or frame side members. I followed the illustrations in the instruction manual and mounted the motors in the standard locations. (Some have asked if the motor can be mounted on the back of the frame and John Hansford has verified that it is possible to do so, if you prefer.) While working with the machine, I realized that even with the motor wires disconnected, the motors can be hard to turn. I added some knobs (RadioShack part number 274-407) to the back shaft of each motor so I could easily turn the shafts for manual zeroing and to save my fingers! Wiring the motors was surprisingly straight forward. The only trick was realizing that several of the wires go to the positive motor supply and can be connected together to one wire in the cable (Figure 12). Make sure you leave enough cable length appropriate for each axis since they all have different travel distances. I mounted the motor drivers, relay board, and breakout board on a piece of wood that was large enough to also hold the power supply (Figure 13).



■ FIGURE 13. 24V Power supply, relay board, three motor drivers, and breakout board mounted with fuse holders.

HARD PART'S DONE, TIME FOR SOME SOFTWARE!

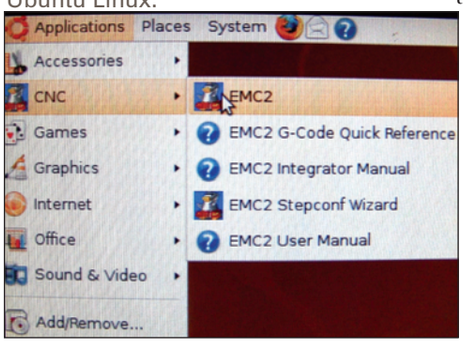
I had help from another good friend, Robot Group member and Linux expert James Delaney in getting the Ubuntu Linux distribution, EMC2 and Inkscape software up and running on my desktop PC (Figure 14). After playing with the software for a bit, I posted a question to the FireBall forum asking questions about Inkscape (a GNU/open-source design software I was trying). I detailed how I had encountered some difficulty with the apparent lack of an integrated software solution for both the design and tool-path planning end of things. I had a look around at the commercial offerings and, after reading some suggestions on the forum, downloaded a trial version of Mach3, an advanced CNC control application (Figure 15).

Meanwhile, John Hansford answered my posting (he's quite active in the forum) saying he encountered similar issues and suggested a software package from Vectric called Vcarve Pro. I downloaded the trial version of the software that allows you to try out the design aspect and then cut the example files on your CNC (Figure 16). John spoke with Tony McKenzie at Vectric and arranged for a full copy of VCarve Pro to be sent out to help speed our preparations for Maker Faire (thanks Tony and Vectric!). I used VCarve Pro to import several bit mapped images and perform the tool path planning for our Maker Faire give-aways (Figure 17).

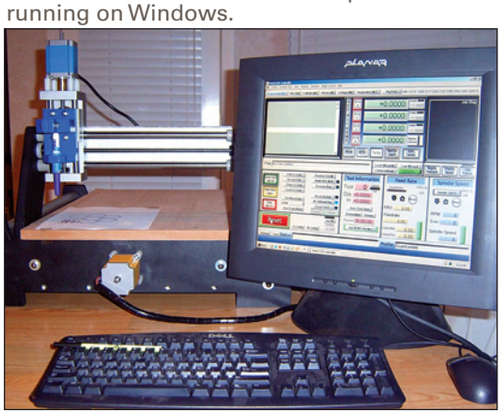
I think it's pretty amazing that there are so many choices for for small-scale CNC software including both GNU/open-source, as well as commercial applications.

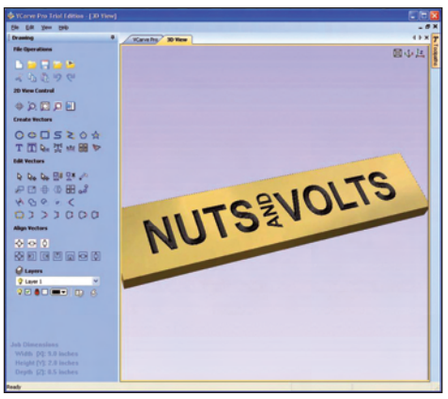
My final approach was a

■ FIGURE 14. Starting up EMC2 on Ubuntu Linux.

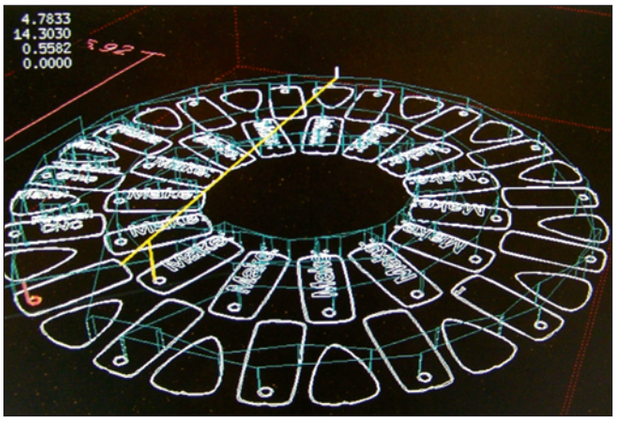


■ FIGURE 15. Mach3 Software up and running on Windows.



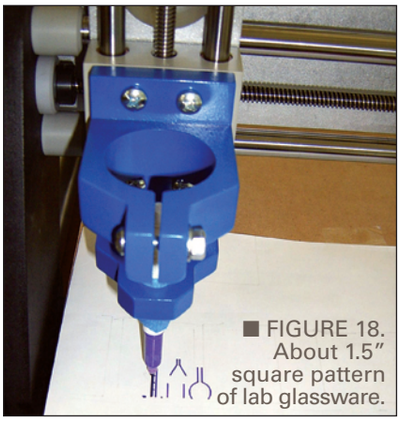


■ FIGURE 16. VCarve Pro with example artwork.



■ FIGURE 17. First layout for CNC cutting keychains for Maker Faire.

hybrid of all the different packages. For example, my first attempt at running the machine involved manual jogging and running the motor tuning setup within EMC2. I then mounted the standard tool holder which is designed to work with a Dremel model 300 rotary tool and then placed a felt-tip marker in it to test out some drawings. I drew several patterns using the various tools and had success drawing on paper taped to the work surface (Figure 18). By now, I was feeling more confident that I knew what I was doing so it looked like it was finally time to cut something.



■ FIGURE 18. About 1.5" square pattern of lab glassware.

CUT IT OUT, ALREADY!

I installed my trusty old Dremel model 385 Multipro and found it wasn't quite a snug fit. I shimmed it with some thin card stock and was able to use it for cutting in foam. In fact, I even used one of the few pieces of packing foam from the box to carve the sample torus file in EMC2 (Figure 19). Sure was nice of PROBOTIX to provide some test material!) Carving foam was fun for a while, but then it was time to find a way to make a sacrificial work surface and come up with a clamping system so we could cut something a bit more substantial than packing foam.

■ FIGURE 19. First cut of Torus (rough lower edge due to mismatch of cutter and Z depth).

MAKE: IT HAPPEN!

About this time, Maker Faire Austin was approaching and The Robot Group was preparing a list of projects for the show. As we had a nice new CNC router, we decided to showcase it at the Austin event. We decided the best way to demonstrate the power of the router was to make small give-aways of some type. After toying with cutting shapes out of recycled vinyl LPs (the finished vinyl pieces turned out to be too fragile), we decided on recycled CDs as our media. This required a clamp that could hold down the CD so it could be held tight while being cut. Again, another Robot Group member came to the rescue. Rick Abbott machined an aluminum shoulder washer that perfectly fit the hole in the center of the CD (Figure 20). That solved my

■ FIGURE 20. Custom-machined aluminum shoulder washer holds a CD steady as the Dremel routes a gear pattern.

HISTORICAL OVERVIEW

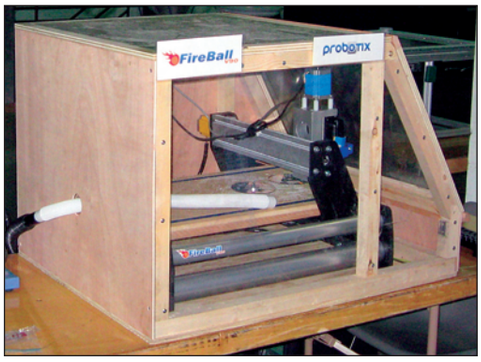
CNC was preceded by NC (Numerically Controlled) machines, which were hard wired and their operating parameters could not be changed. NC was developed in the late 1940s and early 1950s by John T. Parsons in collaboration with the MIT Servomechanisms Laboratory. The first CNC systems used NC style hardware, and the computer was used for the tool compensation calculations and sometimes for editing.

Punched tape continued to be used as a medium for transferring G-codes into the controller for many decades after 1950, until it was eventually superseded by RS-232 cables, then floppy disks, and now is commonly tied directly into plant networks. The files containing the G-codes to be interpreted by the controller are usually saved under the .NC extension. Most shops have their own saving format that matches their ISO certification requirements.

The introduction of CNC machines radically changed the manufacturing industry. Curves are as easy to cut as straight lines, complex 3-D structures are relatively easy to produce, and the number of machining steps that require human action have been dramatically reduced.

With the increased automation of manufacturing processes with CNC machining, considerable improvements in consistency and quality have been achieved with no strain on the operator. CNC automation reduced the frequency of errors and provided CNC operators with time to perform additional tasks. CNC automation also allows for more flexibility in the way parts are held in the manufacturing process and the time required to change the machine to produce different components.

***From Wikipedia*



■ FIGURE 21. Containment/protection display box created for Maker Faire.

clamping issue, but I had some problems cutting plastic without melting it and soon found out that special cutters and lower cutting speeds are required. Fortunately, Len over at PROBOTIX was willing to do some research on cutting bits and even offered to fly down for the show to provide on-site technical (and moral) support!

■ FIGURE 23. Recycled CDROMs cut into Keychains.

As the router would be operated in a public area, I thought it would be a good idea to create a display cabinet to keep noise and debris inside and curious fingers out. I enlisted Wolf Dilworth (yep, another Robot Group member) and Bruce Tabor to help craft a nice wood and Plexiglas cabinet to showcase the CNC machine. The display case was transparent on three sides and incorporated an internal lighting system making it easy to see the router strut its stuff (Figure 21).

The day of the show arrived and Paul Atkinson stepped up to the plate to operate the CNC router with Len Shelton from PROBOTIX at his side for two full days of exhausting, exhilarating Maker Faire fun (Figure 22). Len spent a considerable amount of time tuning the system and sharing his experience with us. He even solved the "cutting bit melting the CD" problem we originally encountered. Len had contacted the

■ FIGURE 22. Paul Atkinson (left) and Len Shelton (right) pose with the FireBall V90 at Maker Faire Austin.

owner of Precise Bits to discuss the results we were getting while cutting CDs. They told us we weren't using an optimal bit and they overnighted the right ones to Len. Turns out a "spiral up-cut bit" was just the thing for cutting CDs cleanly (thanks Precise Bits!).

After spending some time cutting CDs at the show (Figure 23), we noticed my older model 385 exhibited some run-out (off center rotation) it had developed over the years. The very generous folks in the Dremel booth at the show offered us a free Dremel 300 to use in the router! The new Dremel 300 worked the whole day with hardly any noticeable run-out.

On the second day, after getting comfortable with the V90 using the Dremels, we decided to upgrade to a Porter-Cable trim router that Len had brought with him so he could show the versatility of the V90 with a more powerful tool (Figure 24). Len and John both recommend that you get familiar with the V90 and its capabilities using a Dremel tool before you make this upgrade (and for good reason). Using the Dremel, you can learn a lot while not risking

■ FIGURE 24. Many of the finished pieces created and distributed to folks at Maker Faire Austin.

I (TRULY) GET BY WITH A LITTLE HELP FROM MY FRIENDS ...

Some of you may recall from previous articles how I described The Robot Group here in Austin as my "pallet of talent." The group is a tremendous resource and I have found I can always count on them to step up to the plate in a time of need.

Just after I started on this article, I packed up my house and moved out of Austin to Dripping Springs, TX in preparation for building a new house. The move was more disruptive than I could ever have imagined. Paul Atkinson, Vice President of the group and a good friend, came to my rescue by taking over the CNC mill and build as the move left me with no shop of any kind to work in nor any time in which to work!

In addition to assembling the machine, he took a bunch of great photos (all the assembly photos were courtesy of Paul) and even wrote up extensive notes which account for the bulk of the construction detail in this article. I owe Paul a debt of gratitude and probably a BBQ dinner (or two!) out here in the "country!" Thanks Paul! Couldn't have done it without you buddy!

the damage an "oops" with a more powerful router can cause. In fact, for those of you doing only small or fine work, the Dremel may be all you will need.

The V90 worked perfectly for the entirety of Maker Faire, running continuously over the two days and even winning an Editors Choice ribbon for our display (Figure 25)! In reality, we had more down time with clamping issues and/or working on software designs than anything else. Bottom line is the V90 is a solid piece of gears that can be easily assembled in an hour or two. With the well-matched electronics package, it makes a solid CNC machine that you can use and enjoy for hobby and light commercial use. It stood up to a demanding show schedule without skipping a beat.

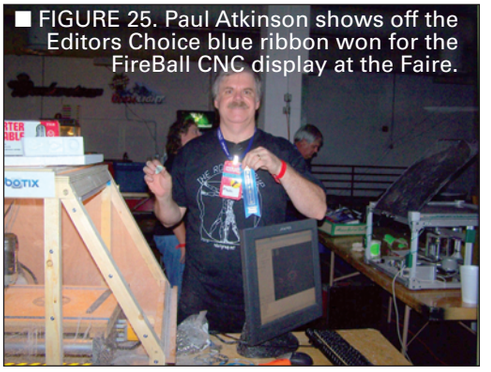
It can cut foam, MDF, wood, plastic, fiberglass, light carbon fiber, printed circuit boards, and solid surface (synthetic counter-top) material and we look forward to trying it out on ALL those materials! Though the FireBall's creator has reservations about doing so, some brave souls have even tried working metals with the V90, performing light cuts in aluminum and brass with very good results (check the Resources section for the V90 forum where users discuss their experiences). It all comes down to having a solid machine (PROBOTIX and FireBall make that part easy) and the patience to learn.

The PROBOTIX FireBall V90 CNC will be a centerpiece in my workspace for the foreseeable future and, based on the results so far, I think you can expect to see another entire article devoted to using the V90 to create parts a bit more useful for hobby robots than key chains (Figure 26)!

As always, if you have any questions, please feel free to email me at vern@txis.com.

NV

■ FIGURE 25. Paul Atkinson shows off the Editors Choice blue ribbon won for the FireBall CNC display at the Faire.



■ FIGURE 26. CD-ROM Gears and Key chains.

I'd like to thank Len Shelton and John Hansford for making the PROBOTIX FireBall V90 CNC a reality and for making a sub-$1,000 commercially available CNC system a reality. Also, special thanks to Tony McKenzie at Vectric for the VCarve Pro we used at Maker Faire. You guys rock!

I'd also like to thank Paul Atkinson (hardware/photography/electronics), James Delaney (software), Rick Abbott (parts fabrication), Wolf Dilworth and Bruce Tabor (display case construction), and Kym Graner (show coordinator) for their assistance and support!

RESOURCES

- PROBOTIX — **www.probotix.com**
- FireBall CNC — **www.fireballcnc.com**
- PROBOTIX FireBall V90 CNC at Maker Faire Austin 2008 — **http://makerfaire.com/pub/e/2151**
- FireBall V90 chat forum — **http://groups.yahoo.com/group/Fireballcnc**
- VCarve Pro — **www.Vectric.com**
- Precise Bits — **www.precisebits.com**
- ArtSoft Mach3 CNC Software — **www.machsupport.com**
- Linux CNC "Enhanced Machine Controller - EMC" — **www.linuxcnc.org**
- Dremel Tools — **www.dremel.com**
- The Robot Group — **www.TheRobotGroup.org**
- Pok-e-Jo's BBQ in Austin — **www.pokejos.com**
- The Train Saver — **www.nutsvolts.com/preview.php?issue=11**