Why CNC?

~

An Introduction

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http://softsolder.com

January 2011
Cabin Fever Expo
York PA
* Must *
* Make *
* Shiny *
* Objects *
Upcoming Events

Things to do with CNC

Machine shops & milling machines
Computer Numerical Control
Numbers and where to find them

G-Code programming
Stepper motors & step timing

Useful (?) household (?) projects (!)

See it in action at the CNC Exhibit!
Not Squishy Objects

Silicone snot bridge

Silicone snot + epoxy LED light

Band over watch

RepRap

Shotglass

Fab@Home
A room, building, or company where machining is done is called a machine shop.
Hey, kids, try this at home!
Milling Machines

http://www.iwsteamrailway.co.uk/pages/locos/mt_2002.htm
Sherline CNC Milling Machine

http://sherline.com/CNCmenu.htm
## Size Matters

### Mill Specifications

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>5000(5100)</th>
<th>5400(5410)</th>
<th>2000 (2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max clearance, table to spindle</td>
<td>8.00&quot; (203 mm)</td>
<td>8.00&quot; (203 mm)</td>
<td>9.00&quot; (229 mm)</td>
</tr>
<tr>
<td>Throat (without headstock spacer)</td>
<td>2.25&quot; (50 mm)</td>
<td>2.25&quot; (50 mm)</td>
<td>Adjustable</td>
</tr>
<tr>
<td>Throat (with headstock spacer block)</td>
<td>(Not included)</td>
<td>Included, 3.50&quot; (89 mm)</td>
<td>Not Required</td>
</tr>
<tr>
<td>Travel, &quot;X&quot; Axis</td>
<td>8.68&quot; (228 mm)</td>
<td>8.68&quot; (228 mm)</td>
<td>8.68&quot; (229 mm)</td>
</tr>
<tr>
<td></td>
<td>(9&quot; w/ stop screw removed)</td>
<td>(9&quot; w/ stop screw removed)</td>
<td>(9&quot; w/ stop screw removed)</td>
</tr>
<tr>
<td>Travel, &quot;Y&quot; Axis</td>
<td>3.00&quot; (76 mm)</td>
<td>5.00&quot; (127 mm)</td>
<td>7.00&quot; (178 mm)</td>
</tr>
<tr>
<td>Travel, &quot;Z&quot; Axis</td>
<td>6.25&quot; (159 mm)</td>
<td>6.25&quot; (159 mm)</td>
<td>5.38&quot; (137 mm)</td>
</tr>
<tr>
<td>Hole through spindle</td>
<td>.405&quot; (10 mm)</td>
<td>.405&quot; (10 mm)</td>
<td>.405 (10 mm)</td>
</tr>
</tbody>
</table>

[http://sherline.com/specs.htm](http://sherline.com/specs.htm)
Shape Matters

Given that the mill has
- Table moving in X & Y
- Cutter moving in Z

Then the workpiece must be
- Utterly lacking overhang
- Clamped downward
- Fairly durable

You can't cut
- Sharp concave XY corners
- Features smaller than cutter
Small Projects

Well, why not just buy a new door latch?
I did, but it didn't fit… Surprise!
Just Draw What You Want?

http://www.auma.com
For Some Drawings, Maybe

“Chips”
~
LinuxCNC Mascot
G-Code = Coordinates

%  
N05 ( This program is copyright of Rab Gordon, Gary Drew, and Paul Corner.)  
N10 ( It is released here under a GPL without warranty to do with as you may.)  
N15 ( The part is cut from a 100x100x50mm block with the zero point at the )  
N20 ( center top of the block. Cutter is a 10mm ball nose. )  
N30G21  
N40G90  
N50T1M6  
N60M8  
N70S1600M3  
N80G0X53.Y-56.128  
N90Z10.  
N100Z-25.372  
N110G1Z-27.372F225  
N120Y-56.12Z-27.725  
N130Y-56.105Z-27.894  
N140Y-56.06Z-28.152  
N150Y-56.051Z-28.184  
N160Y-55.992Z-28.405  
N170Y-55.902Z-28.651  
N180Y-55.792Z-28.888  

... and much, much more ...
Door Latch Pull

You must have numbers for those fancy CAD drawings!

All circular paths must be tangent or convex to straight paths

Where are all these points? Measure!

Dust off your high-school trigonometry & algebra...
Problem

What happens when a coordinate changes?

It could happen...

Design changes in real projects

For me: part doesn't quite fit
(worn parts, bad measurements)

Design by successive approximation
Solution(s)

Parametric CAD drawings?
If you can afford those programs, great!

“Wizard” program that spits out G-code?
It's been done, but you get stale G-code

G-code “programs” based on measurements?
Requires programming language
Which G-code really isn't:
Can't do much without iteration & logic

But: EMC’s G-Code supports real programming!
G-Code

All the charm of computer machine language

Some of assembly language's user-friendliness

Now with a dash of Pascal!

Dialects

- **RS274D**: current “standard” language
- **RS274X**: Gerber PCB artwork
- **RS274NGC**: NIST extensions
- **RS274?**: whatever the EMC crew is up to
G-Code Big Picture

Assembly language programming for machines

Move the cutting tool in 9-dimensional space

XYZ ABC UVW (you don't want to know)
Linear & circular motion interpolation
Speed control in 6-space w/ per-axis limits

Machine control
- Spindle, coolant, clamps, tool changer...

Programming: loops, subroutines, if-then-else
- A major set of non-standard language features
Door Latch Pull - Numbers

#1110 = [0.125 * 25.4] (cutter diameter, inches -> mm)
#1111 = [0.0005 * 25.4] (chip load, inches/tooth -> mm/tooth)
#1112 = 2 (number of teeth)
#1113 = 1 (tool slot holding this cutter)

-- and much, much, much more like that --

(Part corner coordinates)
(Long body axis parallel to Y, "near" is to front of table = low Y)
(Symmetrical about Y axis, all in X+ range)
(X = even, Y=odd)
(Inside material contour, X+ half)

#2000 = 0.00 (center of bottom)
#2001 = 8.30
#2010 = 4.40 (LR corner)
#2011 = 8.30
#2020 = 4.40 (start of neckdown)
#2021 = 28.30
#2030 = 3.00 (end of neckdown)
#2031 = 29.70
#2040 = 3.00 (UR corner)
#2041 = 36.80
Door Latch Pull – Main Loop

G0 Z#1004  (to traverse level)
#900 = 0  (pass counter - start at surface)
#901 = 0.00  (initial Z)
O200 DO  (mill outline)
O100 CALL [#901]  (do a pass around the outline)
#900 = [#900 + 1]  (tick loop counter)
#901 = [#901 - #1133]  (next Z level)
O200 WHILE [#900 LE #1132]  (mill outline)
G1 X[0-[#2010 - #1200]] Y#2011  (trim final ramp)
M5  (spindle off)
G0 Z#1002  (get air)
G40  (cutter comp off)
G0 X#1000 Y#1001  (return home)
(msg,Done!)
M30  

Looping!

Subroutine to handle one pass

Variable holds Z-axis depth
Door Latch Pull – Cutting!

O100 SUB
G1 X[0-#2010 - #1200] Y#2011 Z#1 (ramp down along slot bottom)
G2 X[0-#2010] Y[#2011 + #1200] I0 J#1200 ( ... LL corner)
#800 = [90 - ATAN [#2031 - #2021] / [#2020 - #2030]] (angle: fillet arc ctr to tangent pt)
#802 = [#2020 - #1200] (fillet arc center X)
#804 = [#802 + [#1200 * COS[#800]]] (tangent pt X)
#805 = [#999 - [#1200 * SIN[#800]]] (fillet arc center Y)
G1 X[0-#2020] Y[#805] (slot side L to fillet start)
G2 X[0-#804] Y#999 I#1200 J0 (fillet)
G1 X[0-#2030] Y#2031 (fillet to neck)
G1 X[0-#2040] Y[#2041 - #1200] (neck L)
G2 X[0-#2040 - #1200] Y#2041 I#1200 J0 (fillet to top)
G1 X#2040 - #1200] Y#2041 (across the top to UR fillet)
G2 X#2040 Y[#2041 - #1200] I0 J[0-#1200] (fillet to neck)
G1 X#2030 Y#2031 (neck R)
G1 X#804 Y#999 (neck to fillet)
G2 X#2020 Y#805 I[0-[#1200 * COS[#800]]] J[0-[#1200 * SIN[#800]]] (fillet to slot R)
G1 X#2010 Y[#2011 + #1200] (slot L)
G2 X[#2010 - #1200] Y#2011 I[0-#1200] J0 (return)
G1 X#2000 Y#2001
O100 ENDSUB

Linear

Circular

Calculate coordinates based on geometry & measurements
Real-world I/O

First you make the fixture

G-code must miss the clamps!
CNC machining requires Numbers

- Numbers
- Coordinates
- Tool Path
- Motion Control
- Motor Drive
Stepper Motors

http://sherline.com/CNCmenu.htm
Stepper Motor

Stepper Motor

Photos by Craig Libuse, Sherline
Stepper Motor Controller

- PWM Motor Drivers
- PIC microcontrollers
- To Motors
- From PC Parallel Port
Stepping Pulses

0.05 mm = 0.002 in / 31 steps ➤ 1.6 μm/step = 63 μ·in/step
Stepping Speed

5 steps in 8.2x100 μs = 160 μs/step = 6 kHz

19 μs/sample
5 samples per division
Speed Matters

63 \mu\text{in/step} \times 6000 \text{step/s} = 0.38 \text{in/s} = 23 \text{in/min}

That's about as fast as a Sherline can move!

- It's a config file setting

- Speeds while cutting metal are \textit{much} lower!
Speed Matters

<table>
<thead>
<tr>
<th>SW Specifications</th>
<th>SW-105</th>
<th>SW-106</th>
<th>SW-1300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work Envelope</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X Axis</td>
<td>39.4in</td>
<td>39.4in</td>
<td>51.2in</td>
</tr>
<tr>
<td>Y Axis</td>
<td>19.7in</td>
<td>23.6in</td>
<td>28in</td>
</tr>
<tr>
<td>Z Axis</td>
<td>22.4in</td>
<td>22.4in</td>
<td>28in</td>
</tr>
<tr>
<td>Max. Spindle Speed</td>
<td>10,000rpm</td>
<td>10,000rpm</td>
<td>10,000rpm</td>
</tr>
<tr>
<td>Max Spindle Power (30min)</td>
<td>20HP</td>
<td>20HP</td>
<td>20HP</td>
</tr>
<tr>
<td>Spindle Taper</td>
<td>No. 40</td>
<td>No. 40</td>
<td>No. 40</td>
</tr>
<tr>
<td>Rapid Feed Rate</td>
<td>945 in/min</td>
<td>945 in/min</td>
<td>945 in/min</td>
</tr>
<tr>
<td>Tool Changer Capacity</td>
<td>24</td>
<td>24</td>
<td>32</td>
</tr>
</tbody>
</table>

That'd be 15 in/s = 244 kHz = 4 µs/step... for my setup

www.milltechcnc.com/sw.html
Motor Control / Driver Boxes

Pricing

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS-5A01-1</td>
<td>USB Signal Generator and Software</td>
<td>$1295</td>
</tr>
</tbody>
</table>

OEM Pricing available for quantity purchases.


http://sherline.com/CNCprices.htm
Home Shop Projects

**Mostly flat**
- More or less 2½ D

**Simple geometry**
- Straight lines
- Circular arcs

**Low precision**
- ≤0.005 inch is perfection

**Simple surface finish**
- As-machined or paint-to-cover: “used-car shine”
Why This Works

Old products have simple designs
  • Non-CNC production machinery
  • Screw-machine, stampings, turnings

Bash to fit, file to hide…
  • Don’t (try to) do it all with CNC
  • A manual lathe is helpful

Just Do It!
  • Start simple: machining is hard enough
  • With CNC, you can quickly make “another one”
Storm Window Clips

Anderson Awning Windows
• State-of-the-art, circa 1955
• Glass storm panes held in by nylon clips
• Sun and weather are very unkind to plastic

Replacement windows?
• $1000… more or less
• For each window

Easy to reproduce
• If you’re not fussy
• Oh, that scalloped fin!
Storm Window Clips

Simple design
- Straight edges
- Half-circle
- Circular arc
- Mounting hole

Easy fixture
- Add a second hole to prevent spinning
- Hold it down with 6-32 machine screw

So… why bother with CNC?
Storm Window Clips

(22 windows) × (4 or 5 clips each)
Storm Window Clips

Fixture array?
- Copy & paste
- G54-G59.3
  - Only 9 spots
- “O-word” loop

EMC changes!
- **2005**: Copy
- **2007**: Loop

Pick your poison
RF Adapter Holder

Amateur radio “go-kit” toolbox

Adapters hide in the clutter

Who borrowed that adapter?
RF Adapter Holder

Faired corners to match box
Weeks to find trivial equation
Machining was easy after that!

*The first one didn’t fit…*
Recumbent Bike Chain Idler

Original design
- Aluminum sprocket
- Teeny steel balls
- Plastic race insert (?!?!)

Improvements
- Aluminum sprocket
- Large cartridge bearing
- Bushing to match original shaft

Do it manually?
- (2 idlers) x (3 bikes)
Recumbent Bike Chain Idler

Drilling
- Chain roller positions
- Hub area cleanout

Milling
- Circular interpolation!
- Many Z-axis levels
Camera Monocular Mount

Monocular
• 8x telescope
• 20x microscope
• Light & compact

Digital Camera + lens
• 114 mm → 912 mm
• f/5.1 → f/41 (ouch)
• Best for sunny scenes!
Camera Monocular Mount

Simple Layout
- Circular arcs
- Right angles
- Polycarbonate!
Demo Madness
Locate Origin

\[ X = Y = Z = 0.000 \]

at corner surface
Drill Clamping Holes

Sacrificial plate
Locate Fixture Origin

Correct origin

Incorrect origin

CNC machine tools lack UnDo buttons!
Outside Cutting

Tight clearance!
Chips Aplenty

Beware of flying objects!
Some Deft Vacuum Work
Outside Done!
Places To Go

Wikipedia CNC article
http://en.wikipedia.org/wiki/Cnc

Nice CNC setup & info
http://www.irritatedvowel.com/Railroad/Workshop/SherlineCNC.aspx

Sherline Products
http://sherline.com

Enhanced Machine Controller Project
http://linuxcnc.org

Flashcut CNC
http://www.flashcutcnc.com

Non-shiny Things
www.fabathome.org
http://reprap.org

Naval Safety Center
http://www.safetycenter.navy.mil/photo/default.htm
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Ed Nisley

Say “NISS-lee”, although we're the half-essed branch of the tree

Engineer (ex PE), Hardware Hacker, Programmer, Author

The Embedded PC’s ISA Bus: Firmware, Gadgets, Practical Tricks

Circuit Cellar www.circuitcellar.com
  Firmware Furnace (1988-1996) - Nasty, grubby hardware bashing
  Above the Ground Plane (2001...) - Analog and RF electronics

Dr. Dobb’s Journal www.ddj.com
  Embedded Space (2001-2006) - All things embedded
  Nisley’s Notebook (2006-2007) - Hardware & software collisions

Digital Machinist www.homeshopmachinist.net
  Along the G-Code Way (2008-) - G-Code and mathematics
If you can’t read this then make a new friend ‘way up front