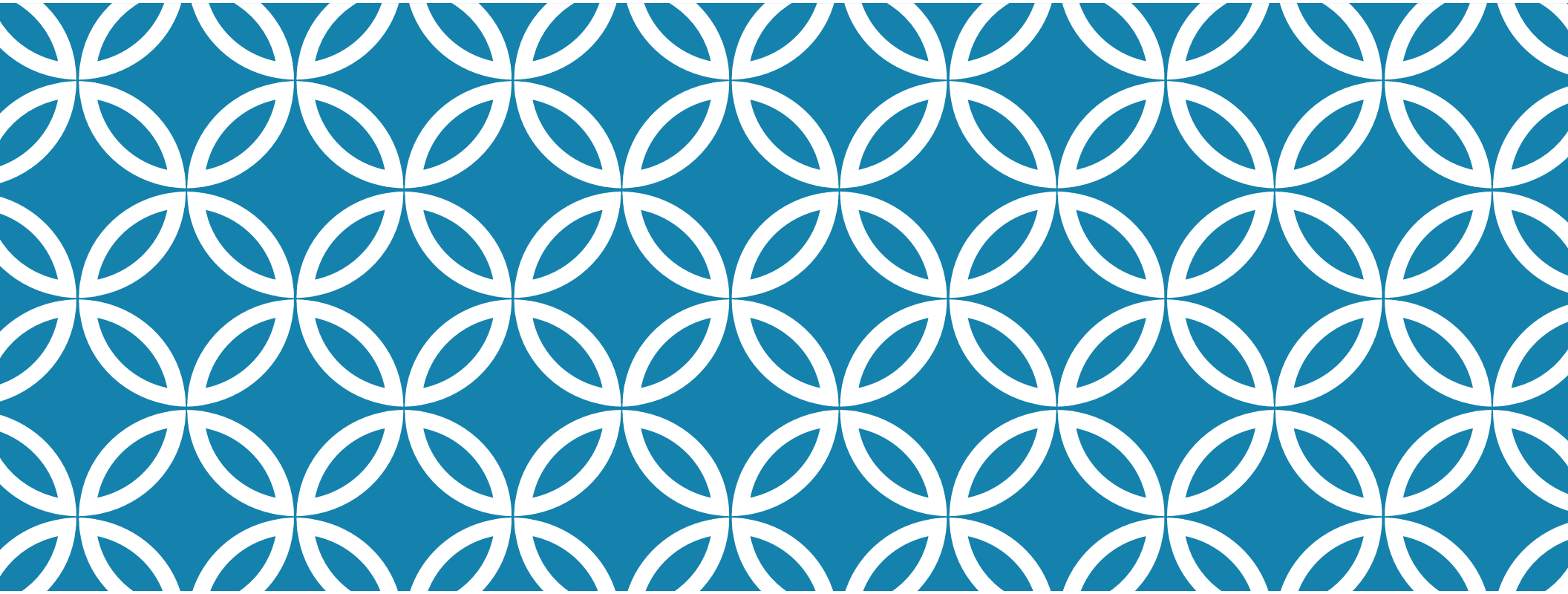


BUILDING YOUR OWN CNC LATHE, MILL OR ROUTER

Martin Kennedy
HMSC
January 9, 2016

OUTLINE

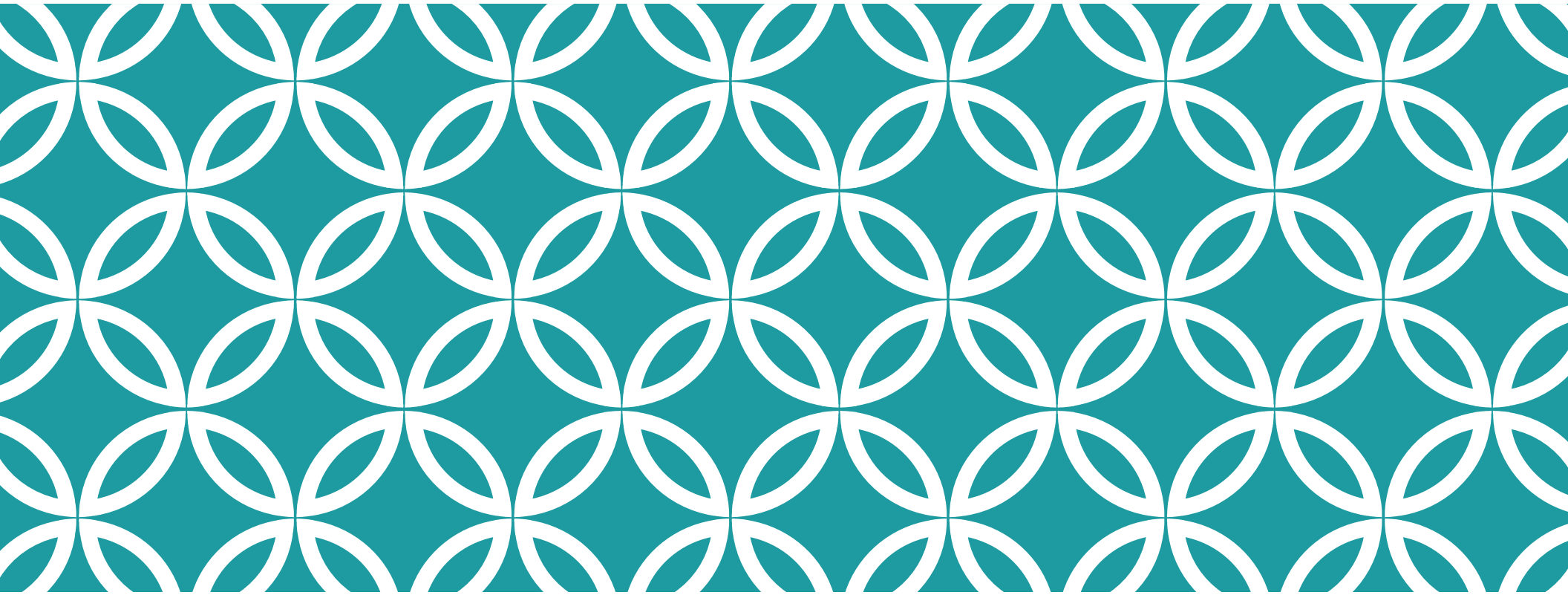
CNC Overview
- What is CNC?
- Why CNC?
- Options for Getting into CNC

Sample CNC Machines
- Mill
- Lathe
- Commercial Conversion
- Custom

CNC Process
- Overall Process
- Conversational vs Conventional CNC
- Software Required
- G-code

Hardware
- Control System Components
- Machine Modifications

Cost



CNC OVERVIEW

CNC – COMPUTER NUMERICAL CONTROL

Automation of machine tools

- Operated by precisely programmed commands encoded on a storage medium
- As opposed to controlled manually by hand wheels or levers, or mechanically automated by cams alone

First built in the 1940's and 1950's

- Modification of existing tools
- Controlled by paper tape

Typically used by hobbyists for:

- Mills
- Lathes
- Routers
- Torch, plasma or laser cutting
- 3D Printing

WHY CNC?

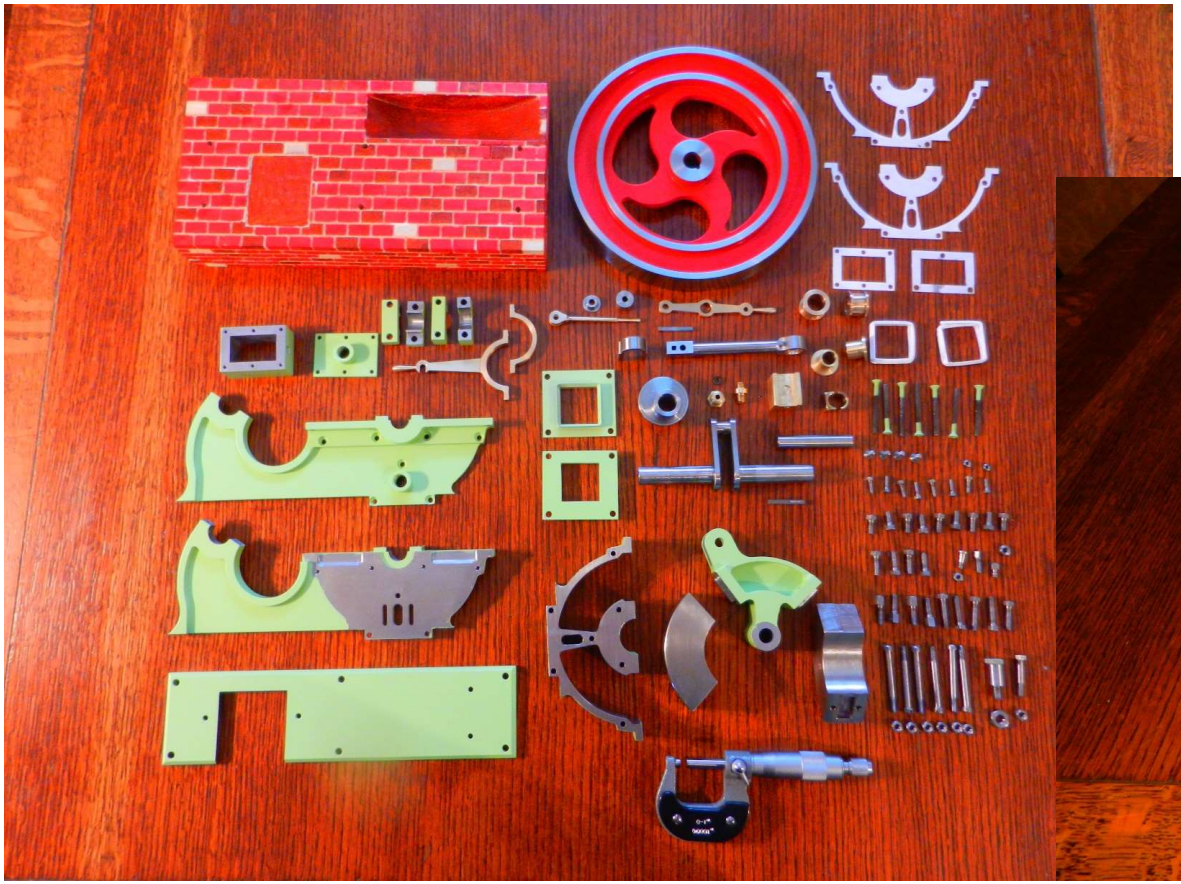
Pros

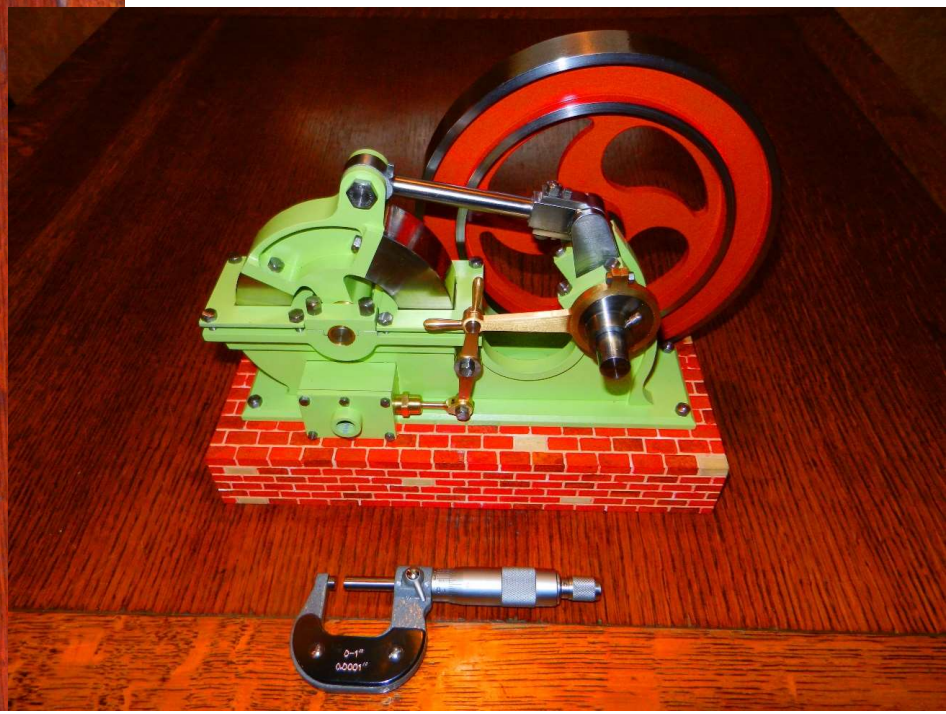
- Can make complex parts
- Easy to manufacture a number of identical parts
- Machining fast compared to manual operations
- Not subject to calculation errors / high precision and repeatability
- “Built in” DRO

Cons

- Requires more time for simple one-off parts due to programming time
- Steep learning curve
- Cost and complexity of support software required (CAD/CAM/control)
- Cost and complexity of hardware required
- Somewhat complicated to build and debug

PARTS THAT LEND THEMSELVES TO CNC





HOW CAN I GET INTO CNC?

Commercial CNC machine

- Upside
  - Relatively inexpensive for older machines
  - No need to design / install control equipment
  - No need to modify hardware
- Downside
  - Relatively expensive for newer machine, although hobbyist equipment available (eg. Tormach)
  - Older machines have:
    - Software obsolescence
    - Software limitations
    - Electronics obsolescence
    - Can be complicated to repair, find parts and obtain service information
    - Limited commercial support

HOW CAN I GET INTO CNC?

Conversion of commercial CNC machine

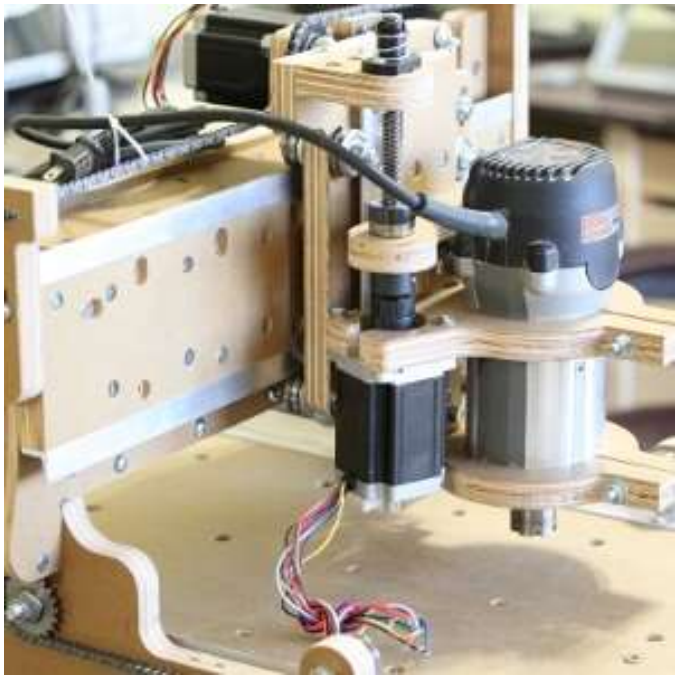
- Upside
  - Already has CNC hardware installed
    - ball screws, drive motors, VFD, switches etc.
- Downside
  - Complicated to integrate hardware to new control system
  - Some hardware may be non-functional or obsolete
  - Parts may be very expensive
  - Requires time commitment

HOW CAN I GET INTO CNC?

Conversion of non-CNC machine

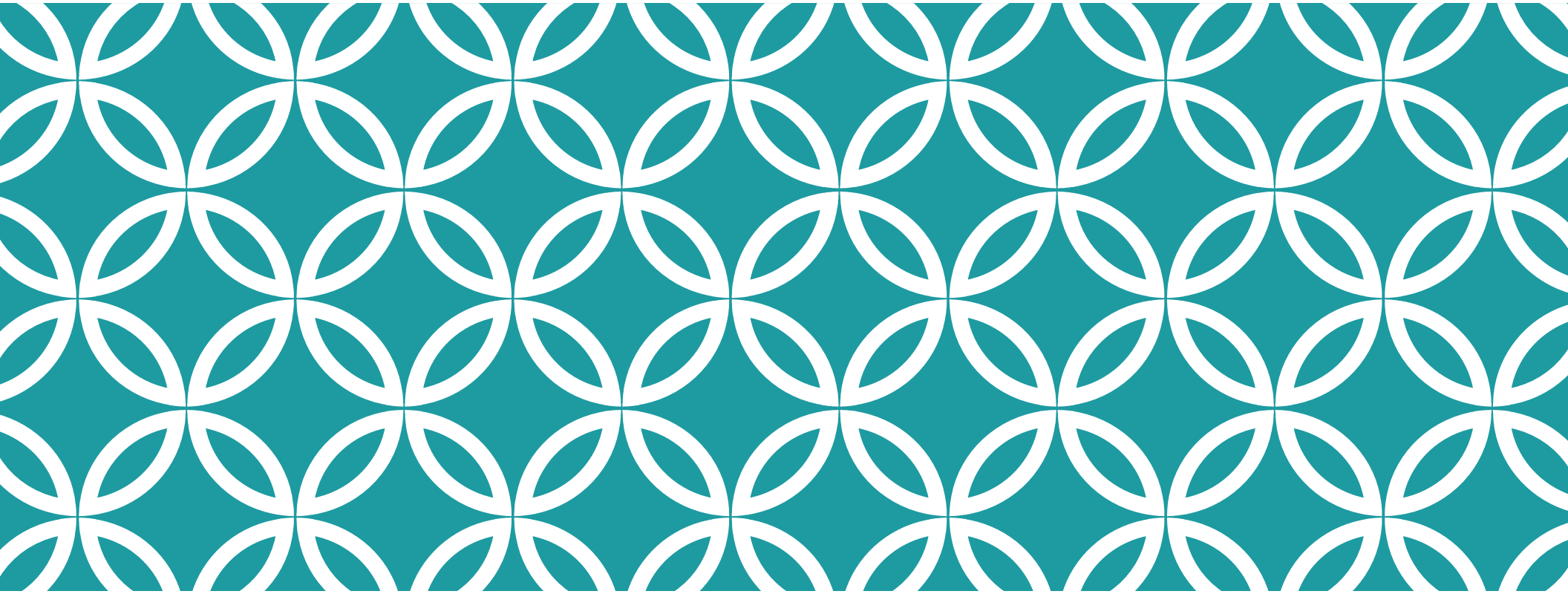
- Upside
  - Can be less expensive
  - Complete understanding of working of system
  - Can build exactly what you want
  - Custom specialized equipment can be built
- Downside
  - Complicated – lots of hardware and software options
  - Requires large time commitment

HOW CAN I GET INTO CNC?



Kit

- Upside
  - Can be less expensive
  - Design details all figured out and tested
  - Parts and assistance available from vendor
  - Great option for router
  - Retrofit kits available for popular equipment
- Downside
  - Requires medium time commitment



SAMPLE CNC MACHINES

CNC MILL

Rong Fu Mill

Originally a commercial conversion

Control system completely rebuilt

4-axis control

Mach3 controller

Touch screen

Pendant

Feed up to 200 ipm!

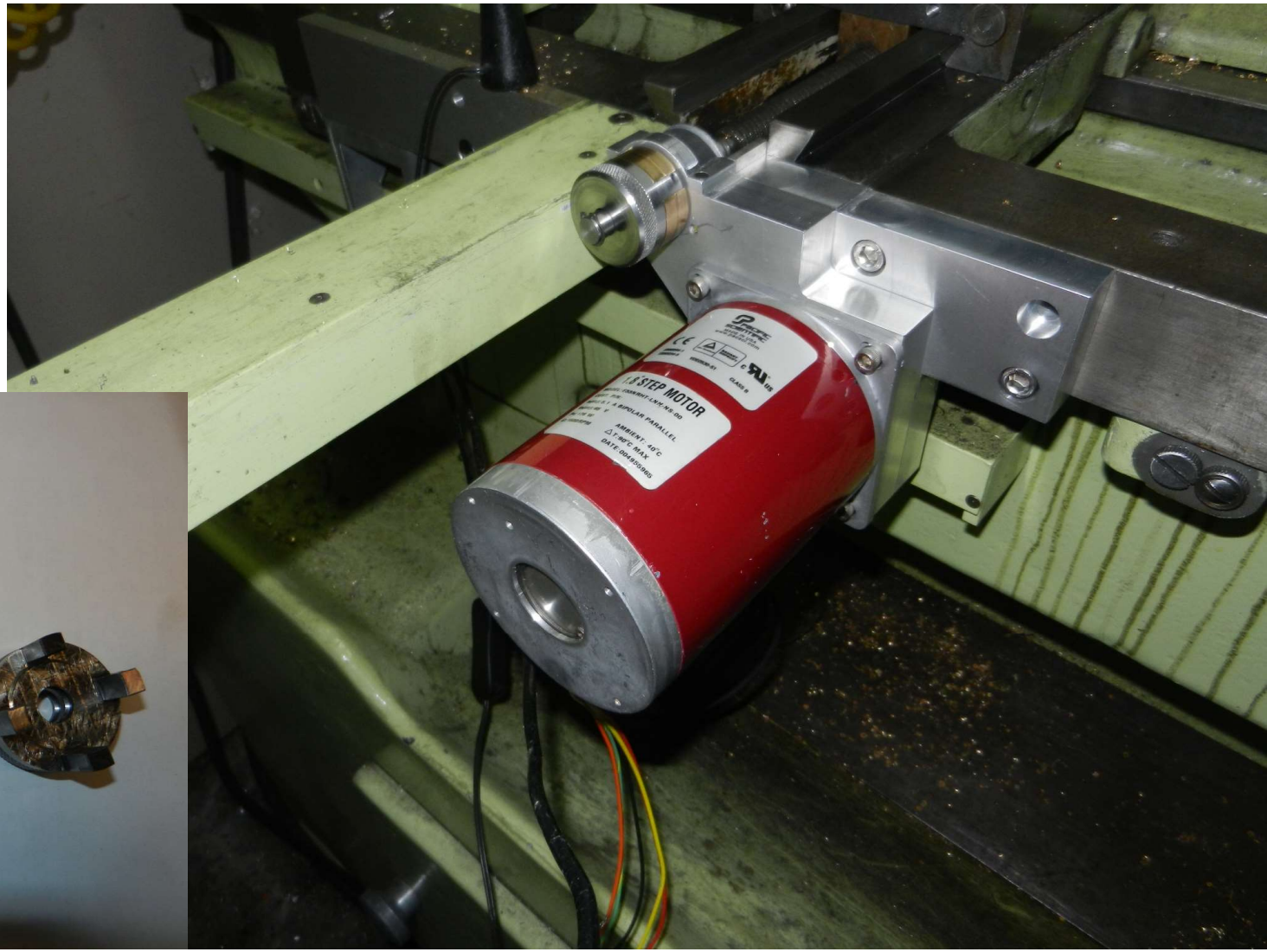
High Speed

4-Axis Milling

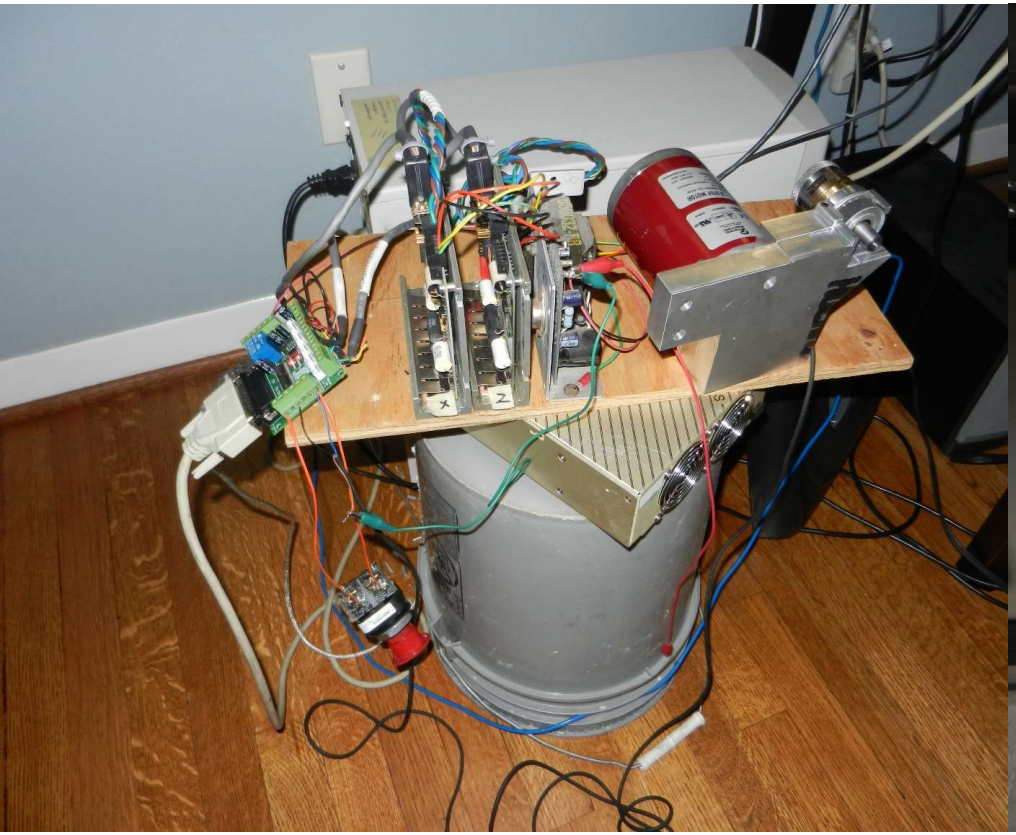
CNC LATHE

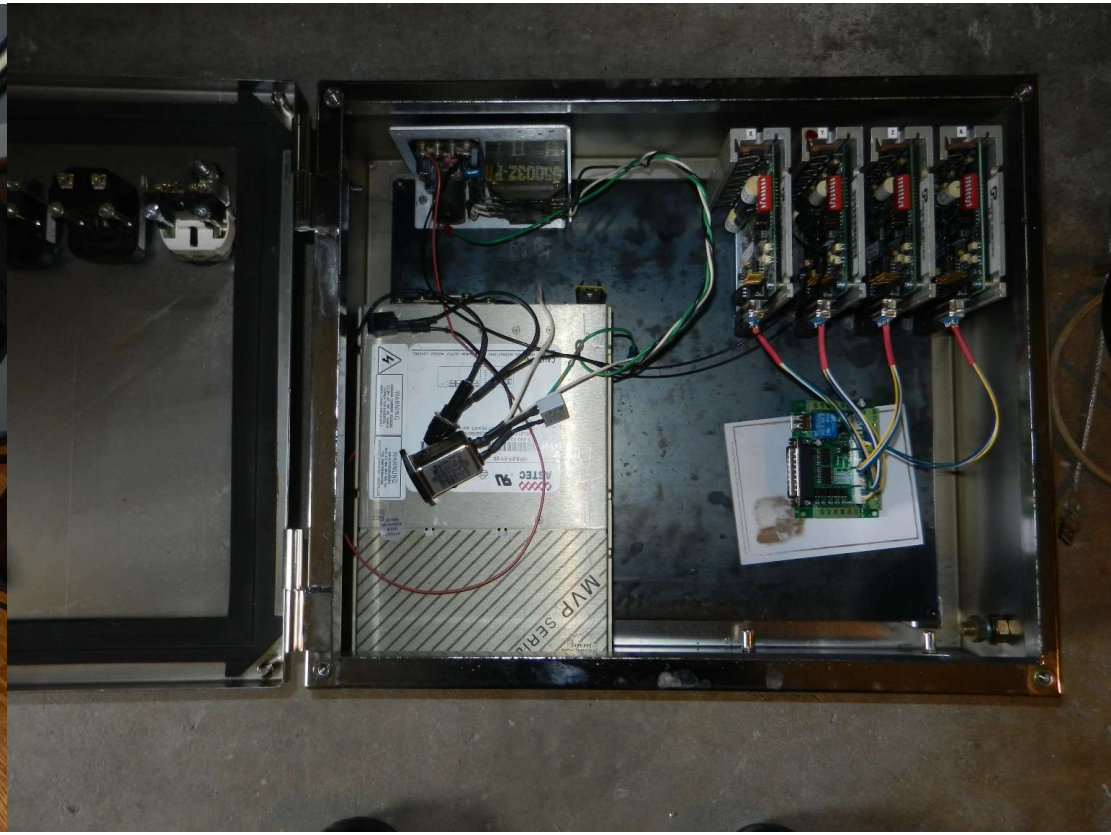
Monarch 10ee

Work in progress



CONTROL SYSTEM





COMMERCIAL CONVERSION

Making Part

Hardinge CHNC Lathe

Centroid Control

Turret tool holder w/8 slots

Automatic stock feeder

Automatic collet

Automatic finished part collector

SPECIALTY CNC – GLASS DRILL

Custom Machine

Makes tray plates for glass distillation column

Drills holes in glass

Replaced lathe with index plate

Takes about 1/3 as much time as lathe

Much more flexible in hole placement

OLD GLASS DRILL

Craftsman Lathe

Index Plate

Motor driven drill on cross slide

NEW GLASS DRILL

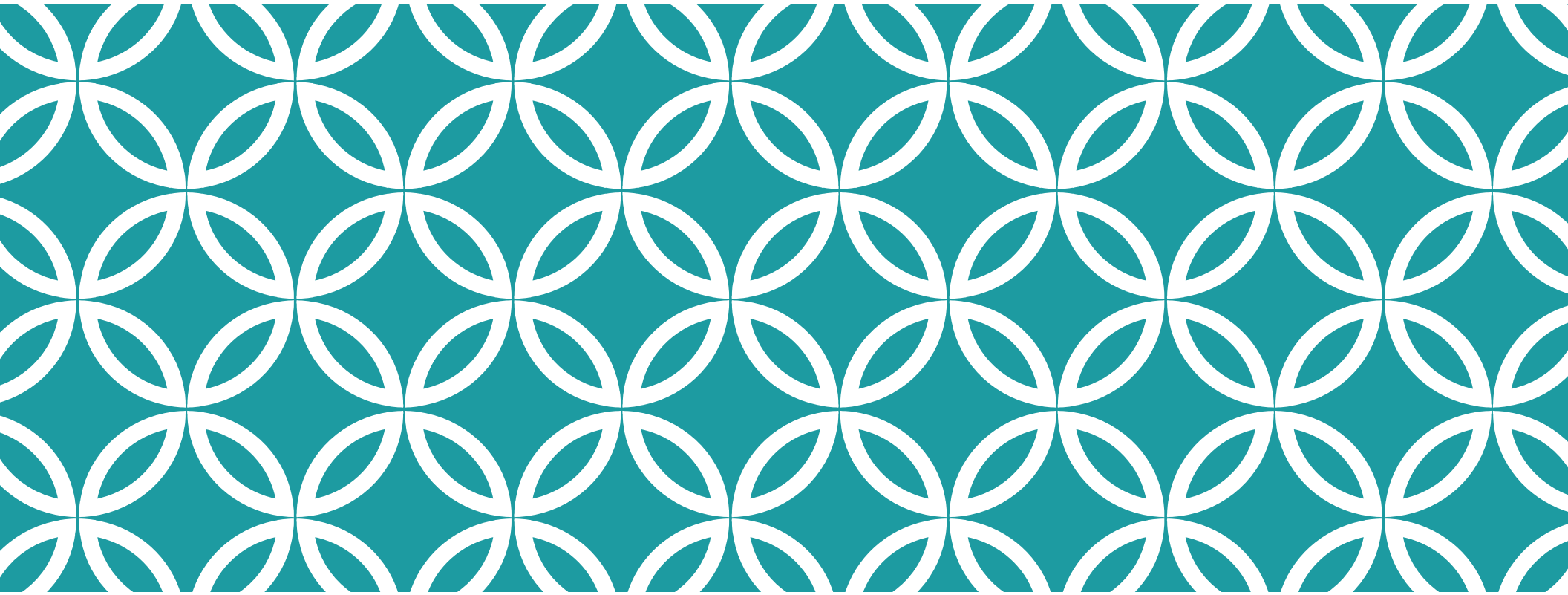
24,000 rpm water-cooled motor

Chuck on cross slide

Custom program

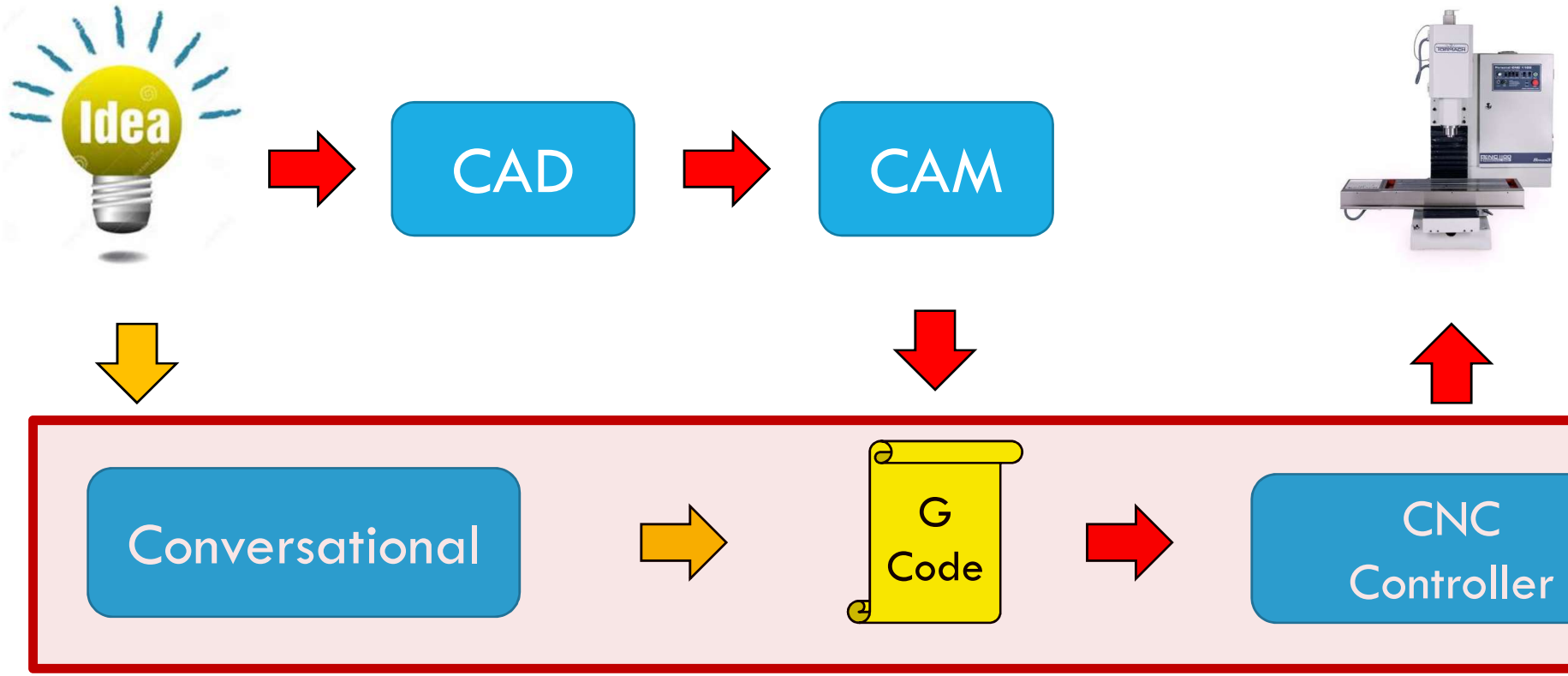
to generate G-code

Drilling



CNC PROCESS

CNC PROCESS



CONVERSATIONAL PROGRAMMING

Built in to most CNC controller packages, including hobbyist (such as Mach3)

In many cases, eliminates need for CAD and CAM software

Simple to learn

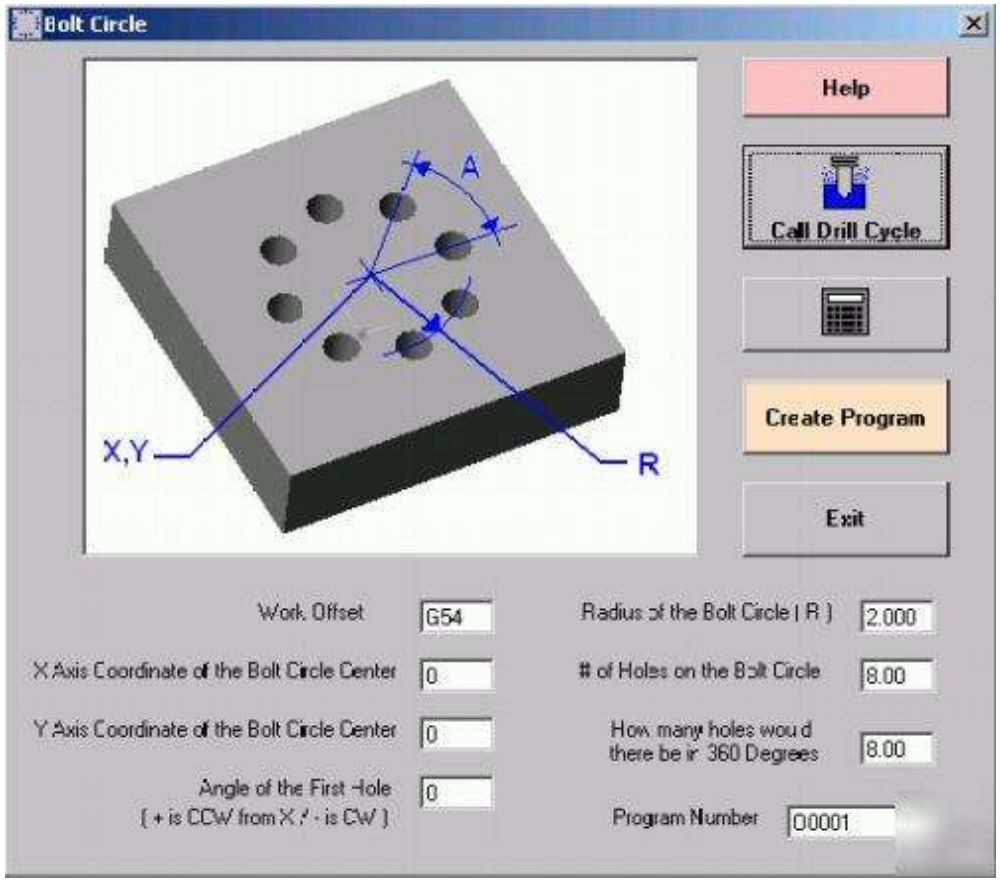
Can be used for relatively simple tasks

- Basic shapes
- Drilling on patterns
- Tapping

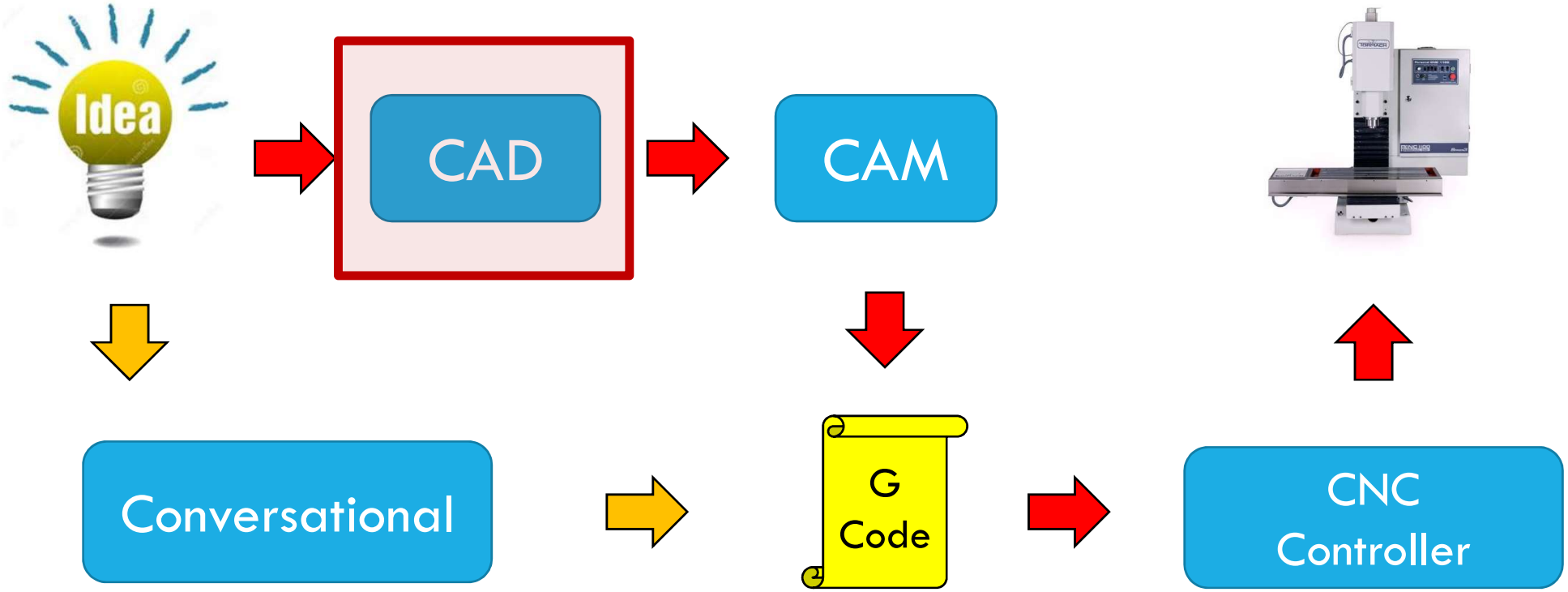
May not be suitable for complicated or 3D geometries

May address all or most of your machining needs

CONVERSATIONAL PROGRAMMING



CNC PROCESS



CAD – COMPUTER AIDED DESIGN

Computer version of paper drawings

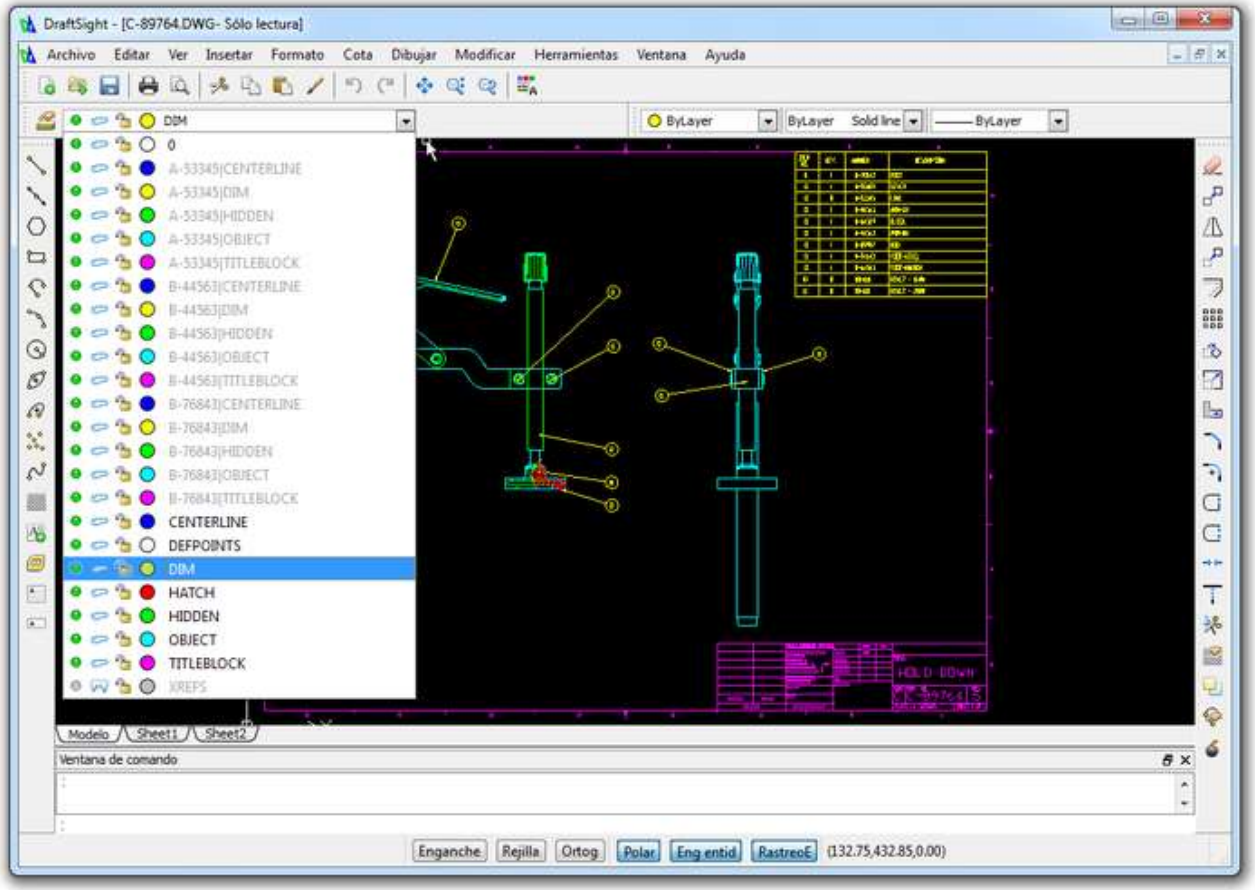
Example Programs

- 2D
  - DraftSight –FREE!
  - AutoCad - $900+
- 3D
  - SketchUp – FREE! (but no path to CAM in free version)
  - Fusion 360 – FREE!
  - TurboCAD - $130
  - BobCAD - $395
  - Alibre / Geomagic – was $200, now $1,000+
  - Solidworks - $6,000+
  - Inventor - $6,000+
- Many programs available is multiple versions, depending on desired functionality

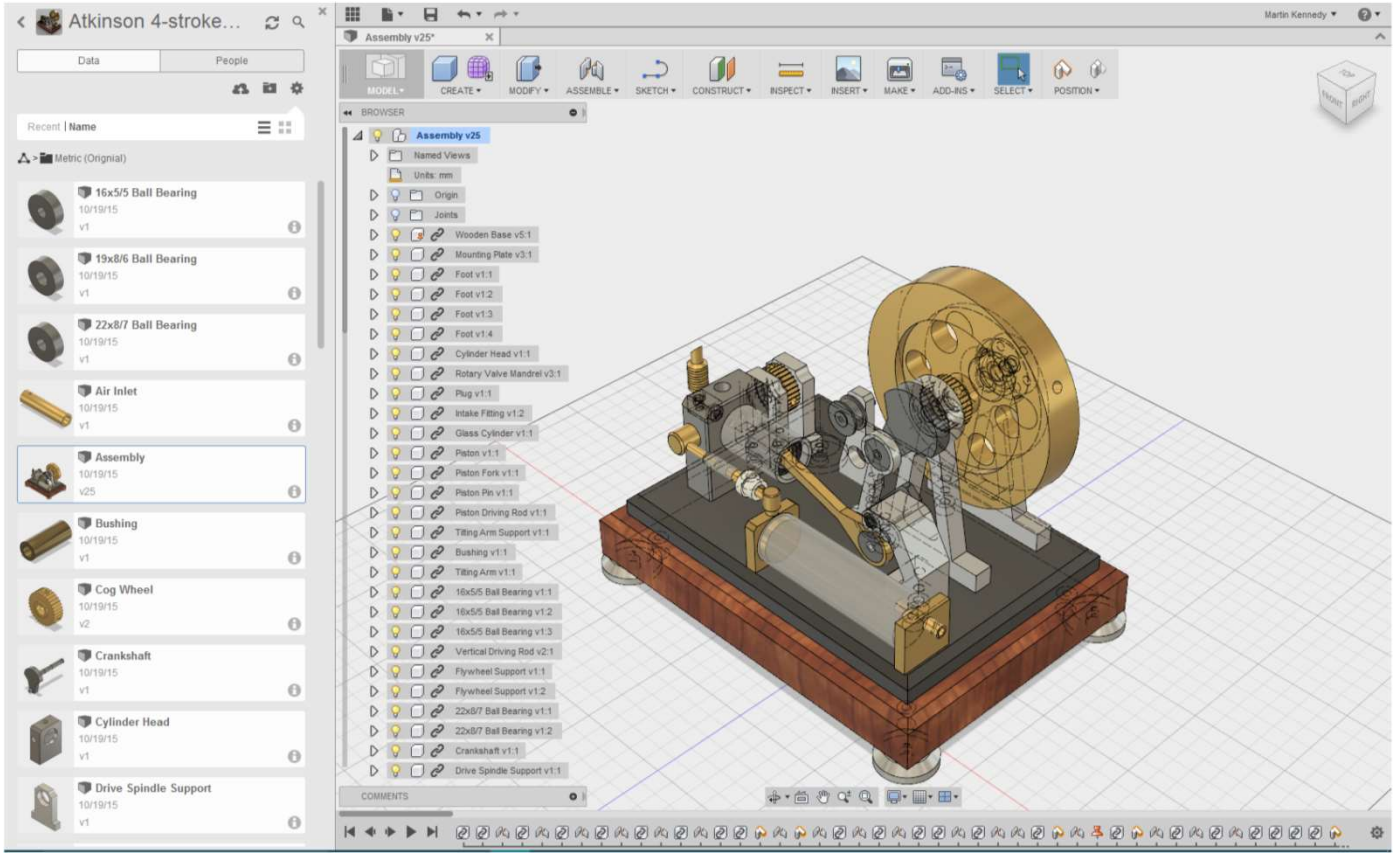
2D VS 3D

3D Milling

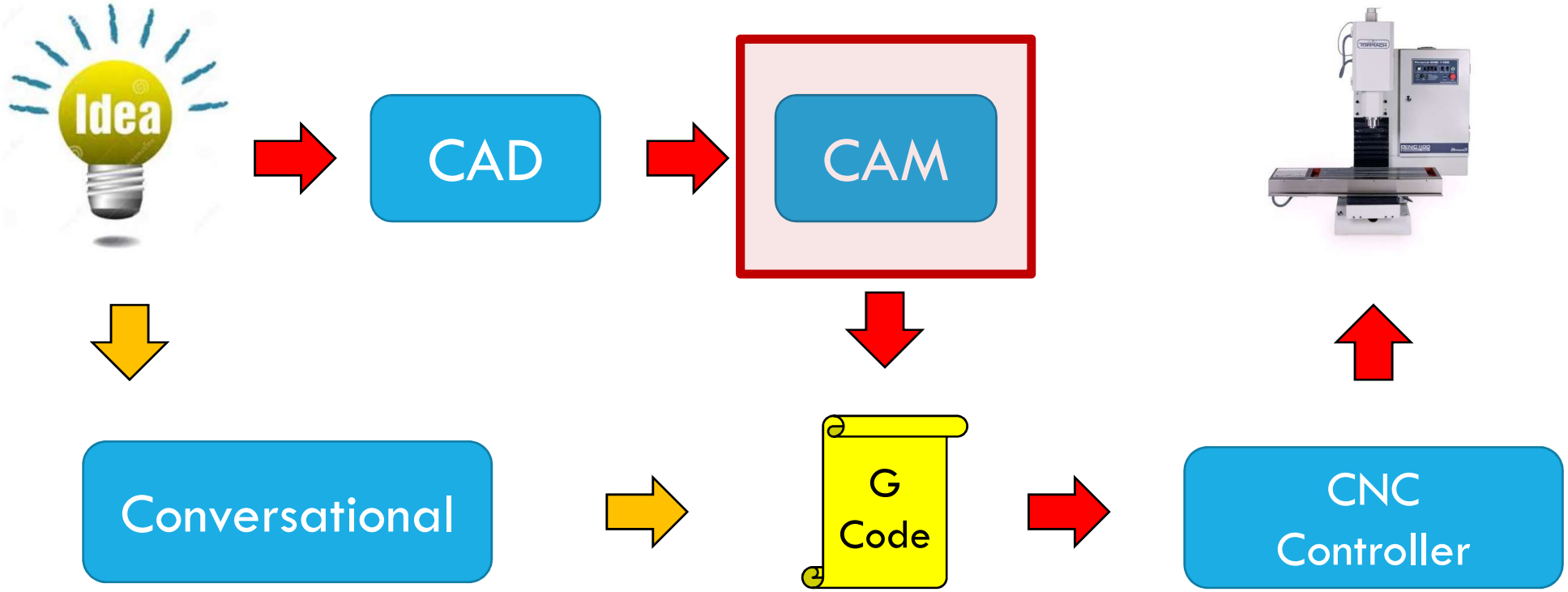
DRAFTSIGHT – 2D



FUSION 360 – 3D



CNC PROCESS



CAM – COMPUTER AIDED MANUFACTURING

Use of computer software to control machine tools

Input – CAD model, Output - G-code

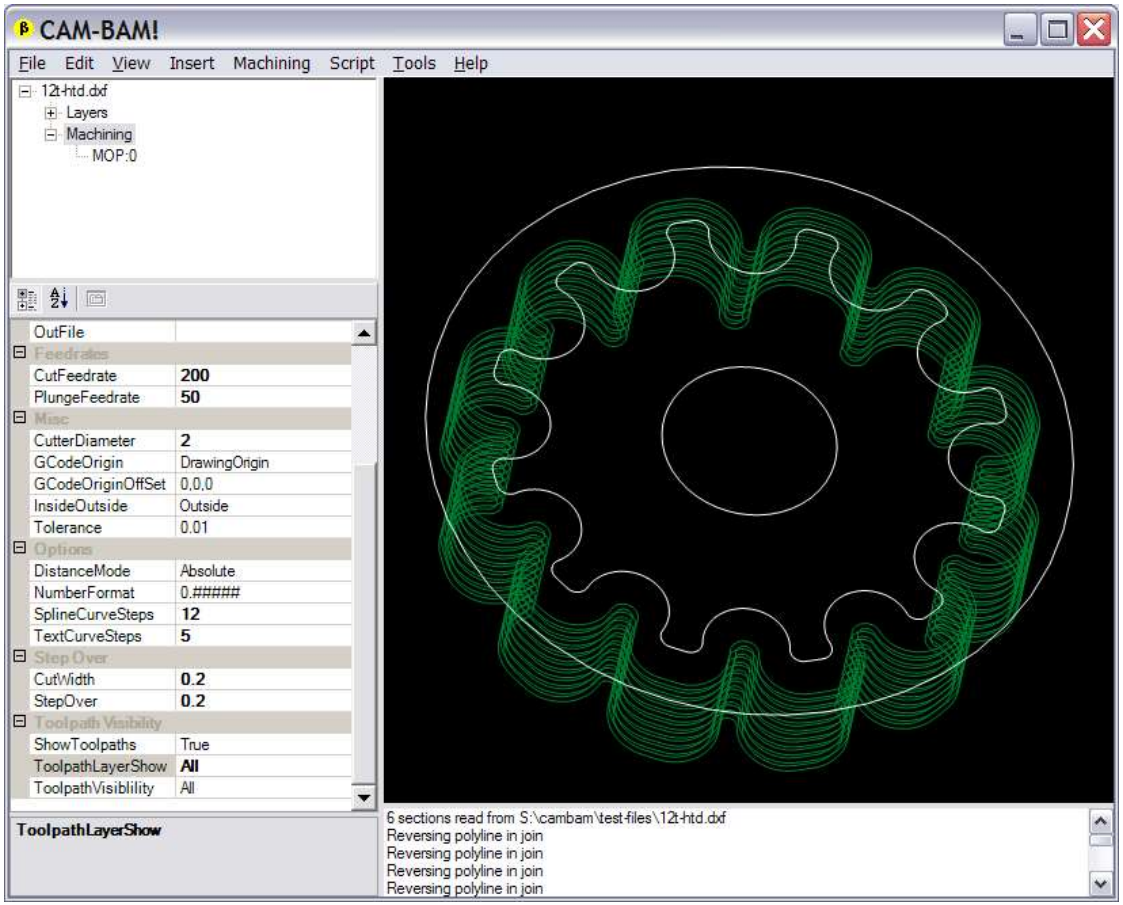
Requires "Post Processor" to customize code generation to your particular equipment

Example Programs
- Fusion 360 – FREE! (for low use)
- CamBam - $150
- Aspire - $350 - 2,000 (Router)
- BobCam - $2,000+
- MasterCam - $6,000+

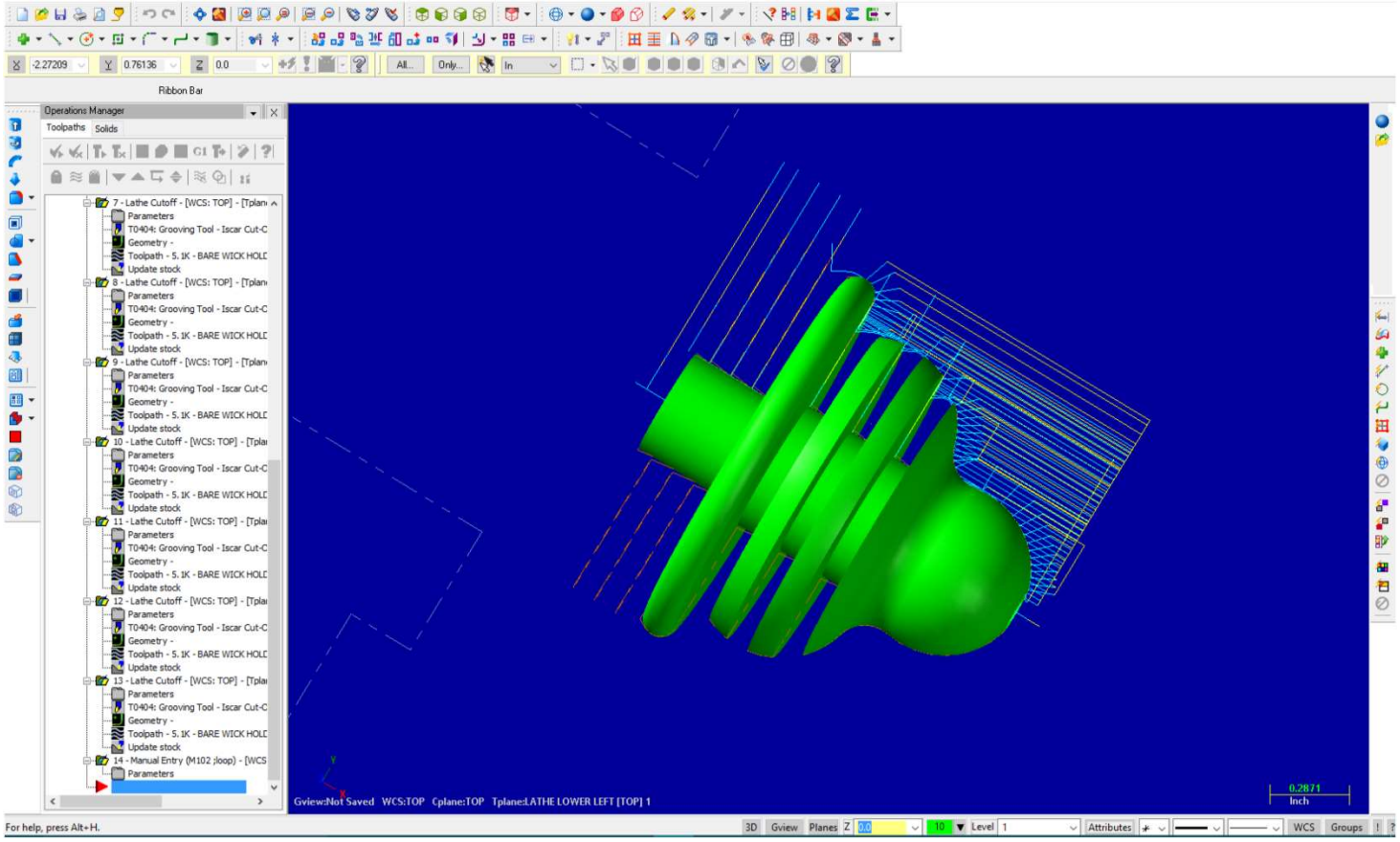
Plugins are available for popular CAD software
- Typically less expensive

Most programs have simulators

CAMBAM


CAM-BAM!
File Edit View Insert Machining Script Tools Help
12t-htd.dxf
Layers
Machining
MOP:0
OutFile
Feedrates
CutFeedrate 200
PlungeFeedrate 50
Misc
CutterDiameter 2
GCodeOrigin DrawingOrigin
GCodeOriginOffSet 0,0,0
InsideOutside Outside
Tolerance 0.01
Options
DistanceMode Absolute
NumberFormat 0.#####
SplineCurveSteps 12
TextCurveSteps 5
Step Over
CutWidth 0.2
StepOver 0.2
Toolpath Visibility
ShowToolpaths True
ToolpathLayerShow All
ToolpathVisiblility All
ToolpathLayerShow
6 sections read from S:\cambam\test-files\12t-htd.dxf
Reversing polyline in join
Reversing polyline in join
Reversing polyline in join
Reversing polyline in join

MASTERCAM


Ribbon Bar
Operations Manager
Toolpaths
Solids
7 - Lathe Cutoff - [WCS: TOP] - [Tplan
8 - Lathe Cutoff - [WCS: TOP] - [Tplan
9 - Lathe Cutoff - [WCS: TOP] - [Tplan
10 - Lathe Cutoff - [WCS: TOP] - [Tplan
11 - Lathe Cutoff - [WCS: TOP] - [Tplan
12 - Lathe Cutoff - [WCS: TOP] - [Tplan
13 - Lathe Cutoff - [WCS: TOP] - [Tplan
14 - Manual Entry (M102 ;loop) - [WCS
Parameters
T0404: Grooving Tool - Iscar Cut-C
Geometry -
Toolpath - 5. 1K - BARE WICK HOLE
Update stock
Gview:Not Saved WCS:TOP Cplane:TOP Tplane:LATHE LOWER LEFT [TOP] 1
0.2871
Inch
For help, press Alt+H.
3D
Gview
Planes
Level
Attributes
WCS
Groups

CNC PROCESS

CAD

CAM

Conversational

G Code

CNC Controller

G-CODE

Numerical control programming language

Most equipment manufacturers have their own variant

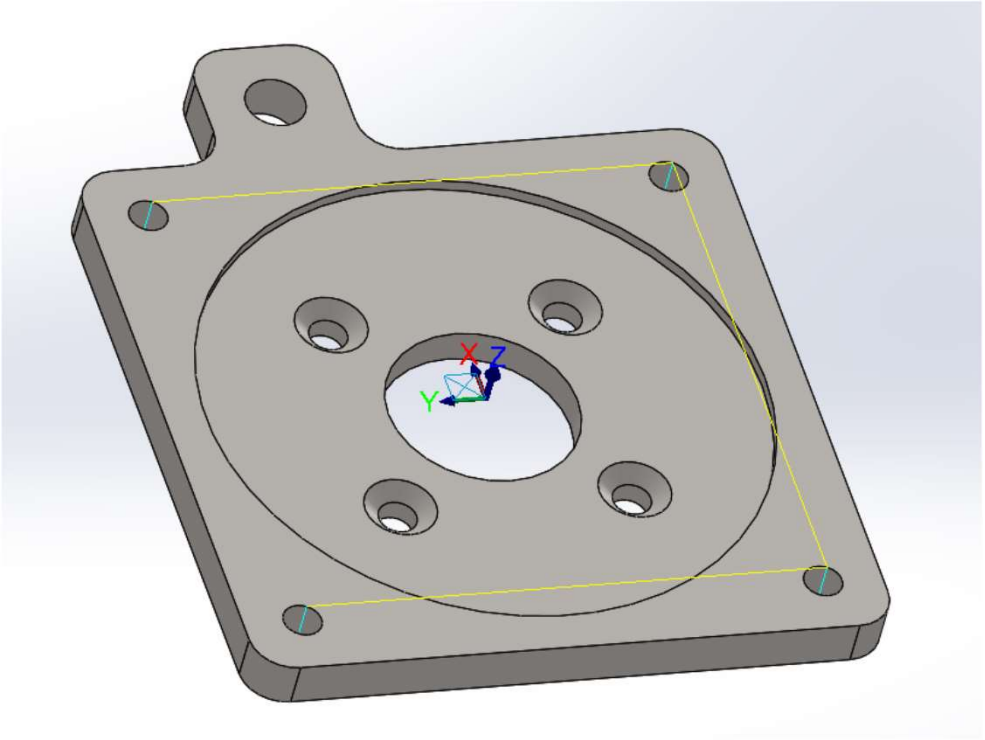
- May address special capabilities of machine
- Hence the need for Post Processors

Typical codes

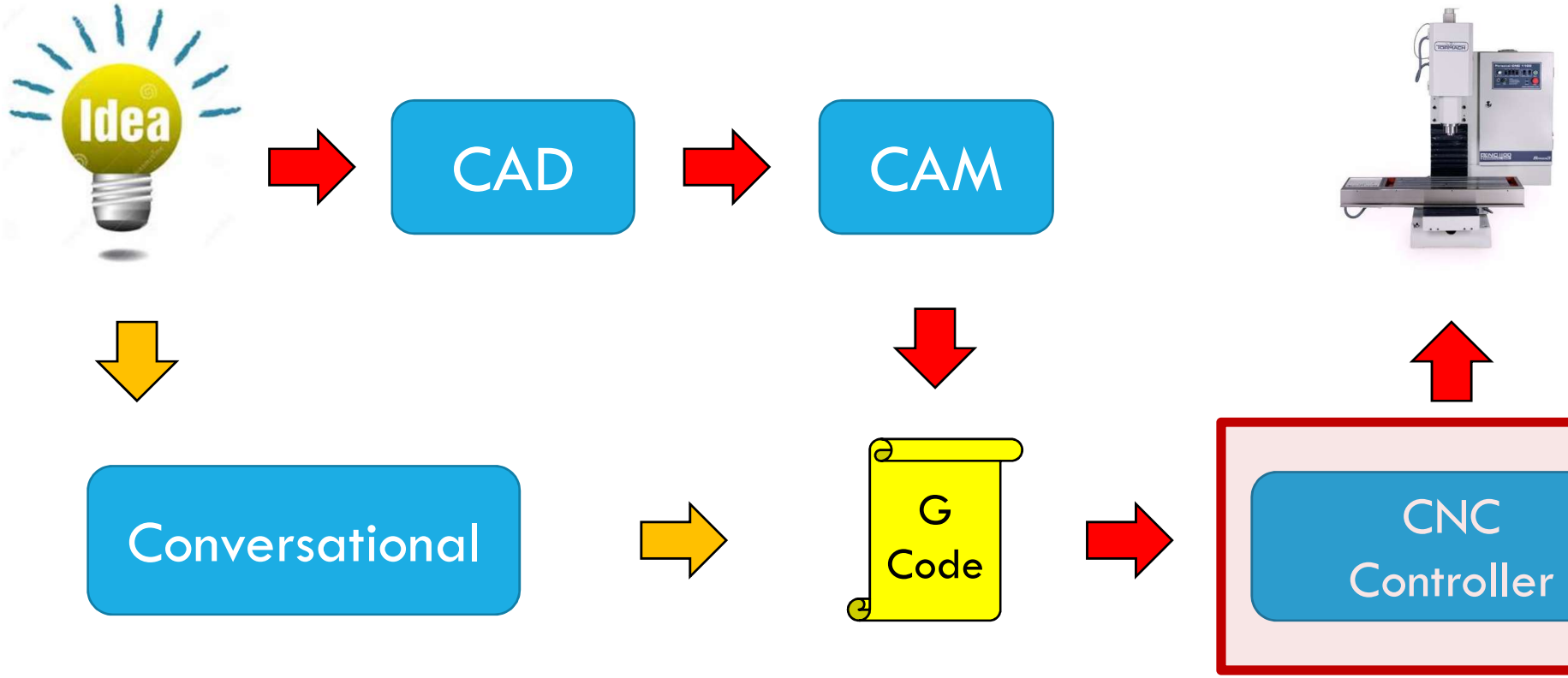
- G – preparatory commands, such as move X or Y
- M – miscellaneous functions, such as turn on spindle
- F – set feed rate
- S – set speed

SIMPLE G-CODE EXAMPLE

```
O0000 (Z MOUNTING PLATE)
(MATERIAL  - ALUMINUM INCH - 2024)
(PROGRAM   - Z MOUNTING PLATE.NC)
(DATE      - JAN-02-16)
(TIME      - 08:27)
(NWDTOOL N" NO. 21 DRILL" T74 D.159 F2. L3. A118. CD2. CL1. SD2. C0)
(NWDSTOCK X0. Y0. Z0. OTC OX0. OY0. OZ0.)
G00 G17 G20 G40 G49 G64 G80 G90
T74 M06 ( NO. 21 DRILL)
(MAX - Z.1)
(MIN - Z-.35)
G00 Z.1 M08
G00 X3.0625 Y3.0625 S1681 M03
G99 G83 Z-.35 R.1 Q.1 F1.25
Y.3125
X.3125
Y3.0625
G80 M09
M05
G90
M30
%
```



CNC PROCESS



CNC CONTROLLER

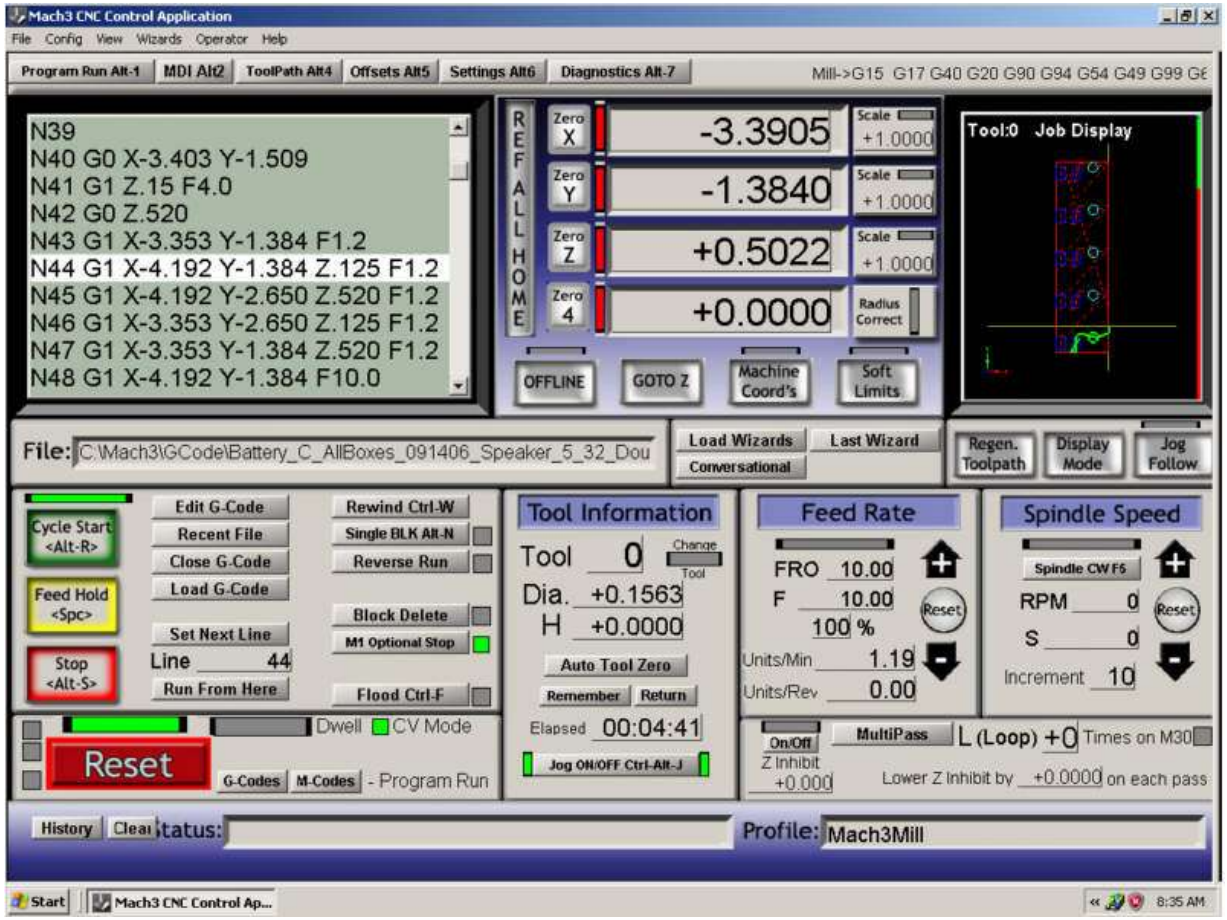
Converts G-Code into electronic pulses to drive machinery

Example software

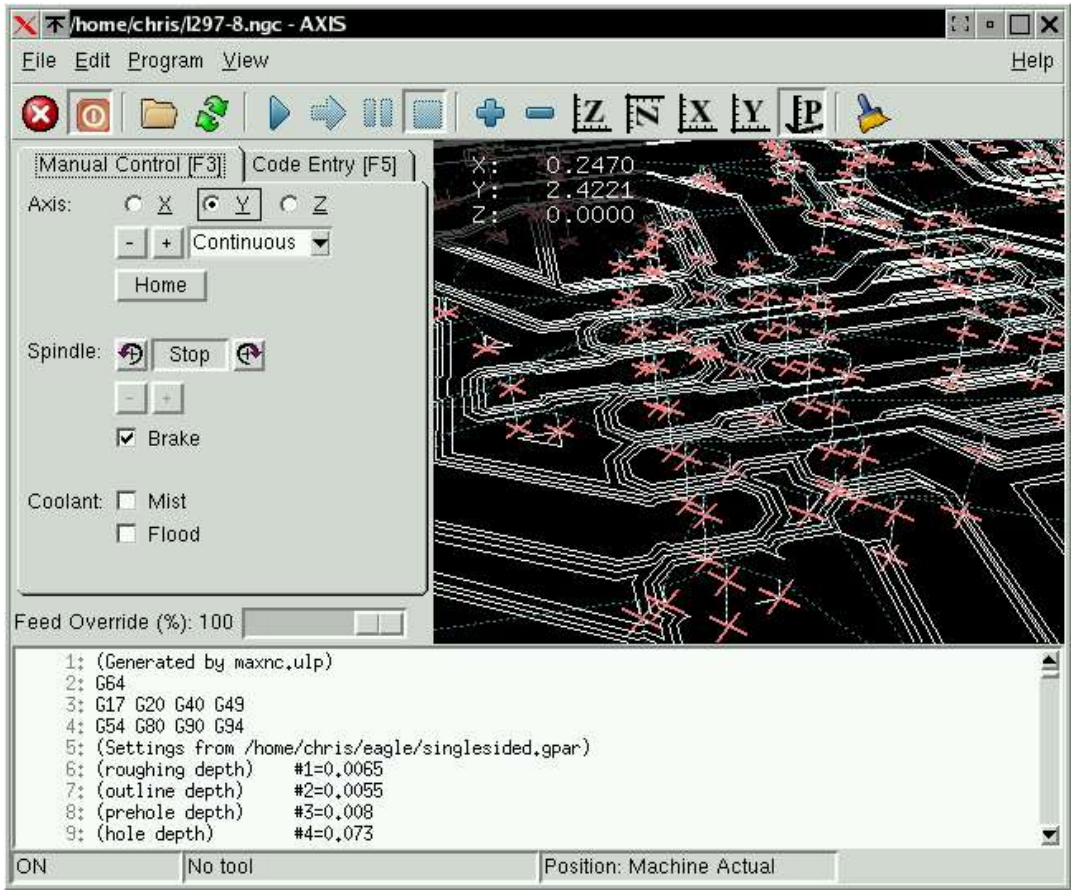
- LinuxCNC – FREE!
- Mach3 - $175
- Centroid - $5,000+, including hardware
- Proprietary (Fanuc, Hass, Bridgeport, etc)

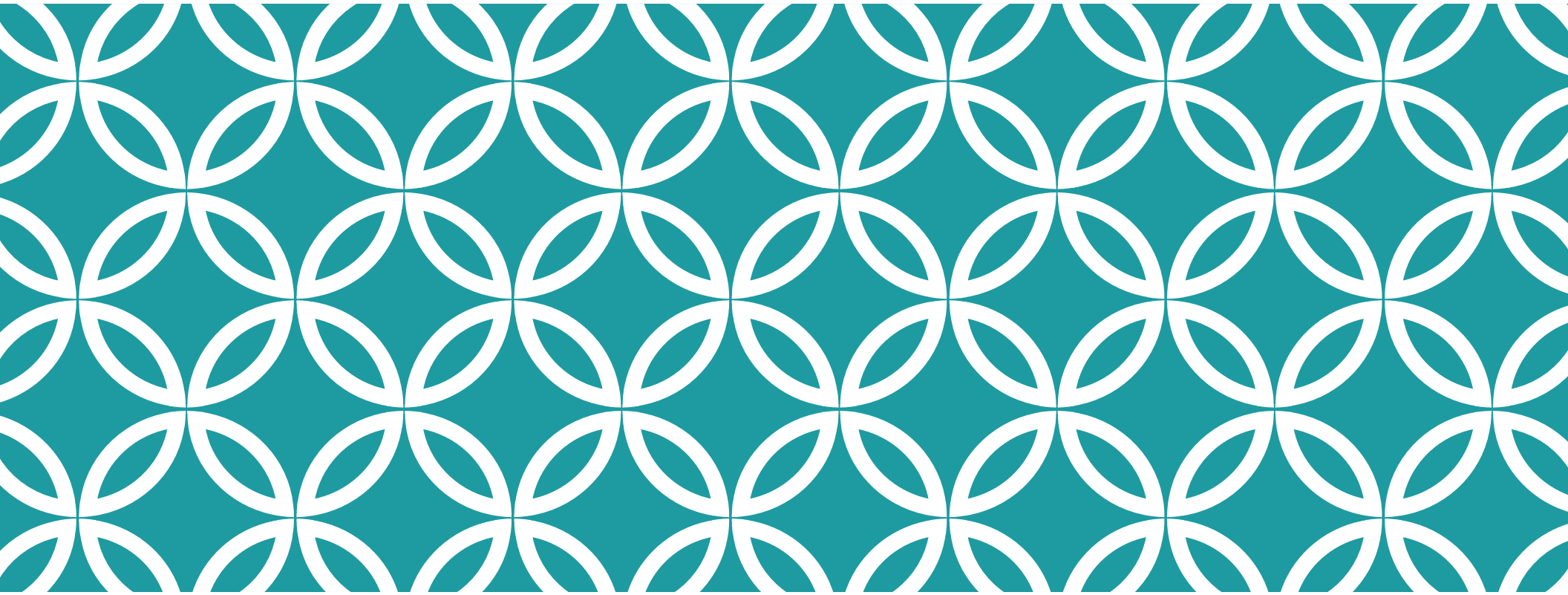
For hobbyist systems, includes ability to customize for your particular machinery

MACH3


Mach3 CNC Control Application
File Config View Wizards Operator Help
Program Run Alt-1 MDI Alt2 ToolPath Alt4 Offsets Alt5 Settings Alt6 Diagnostics Alt-7
Mill->G15 G17 G40 G20 G90 G94 G54 G49 G99 GE
N39
N40 G0 X-3.403 Y-1.509
N41 G1 Z.15 F4.0
N42 G0 Z.520
N43 G1 X-3.353 Y-1.384 F1.2
N44 G1 X-4.192 Y-1.384 Z.125 F1.2
N45 G1 X-4.192 Y-2.650 Z.520 F1.2
N46 G1 X-3.353 Y-2.650 Z.125 F1.2
N47 G1 X-3.353 Y-1.384 Z.520 F1.2
N48 G1 X-4.192 Y-1.384 F10.0
REFALLHOME
Zero X -3.3905 Scale +1.0000
Zero Y -1.3840 Scale +1.0000
Zero Z +0.5022 Scale +1.0000
Zero 4 +0.0000 Radius Correct
OFFLINE GOTO Z Machine Coord's Soft Limits
Tool:0 Job Display
File: C:\Mach3\GCode\Battery_C_AllBoxes_091406_Speaker_5_32_Dou
Load Wizards Last Wizard Conversational
Regen. Toolpath Display Mode Jog Follow
Cycle Start <Alt-R>
Feed Hold <Spc>
Stop <Alt-S>
Edit G-Code Recent File Close G-Code Load G-Code
Set Next Line Line 44 Run From Here
Rewind Ctrl-W Single BLK Alt-N Reverse Run
Block Delete M1 Optional Stop Flood Ctrl-F
Tool Information
Tool 0 Change Tool
Dia. +0.1563
H +0.0000
Auto Tool Zero Remember Return
Elapsed 00:04:41
Jog ON/OFF Ctrl-Alt-J
Feed Rate
FRO 10.00
F 10.00
100 %
Units/Min 1.19
Units/Rev 0.00
Spindle Speed
Spindle CW F5
RPM 0
S 0
Increment 10
Dwell CV Mode
Reset
G-Codes M-Codes - Program Run
On/Off Z Inhibit +0.000
MultiPass L (Loop) +0 Times on M30
Lower Z Inhibit by +0.0000 on each pass
History Clear Status:
Profile: Mach3Mill
Start Mach3 CNC Control Ap... 8:35 AM

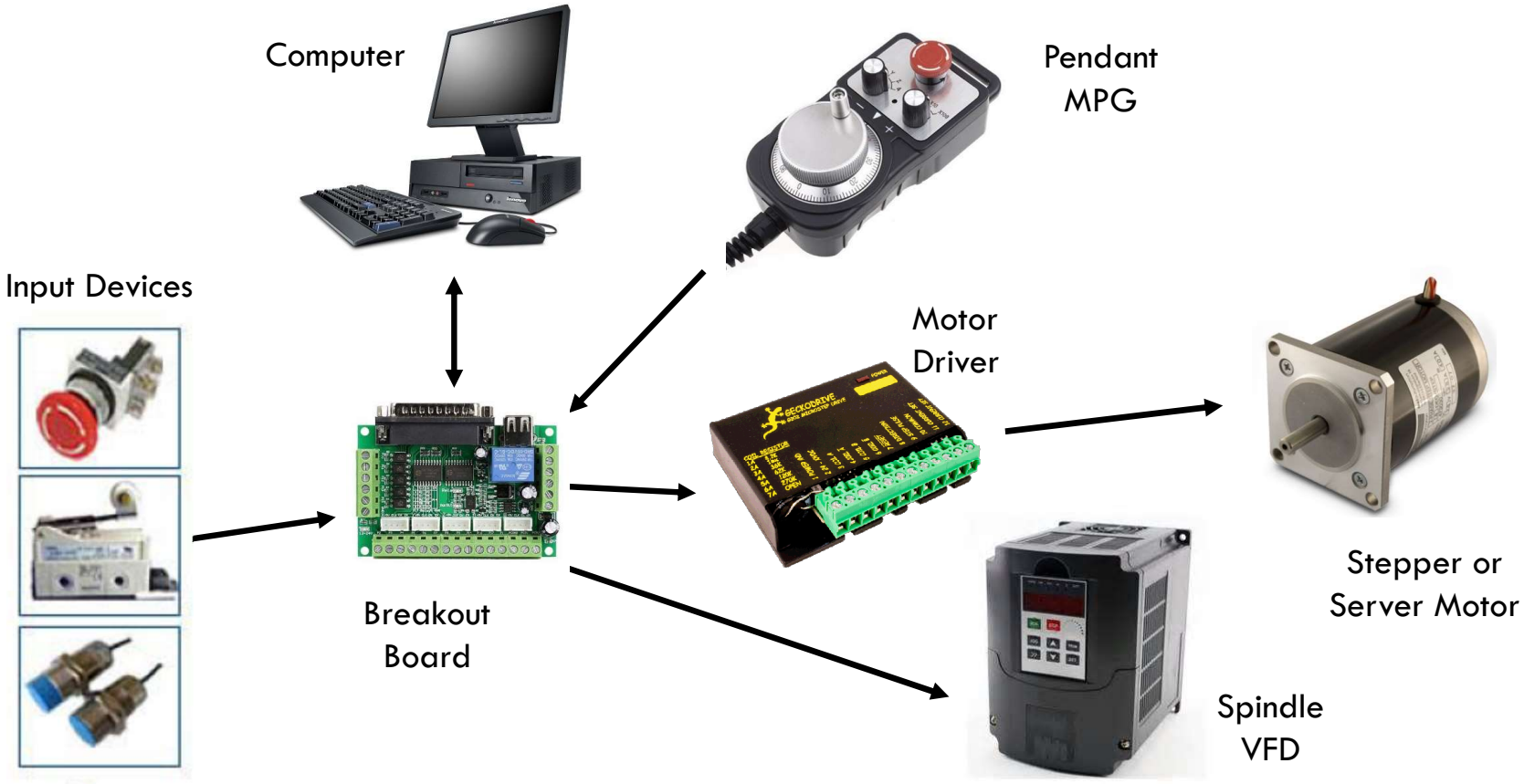
LINUXCNC


/home/chris/l297-8.ngc - AXIS
File Edit Program View Help
Manual Control [F3]
Code Entry [F5]
Axis: X Y Z
Continuous
Home
Spindle: Stop
Brake
Coolant: Mist Flood
Feed Override (%): 100
X: 0.2470
Y: 2.4221
Z: 0.0000
1: (Generated by maxnc.ulp)
2: G64
3: G17 G20 G40 G49
4: G54 G80 G90 G94
5: (Settings from /home/chris/eagle/singlesided.gpar)
6: (roughing depth) #1=0.0065
7: (outline depth) #2=0.0055
8: (prehole depth) #3=0.008
9: (hole depth) #4=0.073
ON
No tool
Position: Machine Actual

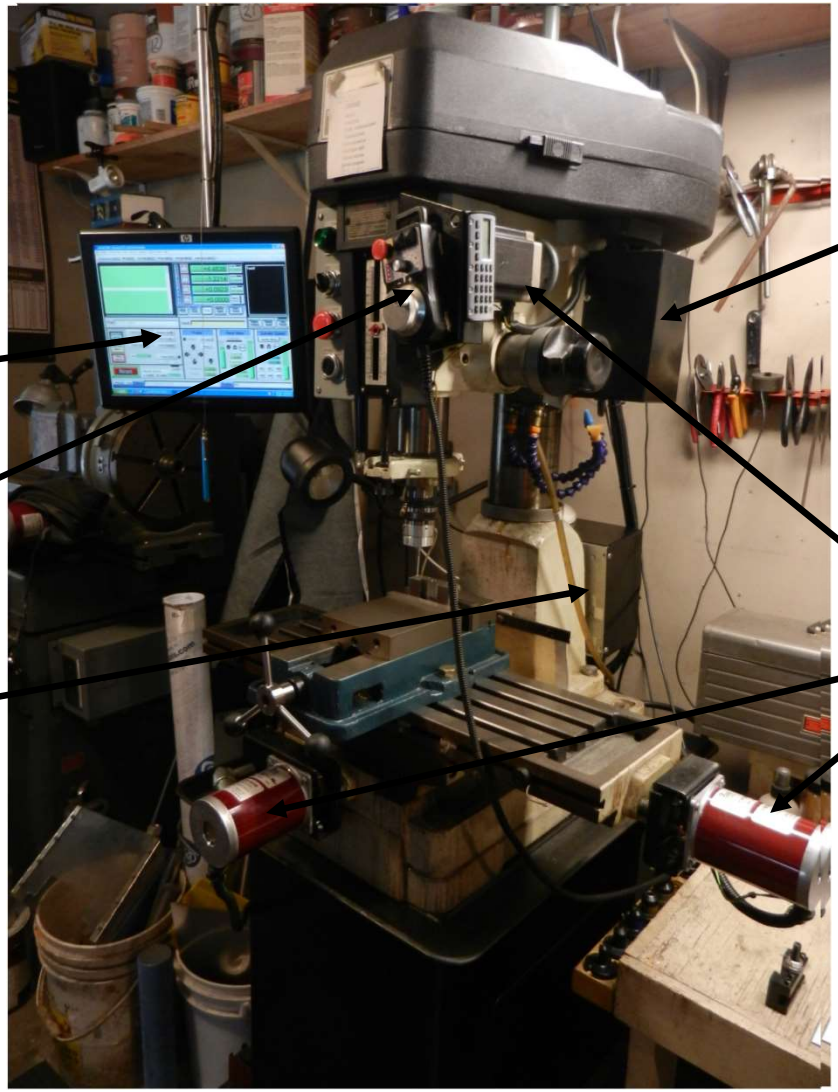


HARDWARE

CNC CONTROL SYSTEM



CNC MILL


VFD
(in enclosure)
Computer
Display
Pendant
MPG
CNC
Electronics
Stepper Motors

CNC ELECTRONICS

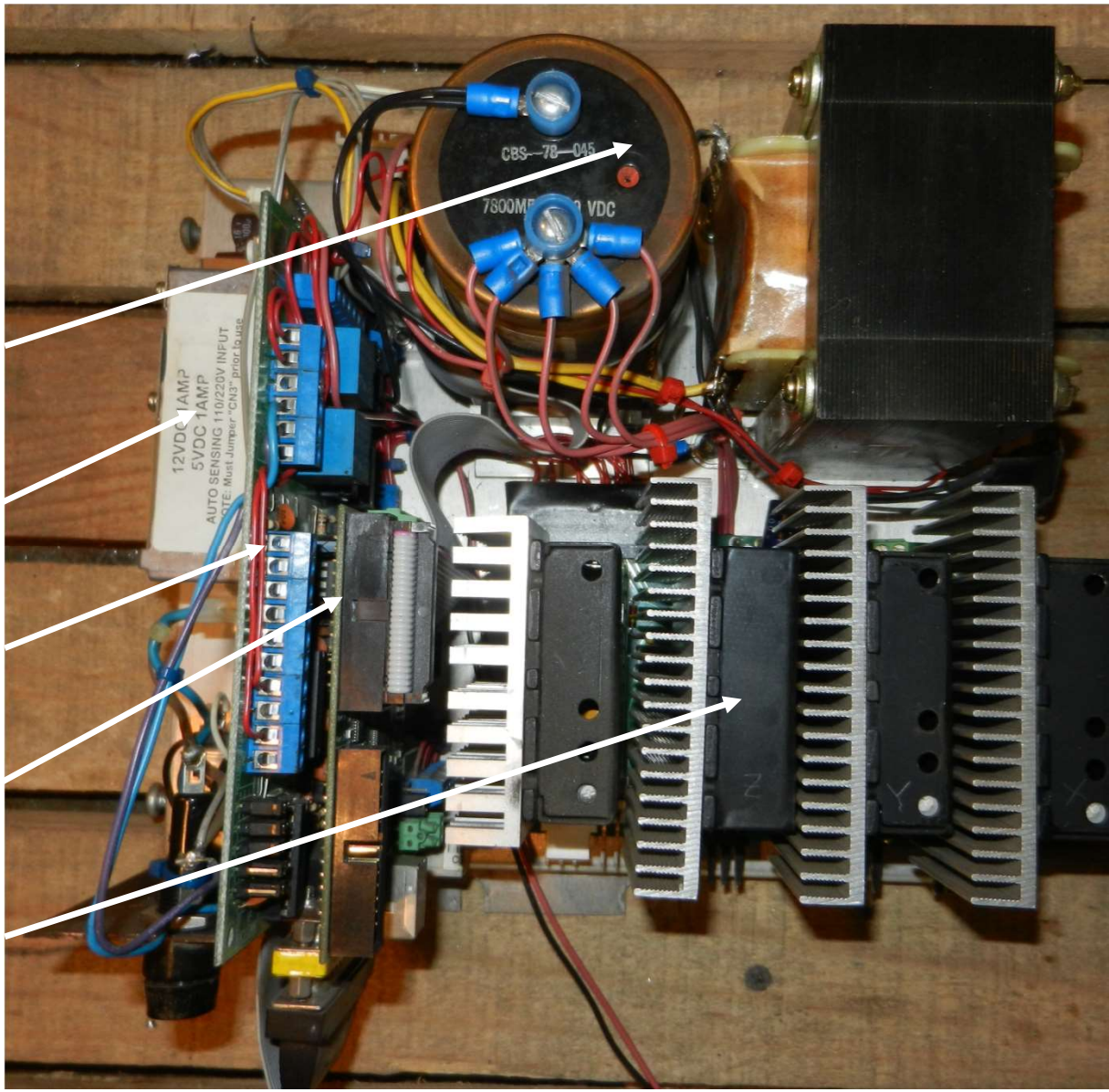
70VDC
Power Supply

12/5VDC
Power Supply

Break Out
Board

Smooth
Stepper

Motor
Drivers



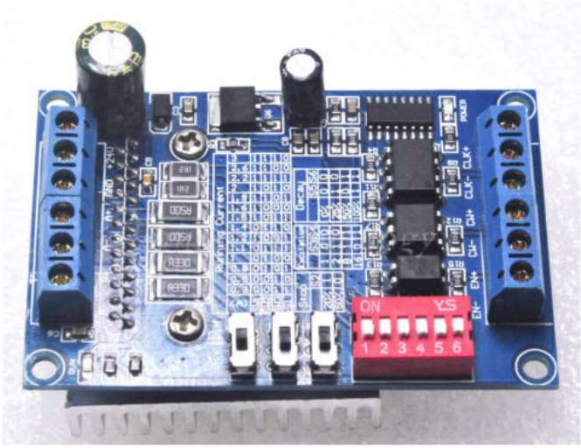
MOTOR DRIVER

Input is step signal and direction signal at 5V level

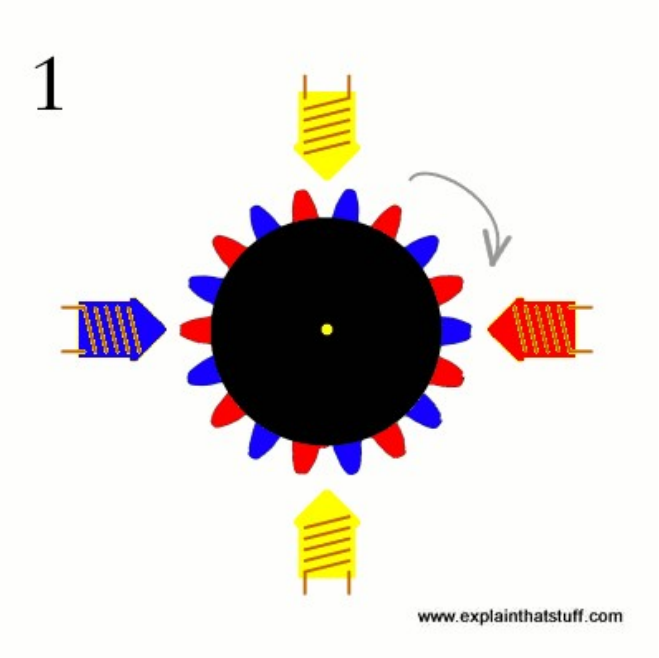
Output is stepper motor drive signals at 50-80VDC (typically)

May include ability to do micro-steps

I've used Gecko, Pacific Scientific and Chinese



STEPPER MOTOR



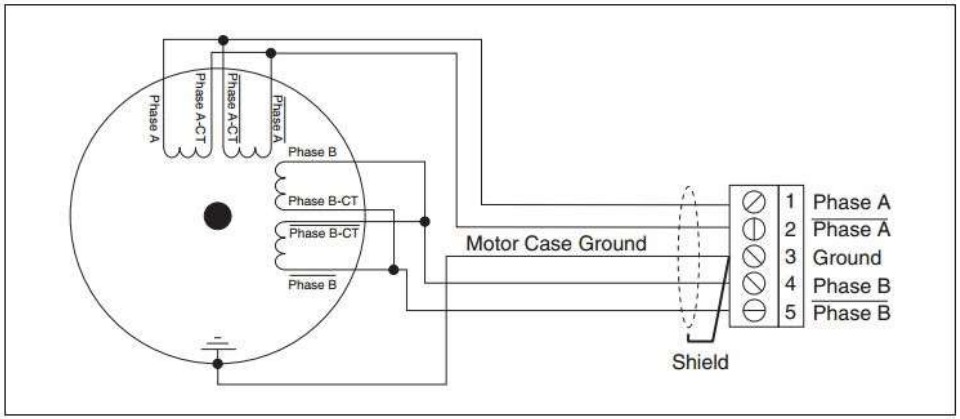
Typically 200 steps per revolution, or 1.8° per step

Specified in oz-in of torque / frame size

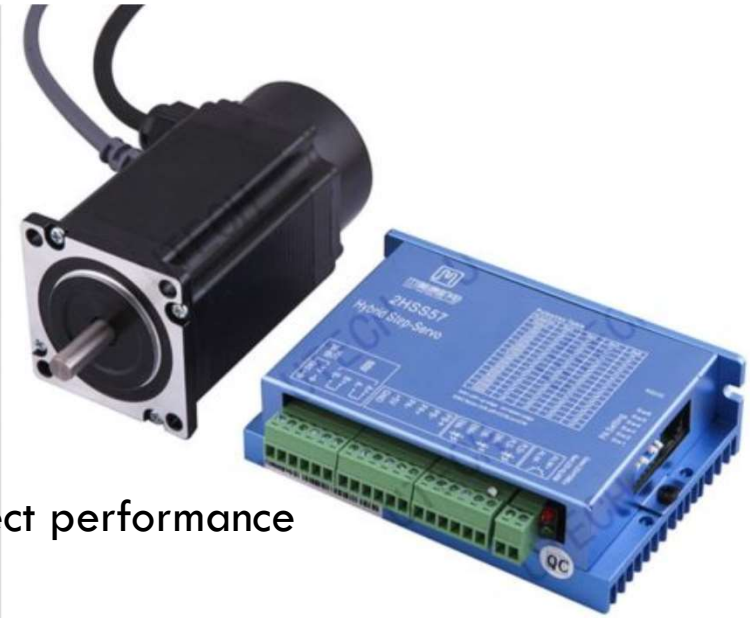
- Torque drops off as speed increases
- More ipm speed and greater table+stock mass require larger motor
- I used NEMA 34 w/975 oz-in for mill

Motor locked when not active

Typically drive a ball screw or Acme screw



SERVO MOTOR



More expensive alternate to stepper motors

Uses feedback (“closed loop”) from rotary encoder to correct performance

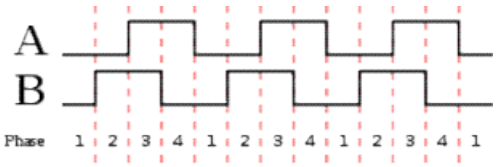
- Typically quadrature encoding
- Encoder may provide index pulse – once per revolution

Unlike stepper motors, can self-correct on error or stall

Requires different motor controller

Supported by LinuxCNC

Indirect support by Mach3



BREAKOUT BOARD

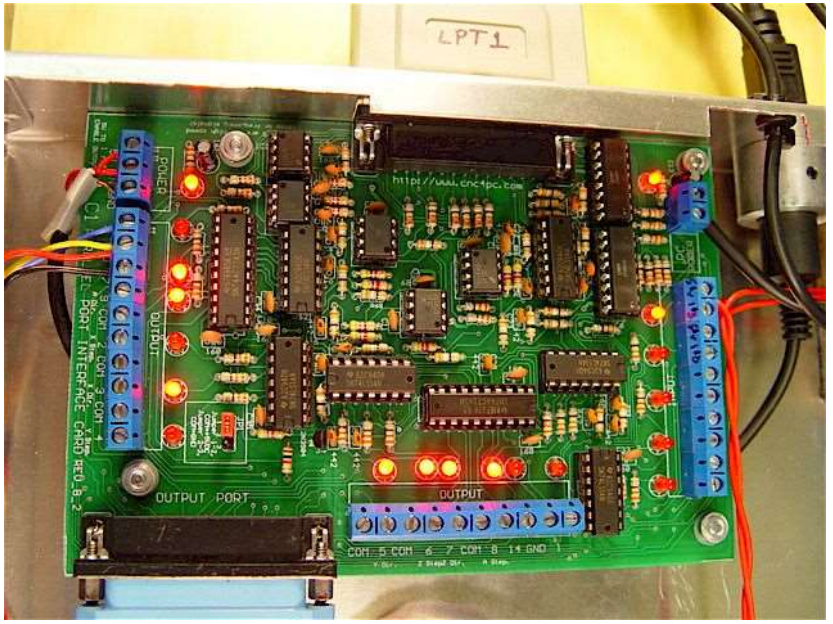
Takes signals from computer and breaks them out to individual terminals

Usually include

- I/O w/Opto-isolation
- Relays
- VFD control (0-10V)

Interfaces

- Parallel
  - most popular / widest support
- USB
  - Not much hardware available
  - Timing issues
- Ethernet
  - Growing support



A LITTLE MATH

Step frequency calculation example

Stepper motor has 200 steps / revolution

Microstepper controller card provides 8 microsteps / step

Screw is 8 turns / inch (or 1/8” per turn)

We want to be able to move at 100 inches / minute

So:

Frequency = 200 * 8 * 8 * 100 / 60

Frequency = 21.3 kHz

MOTION CONTROL

Offloads stepper signal generation from computer / Mach3

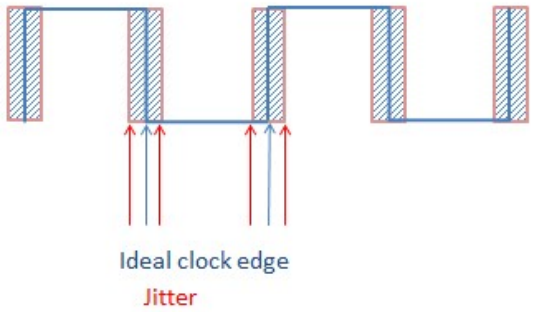
Increases maximum step signal generation frequency

Reduces jitter

Increases maximum movement speed

May offer alternate to parallel interface

- I used Smooth Stepper with USB interface



PENDANT

Allows control of CNC machine

Includes MPG (Manual Pulse Generator)

Very useful for “Manual” Milling

I use VistaCNC.com pendants

VFD – VARIABLE FREQUENCY DRIVE

Makes motor speed variable

Great for changing single phase 220VAC to 3 phase

Frequency typically 20Hz to 120Hz

- Very low or high frequencies can cause motor overheating

For 1750 rpm motor => 580 to 3500 rpm

Typically driven with 0-10VDC signal

Includes many control and monitoring options

- Ramp-up and ramp-down timing
- Currents, voltage

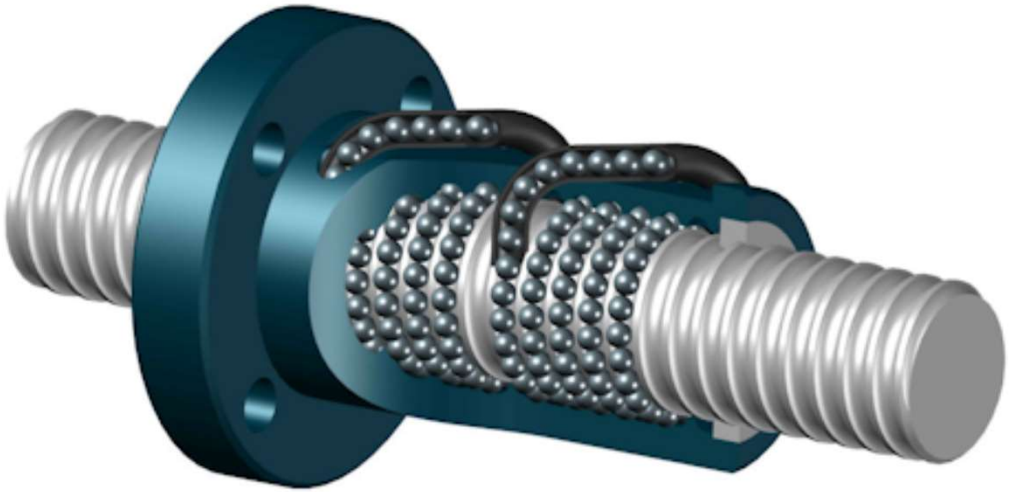
MACHINE HARDWARE MODIFICATIONS

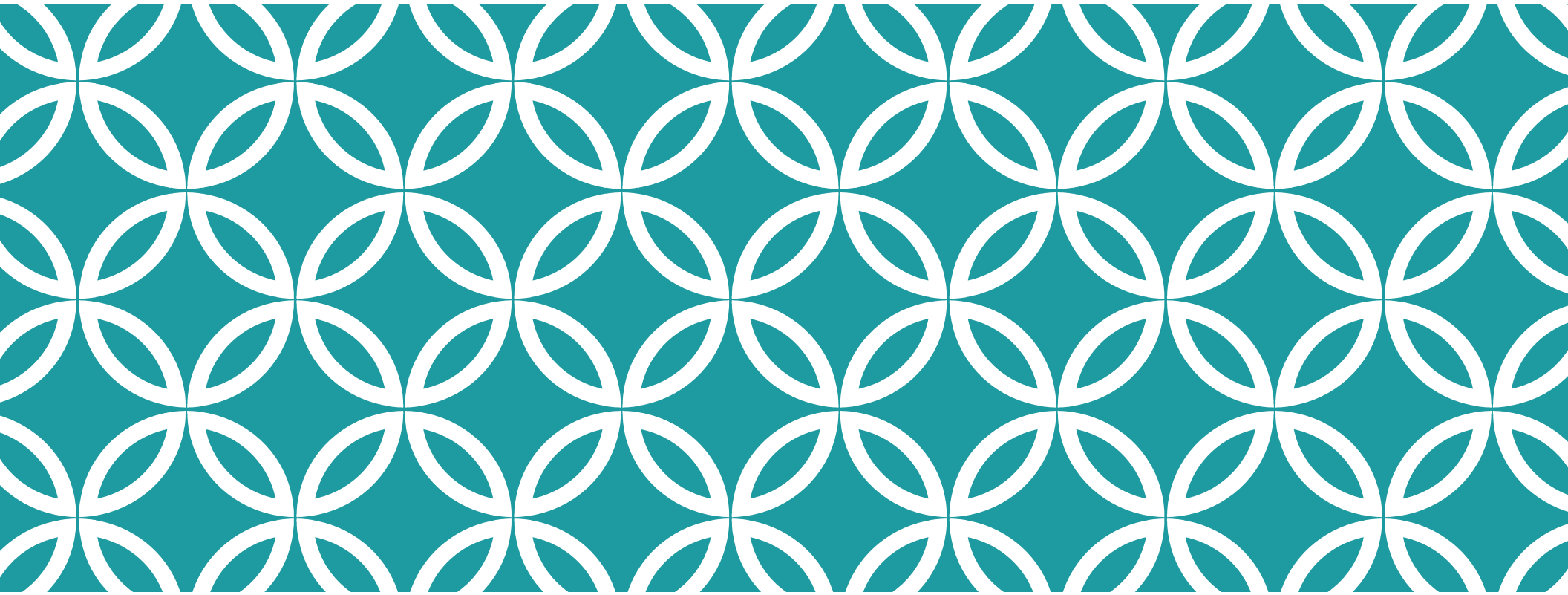
Typical additions / replacements

- Ball screws
- Limit Switches
  - Home, Max/Min
- Brackets, pulleys, etc. for stepper motors

Optional

- VFD
- Flood / mist system
- Rotary encoder
  - Spindle, X-Y-Z servos
- Probe / digitizer





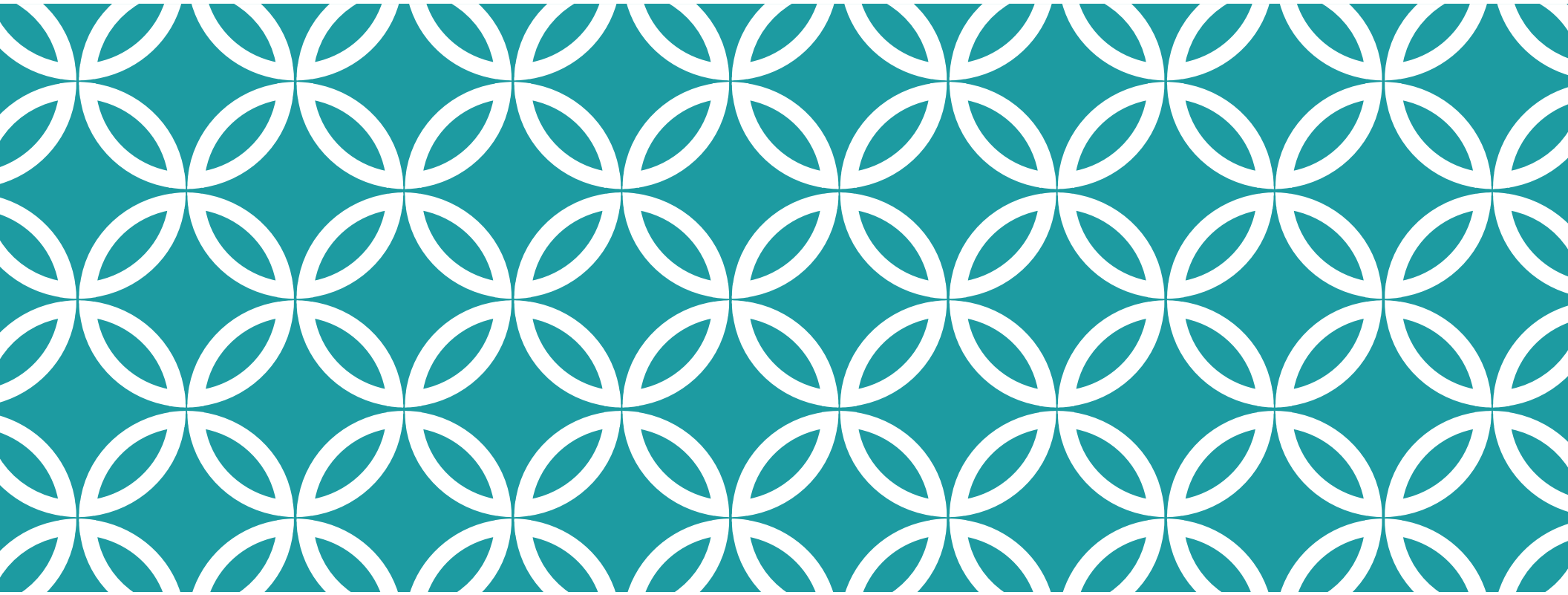
COST

SYSTEM COSTS

Sample costs.
"Your mileage may vary!"

	Low	Med	Hi
Computer	-	400	1000
Monitor	-	200	300
Stepper Motor	180	450	-
Servo Motor	-	-	kit
Encoder	-	-	kit
Home/Limit Switches	-	70	present
Ball Screws	-	650	present
Breakout Board	10	100	kit
Stepper Drivers	120	375	kit
Power Supply 60VDC	75	200	kit
Power Supply 5/12VDC	15	15	kit
Enclosure	-	50	present
Software	-	175	kit
Pendant	-	175	kit
VFD	-	140	present
Centroid kit			7150
TOTAL	400	3000	8450

Based on 3-axis 2-3HP mill conversion
Hi system based on Centroid / Bridgeport



QUESTIONS?