

Converting an existing Bridgeport CNC to modern control with Mach4

This document will cover the construction and initial setup of all control components needed to retrofit an existing CNC knee mill with a modern controller setup utilizing mach4 software. The machine used for this conversion had existing Glentek 180VDC servo motors which were retained.

Components and descriptions:

- CNC software:

Mach4, in this case, is the interface that the operator will use to control the system. This includes setting work and tool offsets, jogging the system manually, entering code via MDI, and uploading programs from your CAM software.

- Computer:

A desktop computer and monitor (or laptop) are required to operate Mach4 and effectively the entire system. The minimal requirements for a computer for this purpose can be found at the following link: <http://www.machsupport.com/software/mach4/>

- Motion Controller:

The motion controller is the initial interface between the Mach4 software and the rest of the system. The purpose is to translate inputs from the user to actual motion in the machine. For this project the Ethernet Smoothstepper (ESS) made by Warp9 was used. The ESS motion controller was chosen due to its ethernet functionality, the board connects to the computer via 1 ethernet connection. Ethernet cables are also a much more stable platform to transmit data as opposed to a USB format. Ethernet functionality was a driving factor in deciding on multiple components used on this project.

- Breakout Board:

The Breakout board is used to manage information utilized by the ESS board. While the breakout board is not entirely necessary it allows for drastically increased functionality within the system, which helps close the gap between a hobby machine and a commercial CNC knee mill. The breakout board also allows for quick and easy system changes, allows for many additional safety features, and reduces total system wiring. For this project the C62 breakout board produced by CNC4PC.com was used. This board was chosen for a multitude of reason including: it was designed specifically to work with the ESS board, it utilizes Ethernet connections anywhere possible, it has almost limitless I/O's, it supports direct connection with a control pendant, and it allows connectivity with a VFD (variable frequency driver) to give the system control of the spindle. This board is available at CNC4PC.com

- Motor Drivers:

The motor drivers get a low power signal from the breakout board and use an external power source to translate the low power signal into a high power input to the motors. The motor driver also receives data directly from the encoders to enable accurate movement. For this project the CNCDrives DG4S-16035 was used. The CNCdrives units offer fantastic performance, ease of install, utilize ethernet connections, and have great support as well as an easy to understand manual. These boards are sourced easiest from CNC4PC.com. NOTE: For motors that use less voltage (<80VDC) the DG4S-08020 can be used, all further directions apply to either driver.

- Encoders:

The encoders output positional information to the driver cards and back to Mach4. The encoders can be linear (like DRO glass scales) or rotary style, which measure shaft rotation in the motor. For this build the Rotary style encoders will be used. The AMT102V encoder was chosen due to its ease of install and size of knowledge base from other users. These encoders are also very cost effective and available at CNC4PC.com complete with a line driver board included which allows these to be adapter to an Ethernet connection easily.

- Ancillary Components:

Multiple smaller components were utilized in this build and will be described as they arise.

Full Build List:

PART	QUANTITY	PURCHASE URL	DOCUMENTATION
Motor Driver DG4S-16035	3	https://cnc4pc.com/motion-control/dc-servo-motor-control/servo-driver/dg4s-16035-dc-servo-drive.html	http://cnctrive.com/downloads/DG4S_series_manual.pdf
ESS Motion-control	1	https://cnc4pc.com/motion-control/motion-controllers/smooth-stepper/ethernet-smooth-stepper-board1.html	http://warp9td.com/index.php/documentation/doc-ess
C62 Dual Function Breakout Board	1	https://cnc4pc.com/motion-control/breakout-boards/c62-dual-port-multifunction-board.html	https://cnc4pc.com/motion-control/breakout-boards/c62-dual-port-multifunction-board.html

Encoder AMT102-V	3	https://cnc4pc.com/motion-control/dc-servo-motor-control/encoder/capacitive-encoder-for-nema-23-and-34-motors-w-1ft-cable.html	http://cnc4pc.com/Tech_Docs/AMT10X.pdf
3 Axis Limit Switch Assembly A32	1	https://cnc4pc.com/hardware/index-home-limit/a32-mechanical-switch-assembly-to-rj45.html	http://cnc4pc.com/Tech_Docs/A32R2.JPG
Braking Circuits BRKC-180	3	https://cnc4pc.com/motion-control/dc-servo-motor-control/servo-driver/brkc-180-braking-circuit.html	http://cnctrive.com/downloads/BRKC_XXX_manual.pdf
Programming Stick PRG01	1	https://cnc4pc.com/motion-control/dc-servo-motor-control/servo-driver/prg01-usb-programming-stick.html	
DG4S connector board C34DG4S	3	https://cnc4pc.com/motion-control/breakout-boards/rj45-connector-boards/c34dg4s-connector-board-for-dg4s.html	http://cnc4pc.com/Tech_Docs/C34DG4S_USER%20MANUAL_VER1.pdf
+12VDC Power Supply MS-50-12	1	https://cnc4pc.com/12vdc-at-4-2a-switching-power-supply.html	
Relay Board C55 Dual 25 AMP	1	https://cnc4pc.com/c55-dual-25amp-relay-board.html	http://cnc4pc.com/Tech_Docs/C55_USER_MANUAL_VER.1.pdf
1 Foot CAT5E Patch Cables	5		
Mach4 License	1	https://cnc4pc.com/software-plugins/mach4-license-file-920.html	http://www.machsupport.com/software/mach4/

Construction Steps:

Encoder Install:

The rotary encoders work by mounting on the shaft of the motor. Optimally you would mount the encoders under the cover of the motor. Most servo motors are dual shaft, meaning they have the output shaft which does the work (drives the ball screws in this case) and they have a shaft out the other end which is used to capture the rotation for use with a tachometer or an encoder. In the case of this project the original Glentek motors have a rear shaft which was used with a tachometer for use with linear encoders. To change these over to rotary encoders the rear covers need to be removed and all the tachometer components can be removed as shown:

Before Tachometer Removal



After Tachometer Removal



In the case of these glentek motors a spacer was needed to mount the AMT102V encoders correctly. For this purpose an adapter was designed and 3d printed as shown:



To install the encoder refer to the directions enclosed in the encoder package.

Before installing the Encoder permanently you must decide your encoder step-count quantity. The step count is the number of steps the encoder will count per full rotation of the motor shaft. The quantity is set by the dip switches on the board, for this build it was decided to start with a step count of 1000. The dip switches as well the table showing how the switches are set for each count are shown below. For more information on the encoders refer to the manual (link included in build list at top of document).

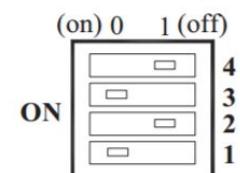


RESOLUTION SETTINGS

Resolution (PPR)	Maximum RPM	4	3	2	1
2048	7500	1	1	1	1
1000	7500	1	1	1	0
800	7500	1	1	0	1
384	7500	1	1	0	0
1024	7500	1	0	1	1
500	7500	1	0	1	0
400	7500	1	0	0	1
192	7500	1	0	0	0
512	15000	0	1	1	1
250	15000	0	1	1	0
200	15000	0	1	0	1
96	15000	0	1	0	0
256	15000	0	0	1	1
125	15000	0	0	1	0
100	15000	0	0	0	1
48	15000	0	0	0	0

DIP switch:

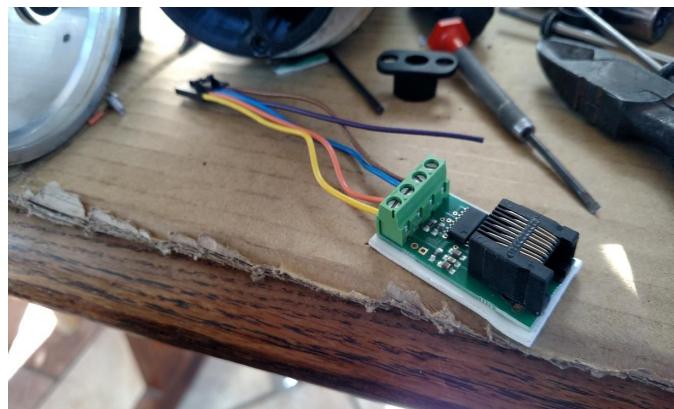
Example setting: 500



Next the Encoder Line Driver boards can be wired via the following table:

AMT102	CABLE	DG6
B	1	4
+5VDC	2	3
A	3	2
X	4	On_PBC
G	5	1

Once the line driver is wired to the encoder connector the connector can be plugged into the encoder and the motor can be sealed up as shown below. The encoder connection has now been converted to an ethernet cable, for this build a CAT5E bulkhead was installed in the motor cover to make this connection also shown below.



Repeat the process of installing the encoders on all 3 motors making sure to set the step counts on each encoder the same for easy of system tuning later on.

Controller Construction and Initial Testing:

The first step in actually assembling all the components will be mounting the drivers in your enclosure. Many different enclosure styles exist so the method of mounting can vary drastically. Shown below are the drivers mounted in the existing control box from the machine used for this build:



The three smaller boards are the BRKC-180 braking circuits. These circuits are used to absorb extra energy created by the motors during the braking process. If the braking circuits are not used the system can exceed the voltage limits of the drivers and cause damage. The next step is to carefully remove the ESS motion controller from its static-proof package, as well as the C62 board from its packaging. These boards are designed to work together and thus will connect together via the two 26 pin parallel plugs as shown below: (ESS on right, C62 on left)



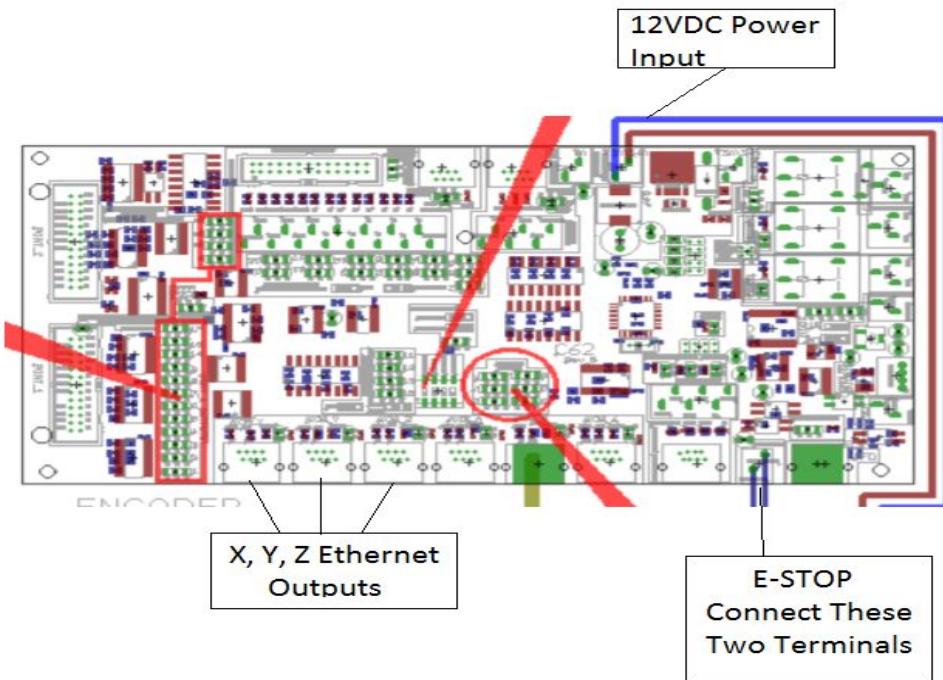
The C62 board and ESS can be installed in the enclosure at this point, however, it will be easier during the initial setup and testing to keep the system separated until after functionality is achieved. Next the C62 board can be wired to the drivers via the C34DG4S connectors shown below:



Ensure that the connector boards are plugged in correctly (male end plugged into C62 board), connect one C34DG4S connector into each of the X,Y, and Z Ethernet connectors on the C62 board (It would be wise to label the driver's X, Y, and Z at this point). Next you can connect an ethernet patch cable into each of the C34DG4S connectors and plug the other end of the patch cable into each of the motor drivers in the ethernet connection labeled “MAIN” as shown below:



Next you can connect your 12VDC power supply into the C62 board via the connections at the top of the board. And you can bypass your main E-stop input with a simple jumper wire both shown below:

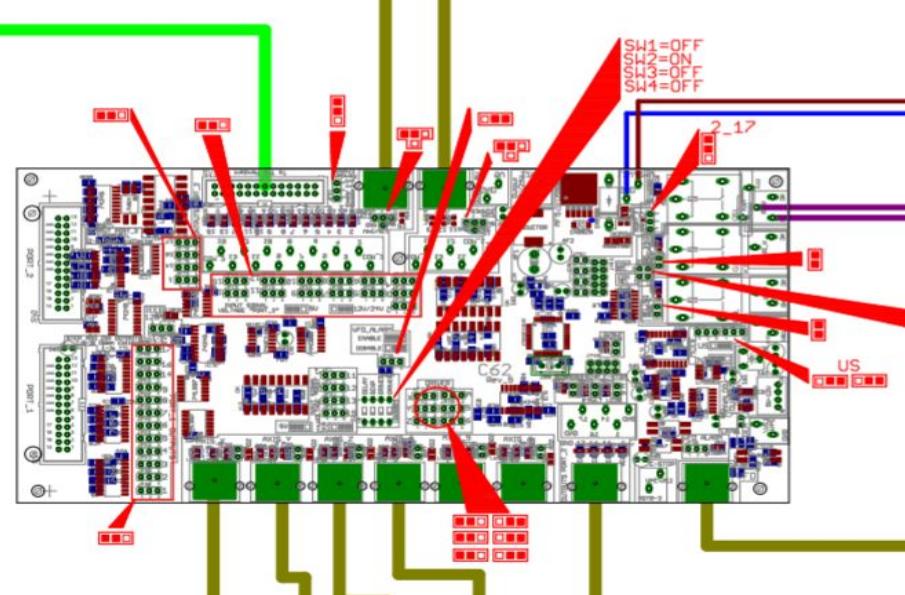


Once you have 12VDC input to the board, X, Y, Z outputs setup, and the main E-stop terminal bypassed. You can configure the dip-switches in the center of the board as follows:

1- OFF , 2- OFF, 3- OFF, 4- ON

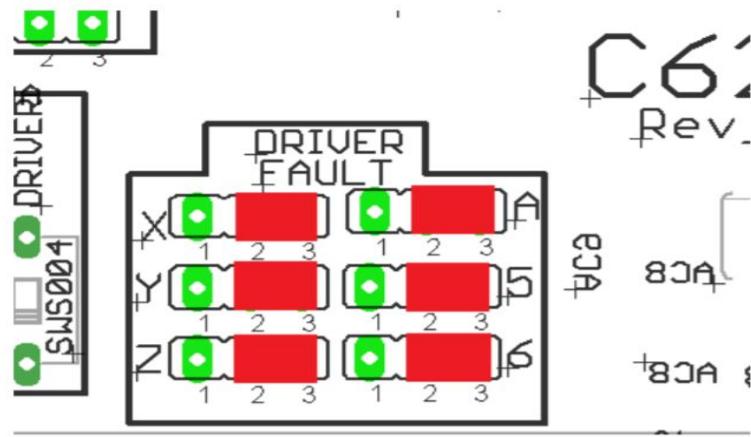
It is important that switch number 2 is off since this is a safety charge pump input, which will not be supplied until later when connectivity to the ESS and Mach4 is achieved, Switch 4 needs to be on since the drivers will send back a motor fault and switch 4 will bypass this.

Next you can start to configure the jumpers on the C62 board as shown below:



The ESS motion control board is NOT IEE1284 compliant so move that jumper to the “NO” position. Once all the jumpers are configured as shown you can turn on the 12vdc power to the board. After a moment of the delay light being on a green LED labeled “Output Status” should go on. At this point the green LED's on each of the motor drivers should start blinking. This indicates that everything is working as it should for now. If you are not getting a green light on the C62 board or you are not getting green blinking lights on your drivers check the following:

- 1) Confirm all the jumpers are configured as shown above
- 2) Move the motor fault jumpers for X, Y, Z (located just above and to the right of the Z axis ethernet connector in the figure above) to the 2-3 position as shown below:



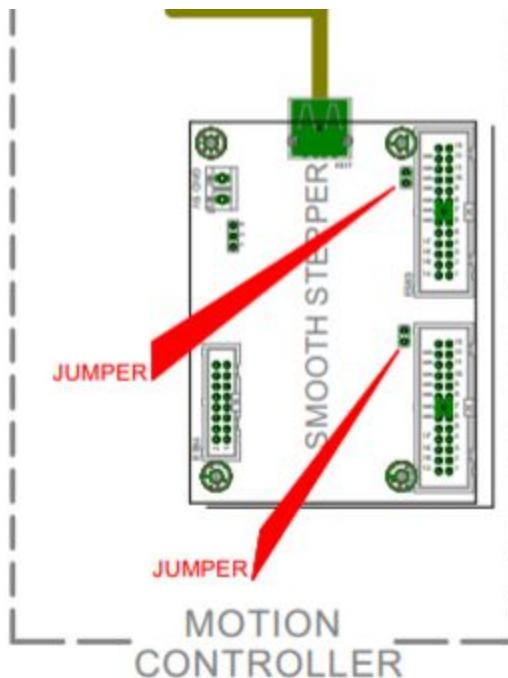
- 3) Ensure that the jumper controlling the pendant is set up on “Disable”, if the pendant is enabled then the machine will look for an E-stop input from the pendant.
- 4) Ensure that the E-stop is either installed and in the proper position or is bypassed as shown above
- 5) Ensure that the jumper for the VFD fault is properly configured to disable this feature
- 6) Ensure that the C34DG4S connectors are connected the correct way as described and shown above (male end plugged into C62 board).
- 7) If the problem persists carefully go through the board and use the jumpers to disable all extra features. The C62 board is very capable and is searching more a multitude of I/O's.

Once the green status LED is lit on the C62 board and the green LED's are blinking on each of the motor drivers you are safe to move forward to the next steps.

After you've confirmed that both the C62 and motor drivers are running with no faults you can wire the power input and output to the drivers and from the drivers to your motors as explained in the manual for the DG4S drivers (we will not cover motor power supplies here as

they vary greatly depending on rated voltage of the motors used) a link to the DG4S manual is included in the parts list table at the top of this document. Make sure not to put both positive and negative leads to a single “Arm” on the drivers on either the input side or the output side. Next you can connect your motor encoders to your driver via ethernet cables into the connector labeled “Encoder”. Make sure the X, Y, and Z axis motors are connected to the corresponding motor driver.

Finally you can setup your ESS board. The ESS board requires 5VDC power to operate, you can either supply this via an external power supply or you can get it from the C62 board directly through the existing connection. To utilize 5VDC from the C62 board simply arrange the ESS jumpers as shown below:



Initial Software Downloads:

To start you can download a demo of Mach4 which can be found at the following link:

<http://www.machsupport.com/software/downloads-updates/#tabs-2>

You will also need to download the Servoconfigurator software used to tune the drivers at the following link:

<http://cnctrain.com/Servoconfig3.html>

You will need to download the ESS plugin for mach4 as well as the system configuration utility (SCU) at the following link:

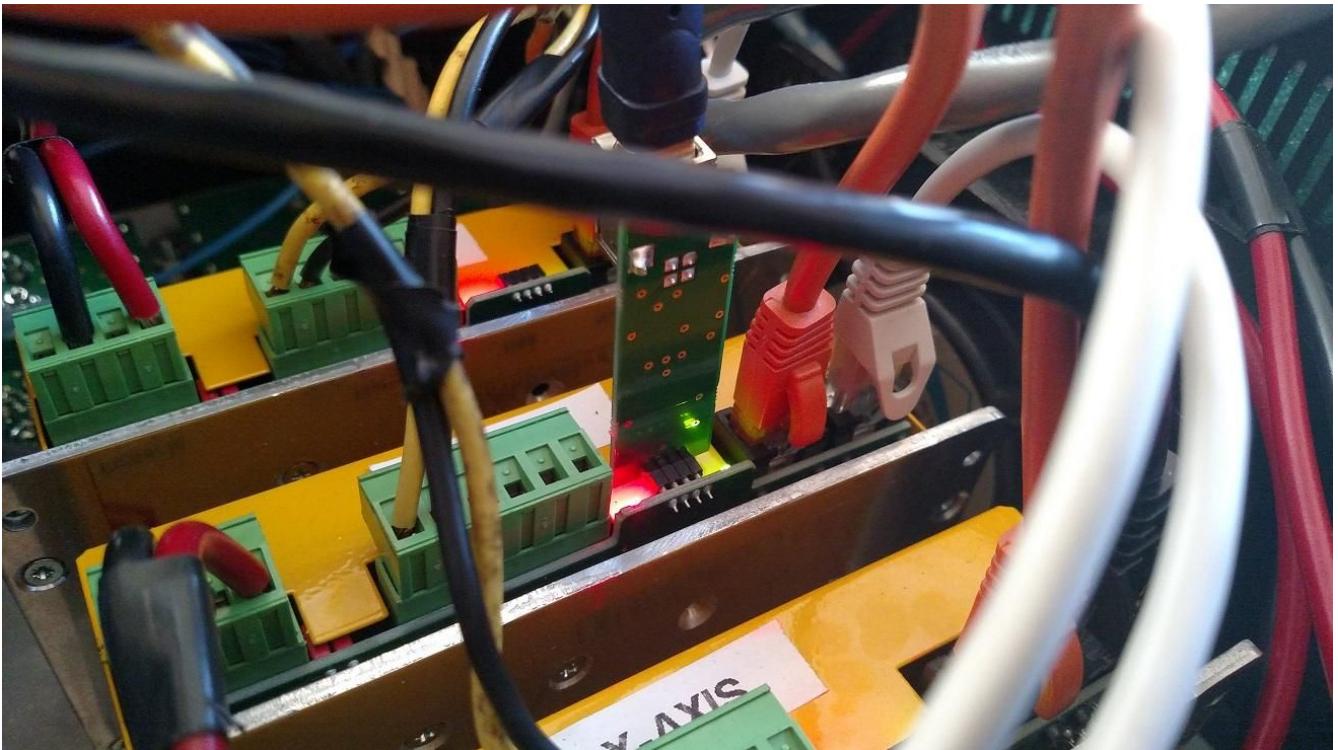
<http://warp9td.com/index.php/sw#PluginEssMachFour>

You will also need to download the Mach4 configuration installer at the following link:

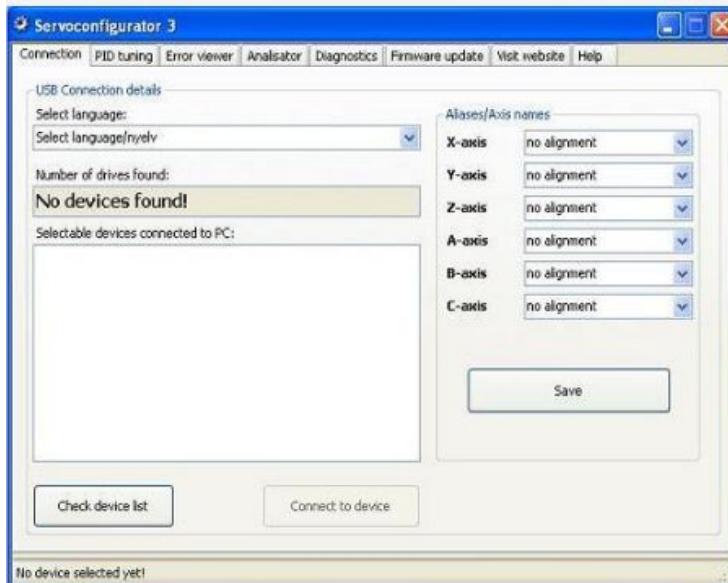
http://cnc4pc.com/Tech_Docs/M4-ESS-5XSD_V2.0.zip

Motor Tuning:

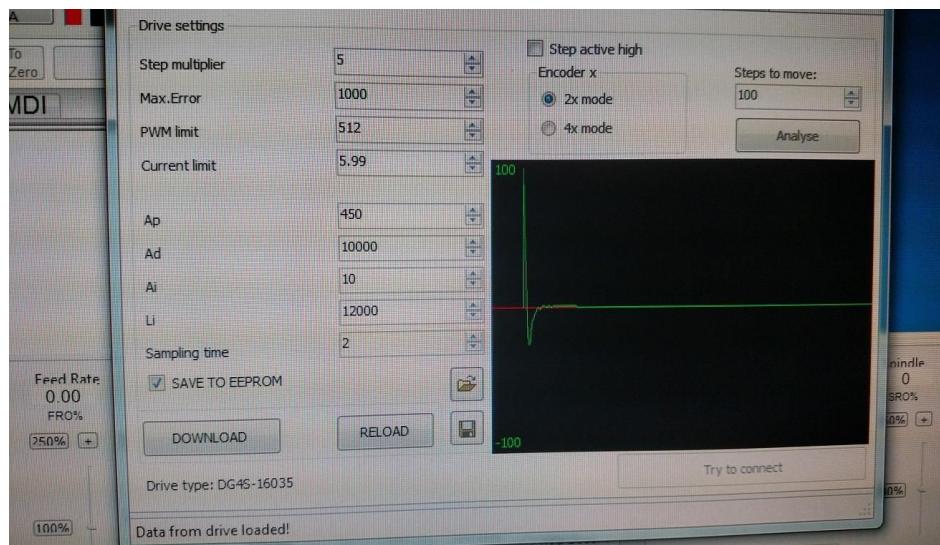
Before attempting any operation in Mach4 you must first tune your servo motors via the servoconfig software. Start by connecting the PRG01 programming stick to your computer via a USB A-B cable and allowing the computer to search for driver information (the driver should be included in the servoconfig download above). Once your computer is communicating with the Programming stick you can cut off all power to your control setup and connect the PRG01 stick to one of your motor drivers as shown below:



Once the programming stick is connected to a motor driver you can turn the power back on to your control system and confirm that the green LED on the driver which is plugged in is blinking. Open the Servoconfig software and you should see the following screen:



The serial number of the driver which the stick is plugged into should appear on this screen in the box labeled “selectable devices connected to PC:”. Select the device and press the “connect to device” button. Once the status line at the bottom of the window says that it is connected to the drive you can move to the “PID tuning” tab which consists of the following screen and variables:

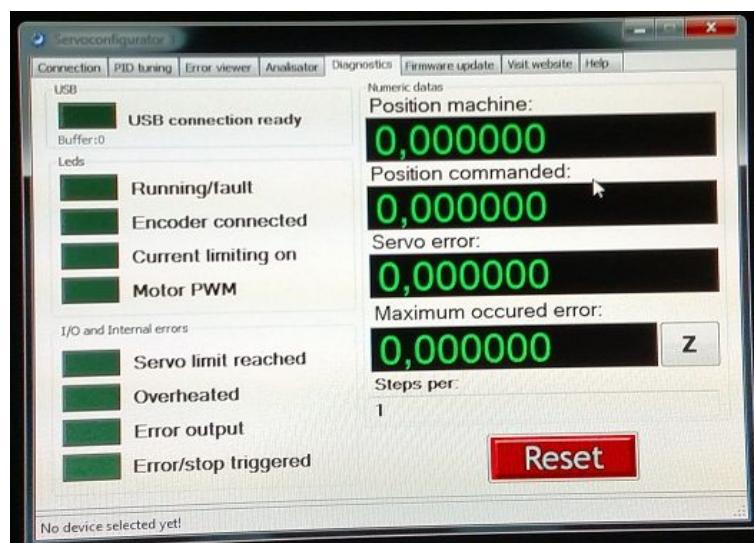


WARNING: The information entered for each variable in the above image are for the motors used in this particular project and may not work for your motors.

To begin with the PID tuning refer to the following documentation:

http://cnc4pc.com/Tech_Docs/PID_tuning_eng.pdf

PID tuning may take some time to get desired results. Care should be taken with the motors when starting out as the movement can be quite violent when the motors are far away from a proper PID tune. To check status of current tune you can click the Diagnostics tab to check motor status and calculated error as shown below. Once one motor is setup properly repeat the previous steps on each of the other drivers/motors. DO NOT PLUG IN OR UNPLUG PRG01 PROGRAMMING STICK WITH THE POWER TO THE CONTROLLER ON.



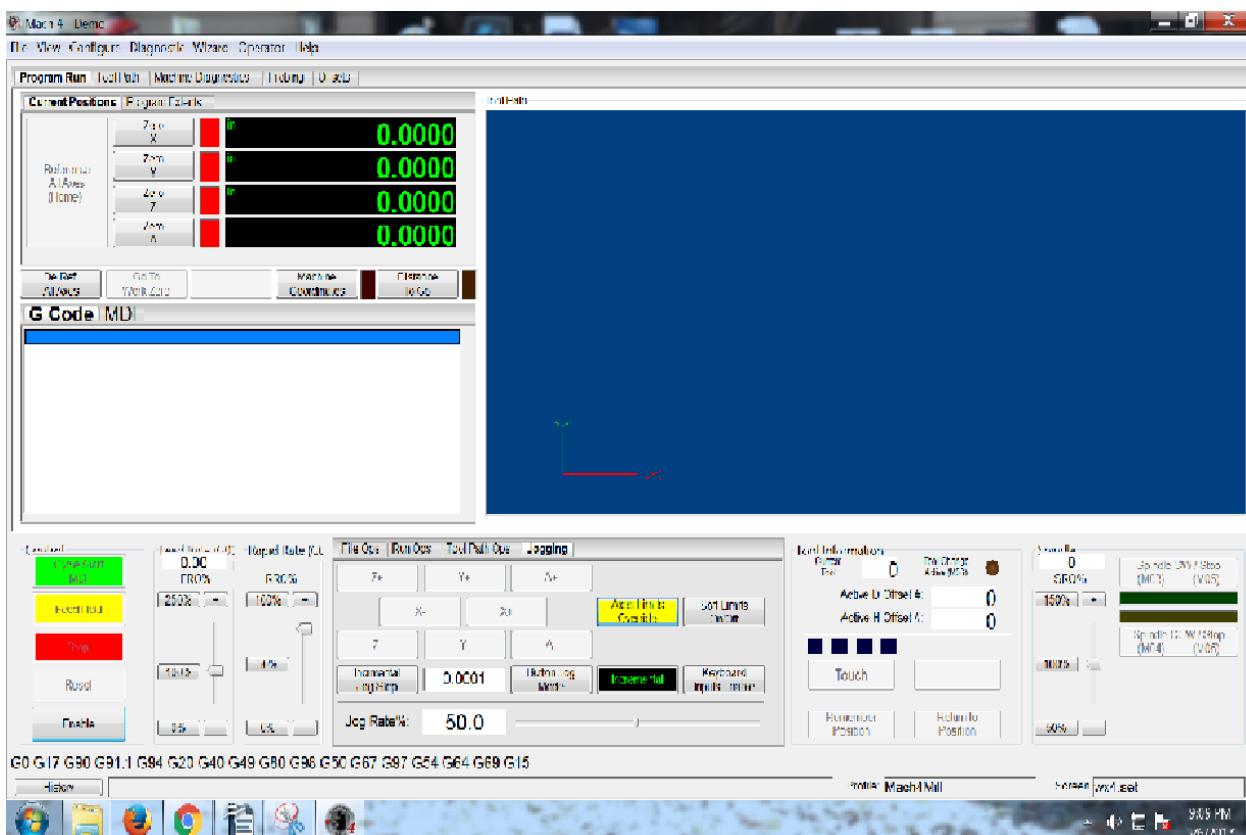
Finishing Setup and Starting with Mach4:

With the motors still sitting free on the table you can now test movement via Mach4 controls. To begin download the Mach4 demo (link above). Next download the system configuration utility as well as the installer package from CNC4PC.com. Connect the ethernet cable in your computer to the ESS board and run the system configuration utility. Follow the directions provided by the program. If you have any problems with connecting your computer with the ESS board refer to the following link:

<http://warp9td.com/index.php/sw>

At this point you can move dip switch #2 on the C62 board to the ON position and dip switch #4 to the OFF position. When you open Mach4 it should activate the C62 board and the status light should turn green, the Drivers should also have the blinking LED lights green. From this point forward the C62 board will not activate the drivers without Mach4 being open UNLESS you turn dip switch #2 back off. This is only advisable for certain troubleshooting applications.

To test the connection and overall function you can select the Jogging tab within Mach4, select the button which says “Axes Limit Override” and press the “Enable” button. This should allow each of the motors to be moved via the jogging buttons within Mach as shown below:



The next step is to setup the ‘counts per unit’ values in mach4. This can be found in the Mach4 config menu under motor setup. The value is the amount of counts (steps) the encoder will see in order for the actual machine travel to move each unit (inch, cm, mm etc). This value is based on the counts per motor rotation (your original encoder count settings on the encoder), the gear reduction between the motor and ballscrew (if any), and the pitch of your ball screws.

Next you’ll need to confirm the the actual machine travel is accurate. To accomplish this you should setup a drop indicator on a magnetic base and zero it out against the spindle in the X axis. Next you should jog the machine into the indicator in a specific increment (.01” for example) and make sure the indicator reads the same value. This is also a good time to confirm the the machine backlash (if any). You can measure backlash by zeroing out and moving into the indicator in any increment as before, but moving backward the same increment and making sure the indicator returns to zero. If you move from zero to a desired distance, and back to zero exactly by only moving the same increment backwards then you have zero backlash. You can take this a step further and measure the actual machine travel with a dial indicator to get a more accurate reading as well. I measured the machine featured in this writeup down to .0005” and found no measureable backlash in the X and Y directions and .003” backlash in the Z direction. Backlash can be compensated for within the mach4 - ESS interface, so it is important to measure it accurately so it can be accounted for.

Finally, you will need to setup your limit switches in order for Mach4 to run and Gcode. On the machine featured here I used a mechanical limit switch setup from CNC4PC.com, however, I will not include information on that as I would HIGHLY recommend the use of inductive switches instead of mechanical. Inductive switches offer a wide variety of advantages and are very similarly priced. These can be purchased at the following link:

<https://cnc4pc.com/hardware/index-home-limit/a61-inductive-switch-assembly-to-rj45.html>

These switches will also connect directly to the C62 board using an RJ45 connection.

Setting up and running the machine past this point is specific to each machine and will be a constant learning process, this write-up should provide the means to get to a point where your machine will accept input Gcode and will run enough to allow the user to learn the system and complete setup to his/her liking.

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