Created By Chris Humphris

PWM Spindle Control using Mach3

Introduction

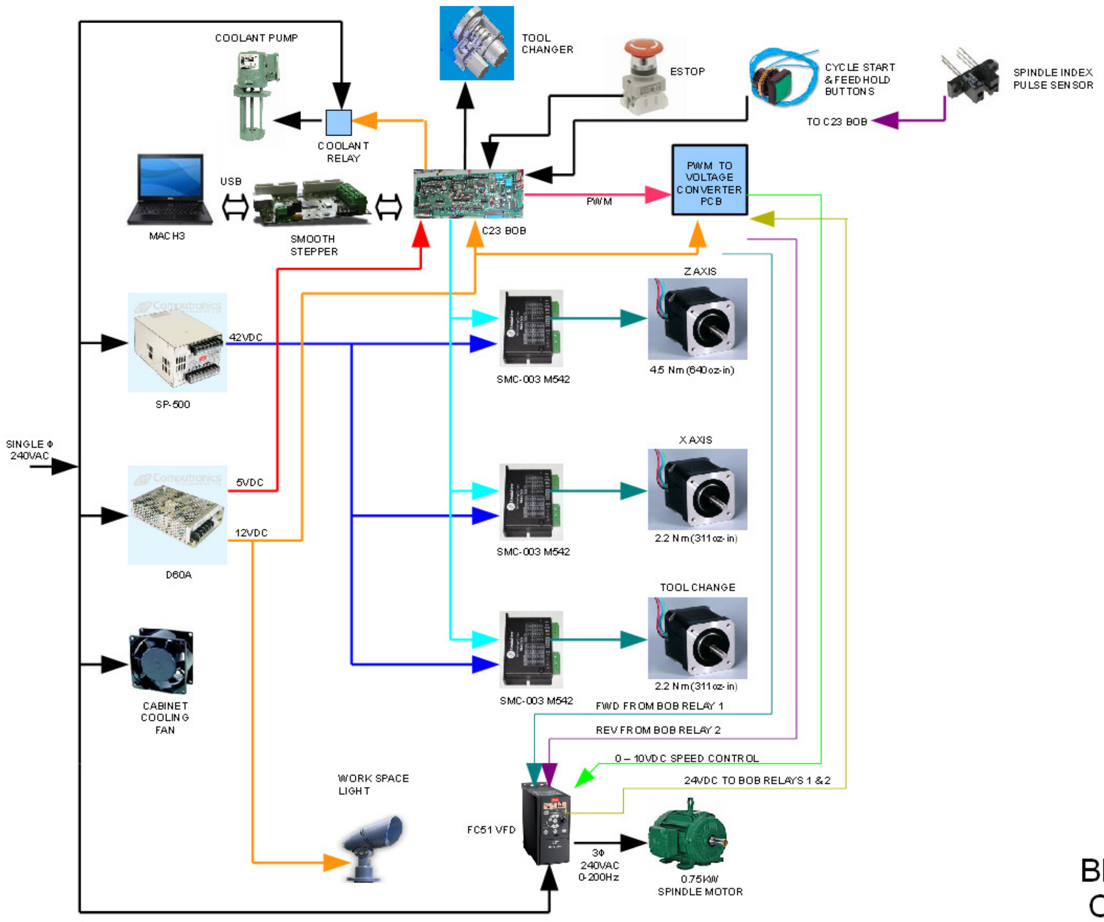
This document outlines my method of controlling spindle speed on various machines. I wanted to pass on to others the experience I gained when I designed and manufactured my cnc lathe. Hopefully this dissertation will make it easier for others.

Consideration of Pulse Width Modulation (PWM) control only is covered. It does not cover Step and Direction or simple Relay control of spindle motors. It also assumes that a Variable Frequency Drive (VFD) is going to be used to control a synchronous 3 phase AC Motor for the spindle motor. The settings for the VFD refer to a Danfoss FC51 VLT Micro Drive. I have no experience with other brands or models although I suspect that the operation of most VFDs is roughly the same.

The spindle on my cnc lathe is controlled using the following components:

- An old Dell Inspiron 8600 Laptop with a Centrino 1.6GHz Processor and 1GB RAM (with no parallel port) and always the latest Version of Mach3
- USB Control via a Warp9 Smoothstepper with Plugin Version 0.015meg controlled by Mach3
- Cnc4pc C23 Breakout Board directly connected to the Smoothstepper
- Danfoss FC51 VLT Micro Drive VFD
- Rototech 0.75KW 3Ø Motor
- A simple homemade PWM to Analogue DC Voltage Converter (Details covered later)
- A Spindle Index Pulse generator based on an Optek Technology OPB982T51Z Optocoupler

The block diagram I came up with using Open Office Draw shown below was essential during initial planning and design of the cnc lathe electronics.



BLOCK DIAGRAM
CJH CNC LATHE

Planning for your Spindle Control

When designing and building my cnc lathe, I quickly realized that you need to fully understand what you are trying to achieve when attempting to fully control your spindle speed with Mach3. A plan is essential to consider all that is needed to control you spindle speed, direction and synchronization.

Using such a plan minimizes mistakes and helps to makes things work as intended. It also provides a baseline to go back to if things start to go off the rails.

I would advise the following points be considered before starting:

1. Pulley Ratio (an accurate ratio is required for Mach3 to be able to calculate the correct PWM to control the spindle motor closely).
2. The maximum and minimum speeds (RPM) that the spindle will experience in normal operation.
3. Spindle Rotation Feedback mechanism for synchronous operations such as threading.
4. Selection of a Base Frequency for PWM.
5. A method of controlling forward (M3) and reverse (M4) spindle direction.
6. Motor Output Signal Setup for Mach3 Pins and Ports.
7. Spindle Input Signals required for Mach3 Ports and Pins.
8. A method of converting PWM signals from Mach3 to a DC Voltage to control VFD frequency and hence, spindle rpm.
9. The correct Spindle Setup under Mach3 Ports and Pins.
10. Whether the logic needs to be *High* or *Low* for various Ports and Pins settings to be used.
11. A method of calibrating the spindle rpm to Mach3 commanded rpm.

Software Bugs I have to contend with

Mach3 has a bug in the initial commanded spindle speed under PWM control. It manifests itself as resulting in a higher initial speed than that requested.

For example, on my lathe, if you request S500 the spindle will go to 643rpm. If you then perform either of the following actions, the speed will come back to the requested 500rpm:

1. Press Spindle Speed Override Reset Button, or
2. Issue another S500 command from Mach3 via DRO or MDI

Subsequent requested spindle speeds are then true until you stop the spindle and start again.

I don't know if this bug exists under Step and Direction Controlled spindles because all my machines use PWM and they all exhibit this problem. It has nothing to do with Smoothstepper because one machine is not controlled with a Smoothstepper and it behaves exactly the same.

My workaround for this bug is to ensure that the following G Code example (or equivalent) to start the spindle is inserted into all of my cnc programs:

M3 S500 (Request Start Spindle CW at 500rpm but it goes to 643rpm)
G4 P1 (Wait for 1 second)
S500 (The spindle then comes back to 500rpm)

SmoothStepper has a bug in that the G4 Dwell command is expressed in Seconds regardless of what you set it to in Mach3 / *General Config*.

I use Plugin Version 0.015meg because the spindle rpm DRO function works for me. I cannot get the spindle rpm DRO in later Plugin Versions to work. Being able to read accurate rpm values is important to me.

Pulley Ratio

Mach3 needs to know the difference in rpm between the driving motor and the spindle in terms of an accurate ratio. This ratio (which needs to be expressed as Spindle rpm to Motor rpm) must be calculated or measured and entered into Mach3 in the dialog box shown in Figure 4.

Pulley setup is covered in detail in the Mach3 Mill Manual in Section 5.5.6. If the spindle is driven directly by the motor, the ratio is 1:1. Mach3 allows for up to 4 pulley ratios to be setup individually. Because I have only one pulley, I setup for "Pulley 1" (the default) only.

To calculate the ratio, I used the method of measuring accurately the rpm of the motor shaft and spindle shaft and dividing the spindle rpm by the motor rpm. (Example below)

I use an inexpensive laser digital optical tachometer shown in Figure 1 to do the measurements. I attached small pieces of adhesive reflective tape supplied with the tachometer attached to the motor and spindle shafts. The reflective tape gives a good return for the laser beam resulting in stable rpm readings.

Pulley Ratio Calculation

1. Turn on the spindle using the manual mode on the VFD and adjust the speed control potentiometer until the spindle rpm as read on the tachometer is exactly 500rpm.
2. Measure and note the rpm of the motor shaft whilst the spindle is at 500rpm. (in my case, this was 1725rpm)
3. Divide 500 by 1725 which = 0.289855 (Pulley Ratio)
4. Enter 0.289855 into the "ratio" dialogue box as shown in Figure 4. This is all Mach3 needs for the pulley ratio.

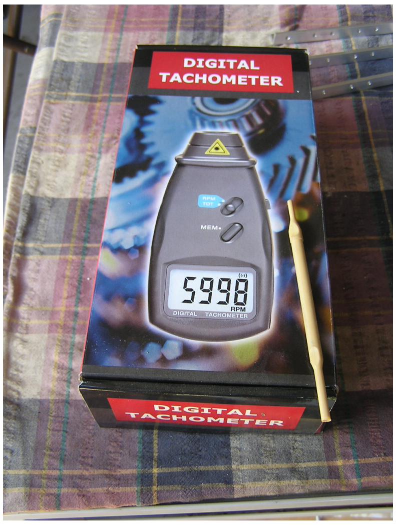


Figure 1

Typical Laser Tacho and Potentiometer Trim Tool

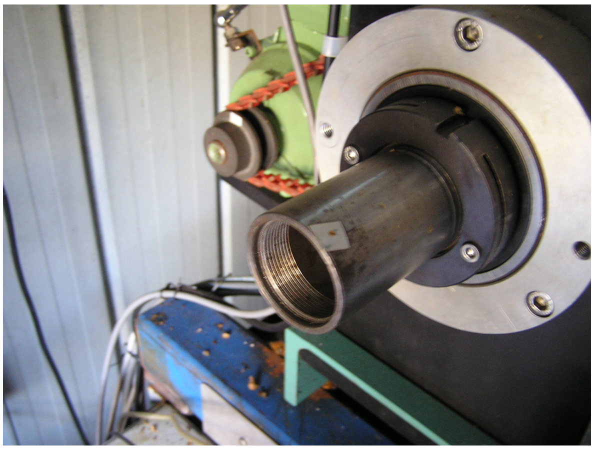


Figure 2

Reflective tape adhered to the motor pulley and spindle shaft

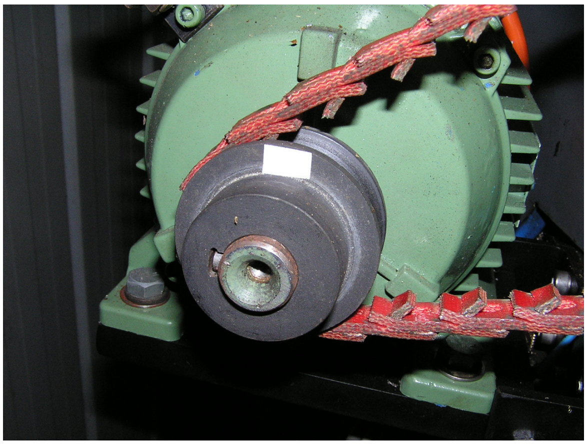


Figure 3

Close up of reflective tape on motor pulley.

Minimum and Maximum Spindle RPM

1. In Mach3, Use *Config / Spindle Pulleys* to open the dialogue box shown in Figure 4.

2. Choose *Pulley Number 1*.

3. Set your desired minimum and maximum spindle rpm. I used 200 and 1500rpm as shown in Figure 4. My minimum designed speed was 250rpm and maximum designed speed was 1150rpm. Choosing 200 and 1500rpm as shown ensures that Mach3 does not detect and present an error unless the actual speeds exceed the set limits during normal operation.

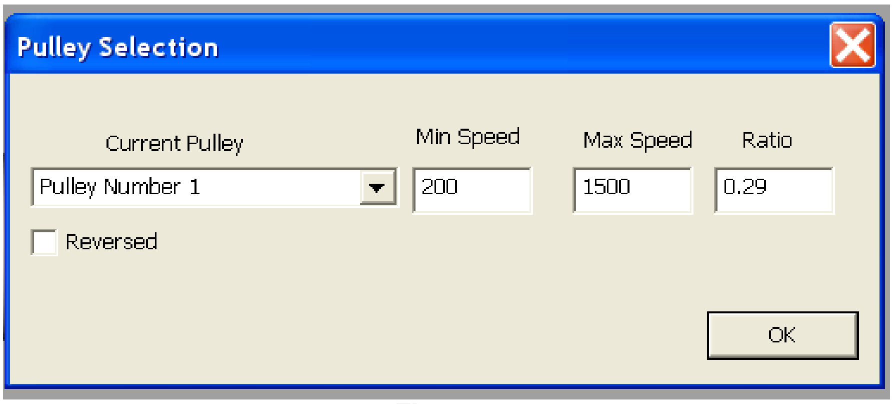


Figure 4

Spindle Rotation Feedback

In order to be able to perform synchronized operations such as threading, it is imperative that Mach3 is fed with rotational information on a continuous basis. Mach3 requires information in the form of one clean pulse per revolution. I used a disc with a single 8mm wide slot mounted to the spindle shaft as shown in Figures 8 and 9 and an Infrared Optocoupler.

Set up the configuration under *Ports & Pins / Spindle Setup / Special Functions* as shown in Figure 5. **Do not use** Closed Loop Spindle Control.

Selecting "*Use Spindle Feedback in Sync Modes*" tells Mach3 to expect feedback pulses from the spindle. Selecting this effectively puts Mach3 into a closed loop mode.

Selecting "*Spindle Speed Averaging*" allows Mach3 to "average out" minor speed fluctuations thus electronically smoothing out synchronized operations.

Under Motor Control, checking "*Use Spindle Motor Output*" tells Mach3 to use a user defined Output Pin (See Figure 11 for example where "Spindle" is checked and the Output Pin is chosen to be Pin 14 on Port2)

Because my VFD required a forward (Start) and reverse 24VDC signal from the VFD itself, I chose to use 2 existing relays on the Breakout Board (BOB) to perform this function. Therefore, I chose not to check "*Disable Spindle Relays*" under *Relay Control*. (See Figure 5)

I then selected *Clockwise (M3)* to *Output 1* and *CCW (M4)* to *Output 2* as shown in Figure 5.

Choosing Relay Control meant that *Relay Control Outputs 1 & 2* also needed to be enabled and pins assigned as shown in Figure 10.

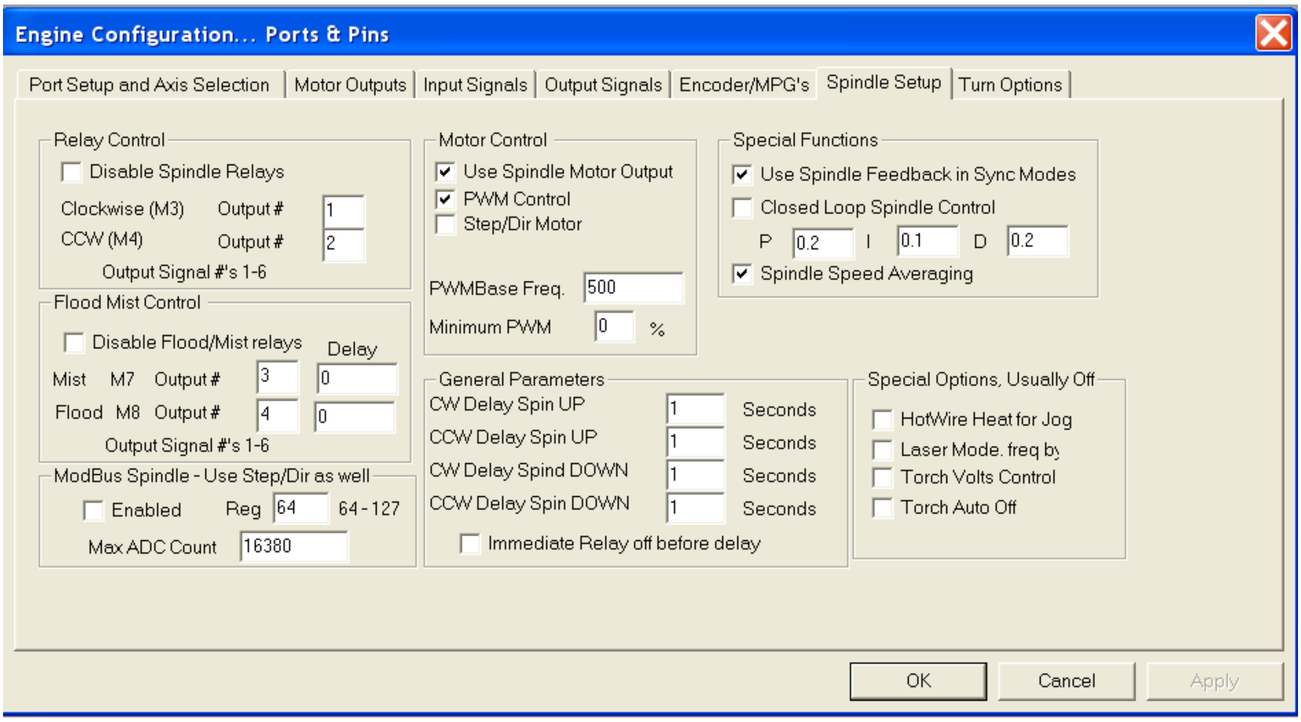


Figure 5

Mach3 Ports & Pins Spindle Setup

Spindle Index Pulse Generator

Figure 6 shows the schematic diagram of an eminently suitable index pulse generator. The clever thing about the OPB982T51Z is that everything needed to generate a clean, rail to rail index pulse is contained in the Optocoupler itself.

All that you need to add is an external limiting resistor R1 for the internal Infrared diode. Figure 7 shows several external limiting resistors mounted directly to 5VDC outputs on the BOB. The optocoupler is available from Farnell, Newark or Digikey. Cost is very reasonable.

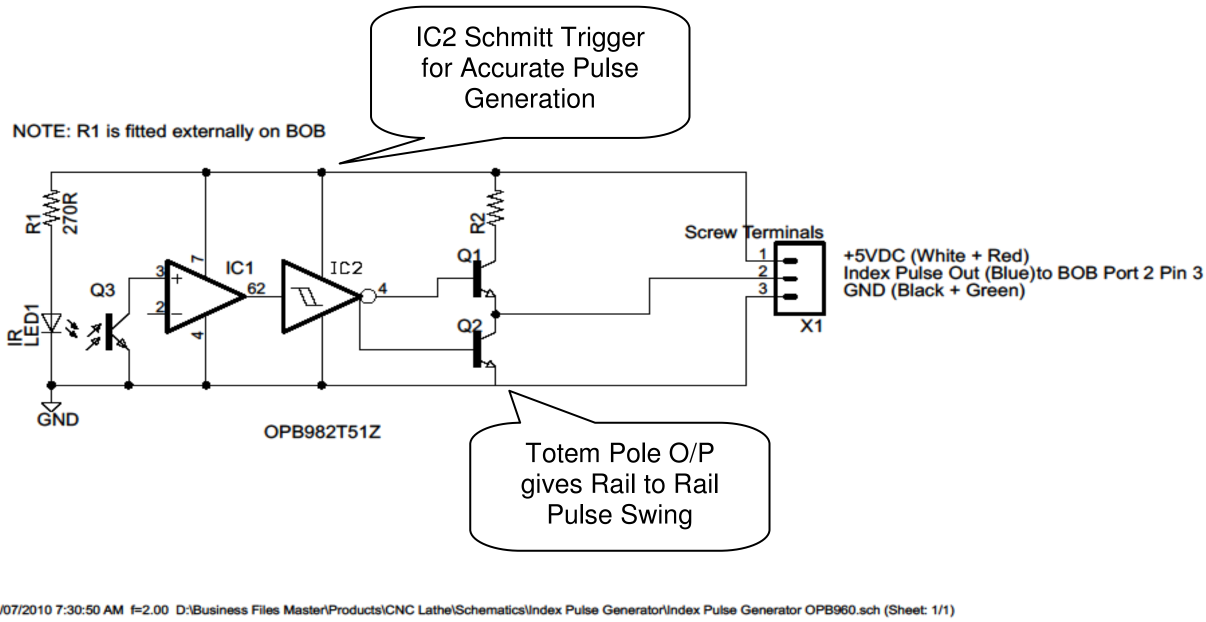


Figure 6

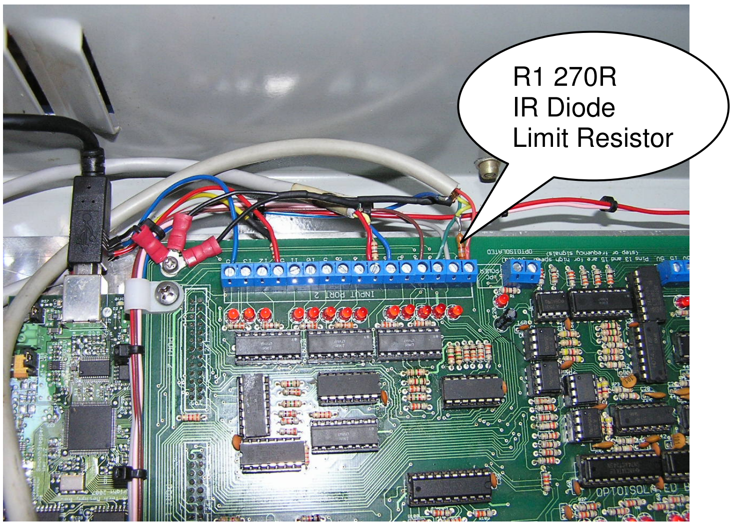


Figure 7

Details of how to mount the IR Diode Limit Resistor to 5VDC on C23 BOB

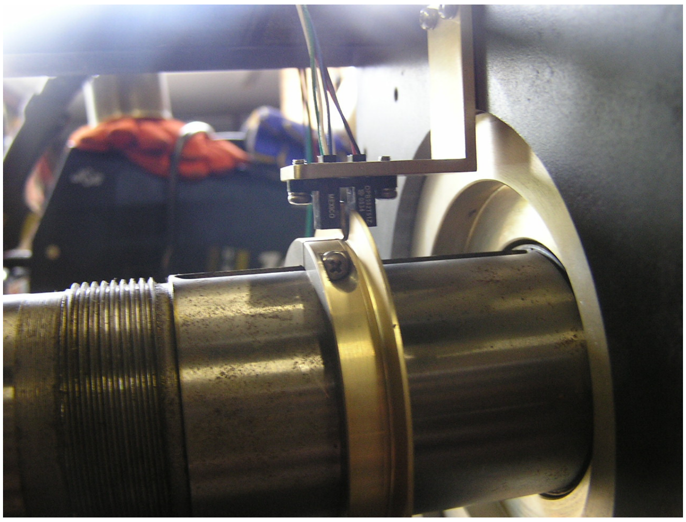


Figure 8

Index Pulse Generator Fitted to Spindle Shaft with a Single 8mm Slot Disc

Figure 9

Mach3 Output Settings Controlling Forward and Reverse Spindle Rotation

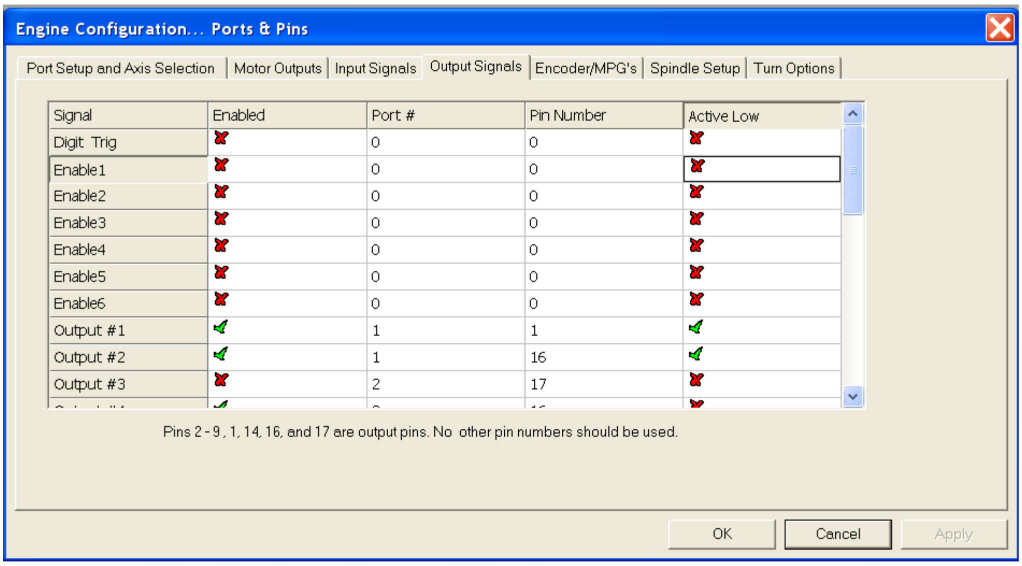


Figure 10

Output 1 and 2 were selected as Forward & Reverse Relay control.

In the example above, Output 1 (CW Rotation M3) is configured to control Relay 1 on the BOB via Pin 1 of Port 1. Output 2 (CCW rotation M4) is configured to control Relay 2 on the BOB via Pin 16 of Port 1.

Because each relay on the BOB has VCC on one side of the coil, *Active Low* needs to be selected to activate each relay when either M3 or M4 is commanded by Mach3.

Mach3 Ports & Pins Spindle Motor Output Settings

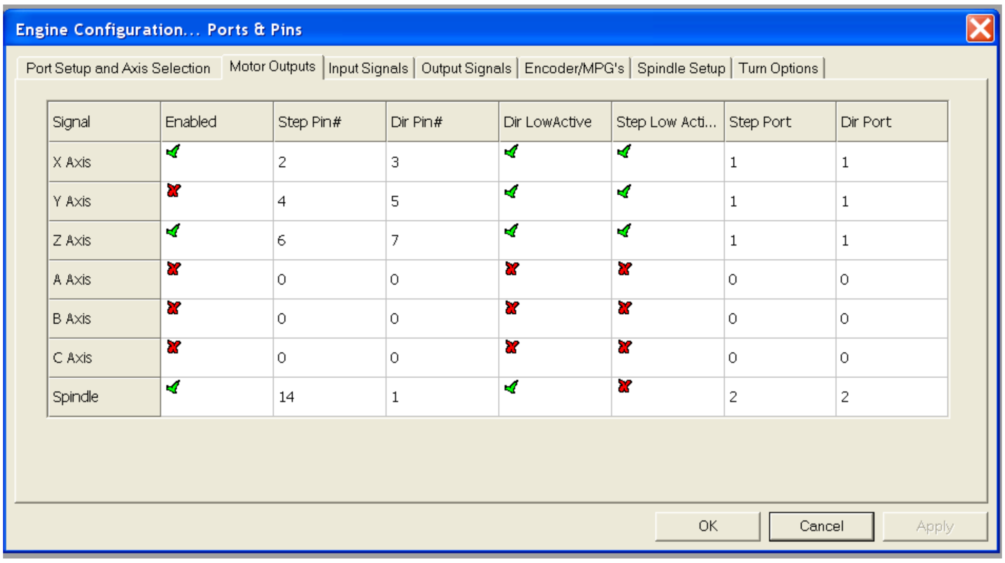


Figure 11

"Spindle" needs to be checked and a Pin defined for the PWM signal output to the PWM to DC Voltage Converter. I chose *Pin 14 Port 2 Active Low* which is connected to the PWM to Analogue DC Converter Board shown in Figure 16.

Note: Even though the Mach3 Mill Manual specifies that you do not need to define a direction pin for PWM Control, I found that it needed to be defined to make the Mach3 / SmoothStepper combination happy. I defined it as *Pin 1 Port 2* but it is not connected to anything. I don't understand why this is necessary, but it works for me.

Mach3 Ports & Pins Spindle Input Settings

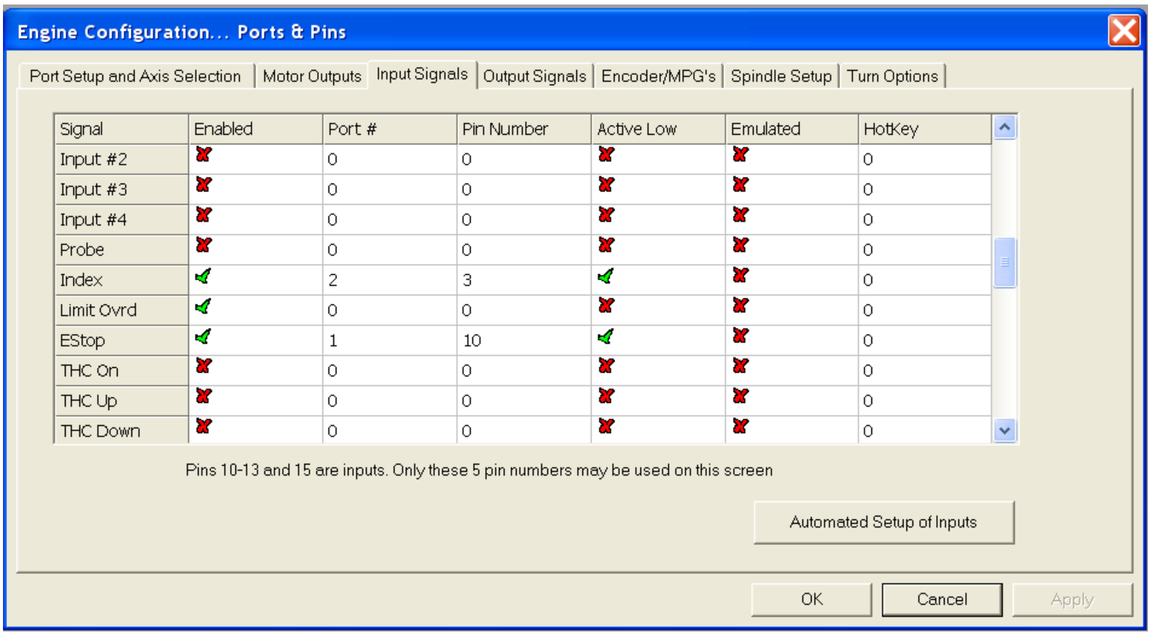


Figure 12

"Index" needs to be checked and an input pin assigned for the index pulses generated by the pulse generator shown in Figure 12. In this case Pin 3 of Port 2 was used. *Active Low* was also selected.

Converting PWM signals to DC Voltages to Control a VFD

I found it necessary to come up with this board design when I was very disappointed with the performance of the Tacho Chip built into the C23 board. I could never get the same rpm twice with the built in circuit. I wasted a lot of time trying to calibrate it but gave up and came up with my own simple circuit that works reliably.

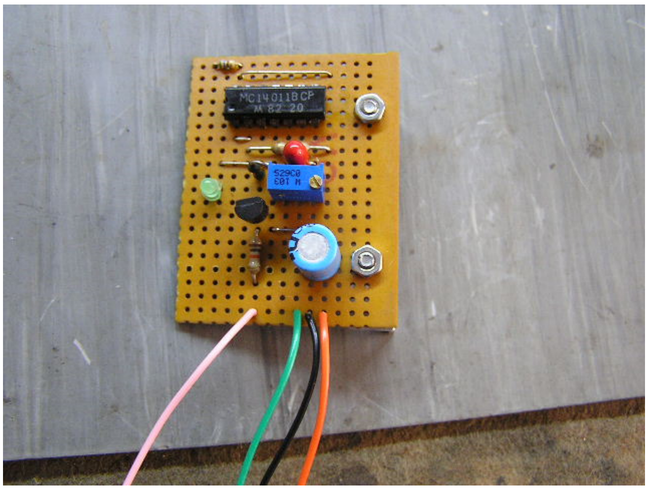


Figure 13

Top View of PWM Converter Board

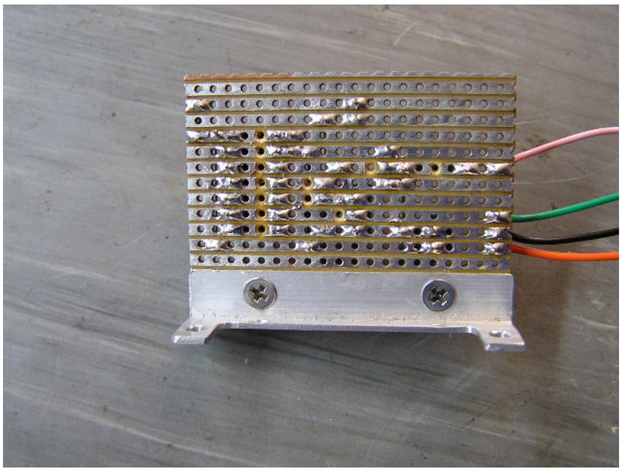


Figure 14

View of Underside of PWM Converter Board

This view shows the cuts on the Veroboard used to manufacture the PWM Converter Board. It also shows the bracket (See Figures 14 & 15 for details) used to conveniently mount the board on to one of the D25 Connectors located on the C23 BOB.

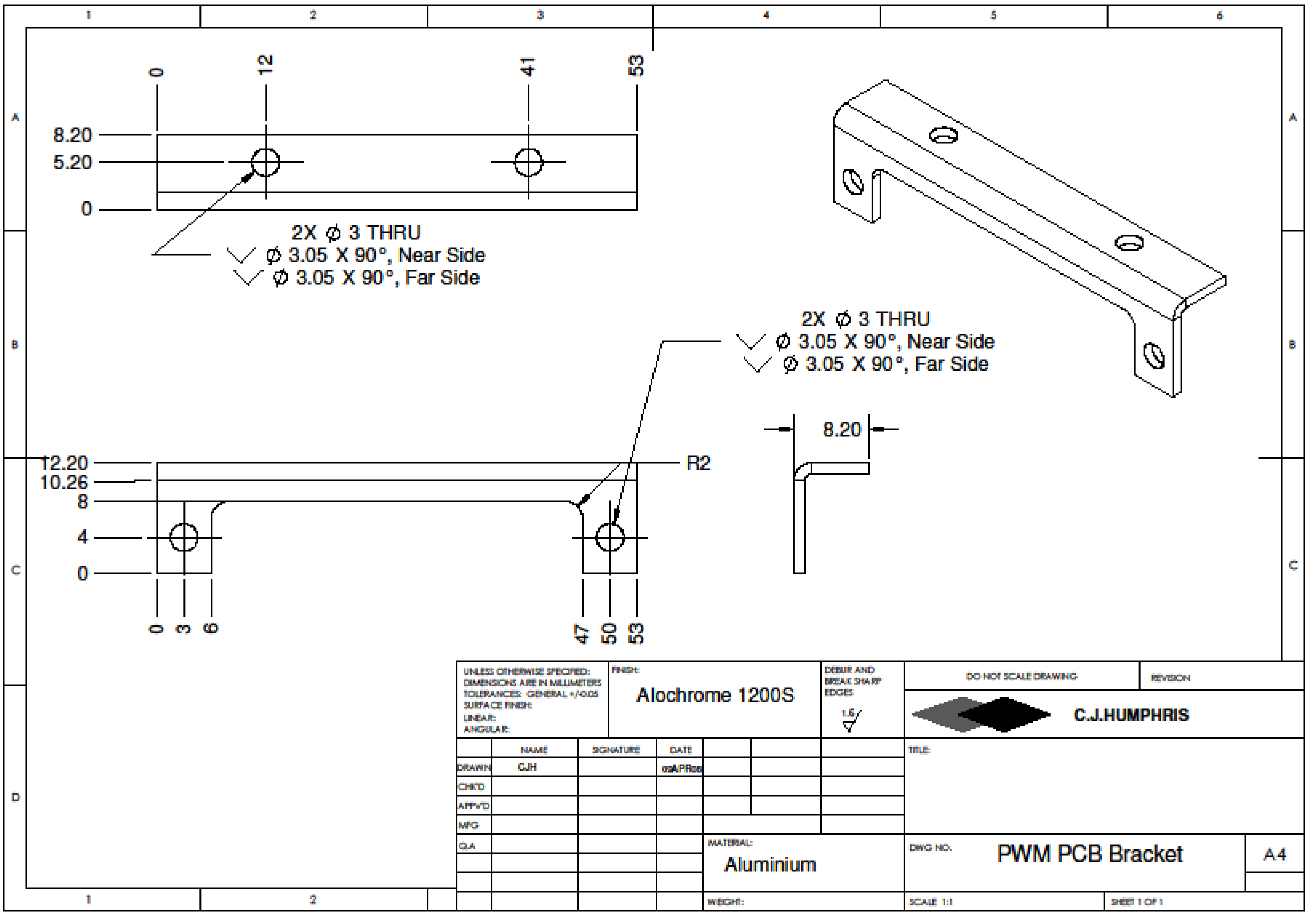


Figure 15

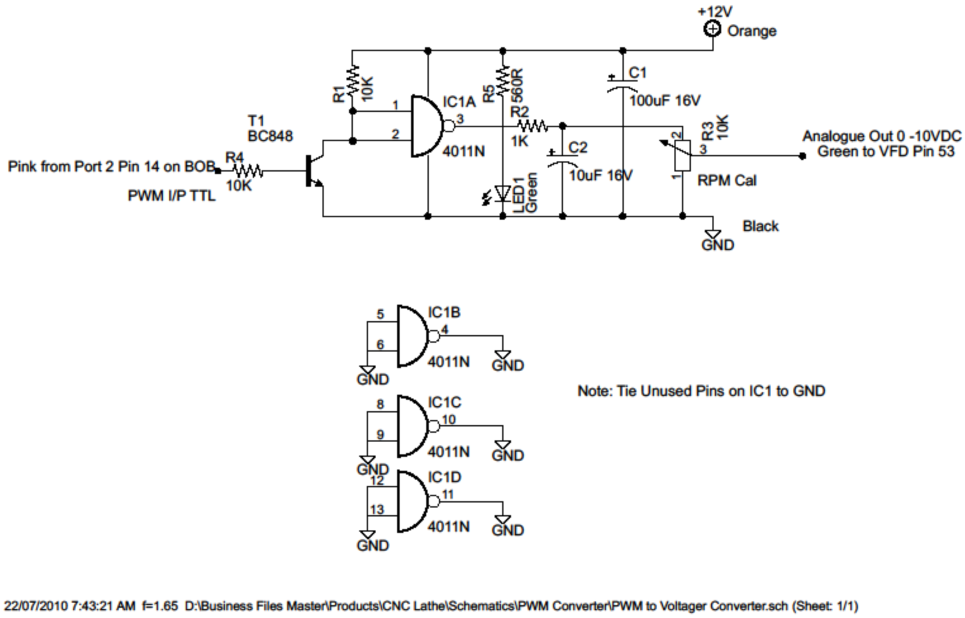


Figure 16

PWM Converter Board Schematic

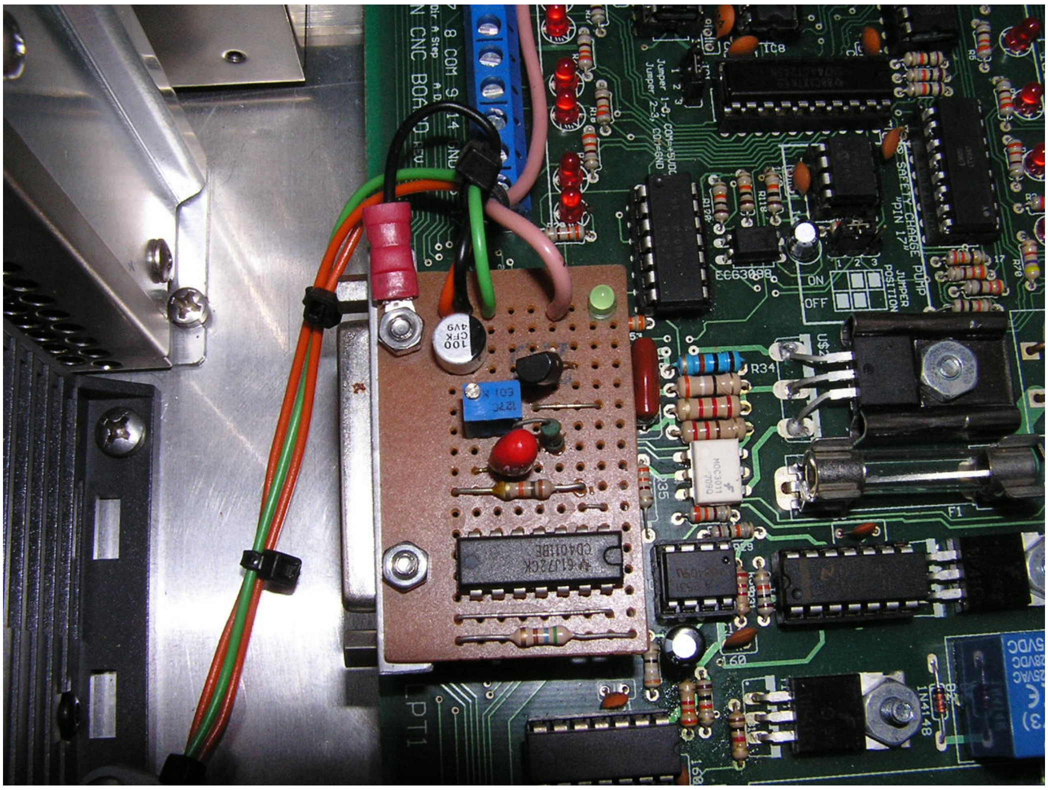


Figure 17

PWM Converter Board Mounted on C23 BOB

The blue potentiometer is used for calibrating the spindle rpm in the final stages of calibration.

Linearity of the PWM Converter Board

The graph in Figure 18 is included only to demonstrate the linearity of the conversion of PWM signals to Analogue DC Voltage.

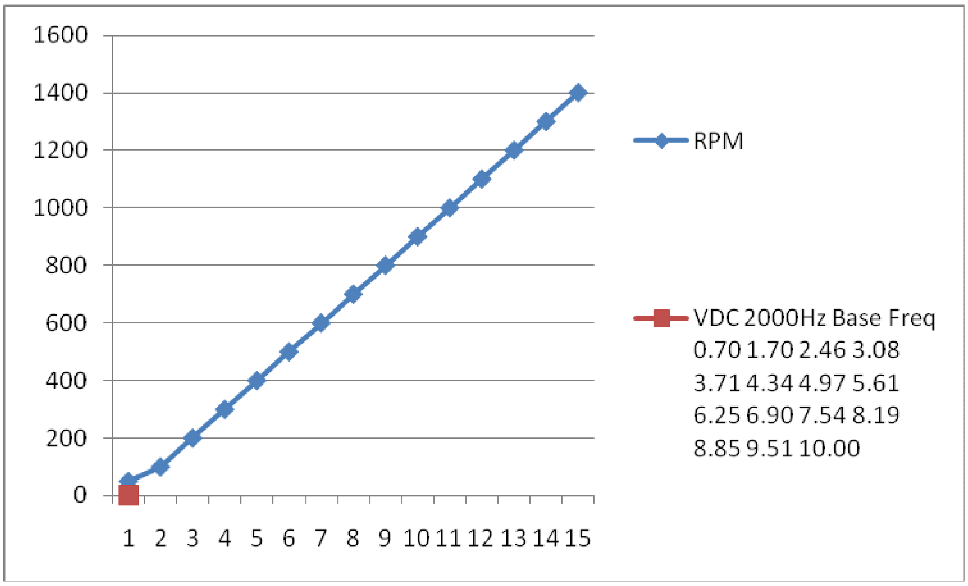


Figure 18

PWM Base Frequency

Because I use a Smoothstepper as the interface between Mach3 and the BOB, I had to use SmoothStepper's PWM facility as shown in Figure 19.

"PWM" is checked and the Base Frequency set at *"2000Hz".*

The default Base Frequency for Smoothstepper as shipped is 1000Hz. I performed tests using both 1000 and 2000Hz and it didn't appear to make much difference so I chose 2000Hz as the Base Frequency simply because higher frequencies are easier to filter.

I don't fully understand the Smoothstepper documentation but these settings work for me.

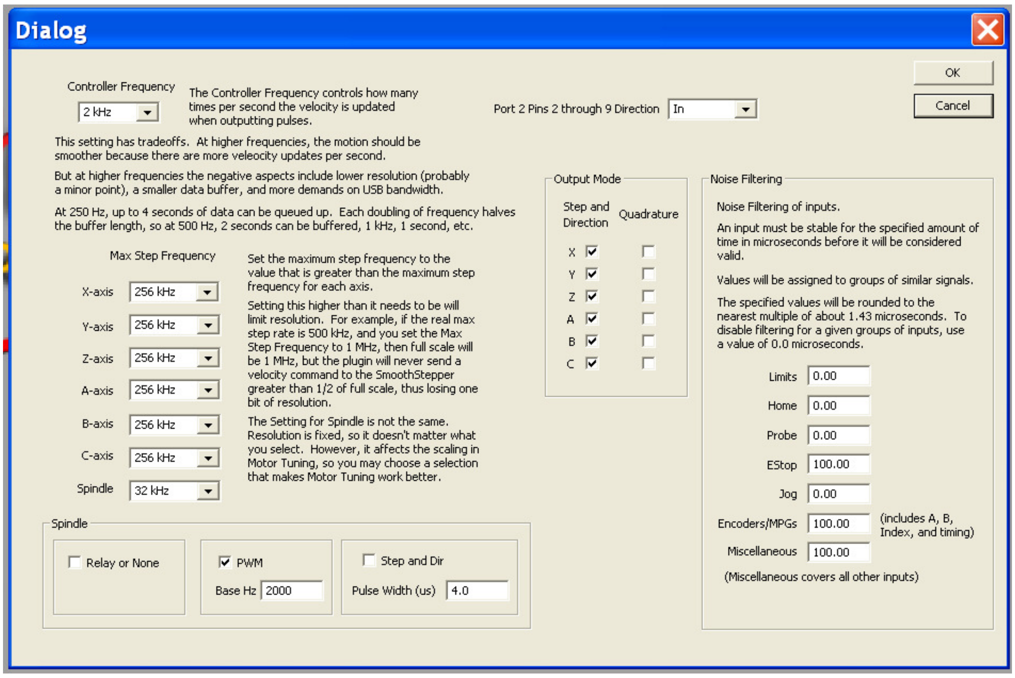


Figure 19

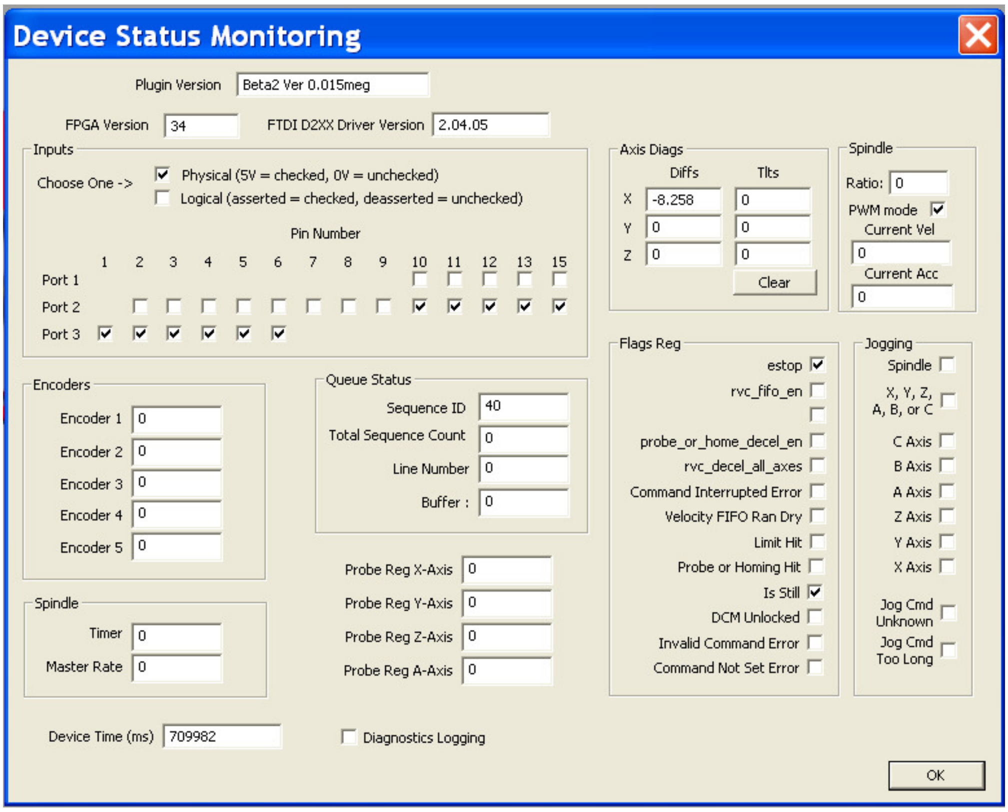


Figure 20

Smoothstepper Status Window

Calibrating the Spindle RPM

Introduction

In order to calibrate the spindle, the VFD must be set up as per its operating manual. This, for me, was a difficult task as I had never worked with a VFD previously. I now have a better understanding. One of the things that made it difficult for me was the Danfoss jargon. I suspect that translation from Danish to English resulted in some quirky language.

Some examples below:

“Hand On” means Local Control

“Auto On” means Remote Control

“Reference” means Frequency

The guys at Automation Direct (where I purchased the VFD and 3Ø Motor) were very helpful in guiding me through the manual.

Figure 21 is the block diagram of a typical VFD setup whilst Figure 22 details the control terminal information for the Danfoss VFD.

VFD Settings

The following basic list (not comprehensive) gives details of the settings that worked for me:

Minimum Reference 20Hz

Maximum Reference 120Hz

Ramp Up Time 1.25s

Ramp Down Time 1.25s (Anything less than this resulted in VFD over current warnings during spindle slowing)

Motor Speed Low Limit 20Hz

Motor Speed High Limit 110Hz

Terminal 18 Digital Input set to “Start” (This input is used for M3 CW Rotation)

Terminal 19 Digital Input set to “Start Reversing” (This input is used for M4 CCW Rotation)

Terminal 53 Analogue Input Low Voltage 0.75V (approximates the output from PWM Converter at Min speed)

Terminal 53 Analogue Input High Voltage 9.0V (approximates the output from PWM Converter at Max speed)

Terminal 53 Low Reference Feedback Value 20Hz

Terminal 53 High Reference Feedback Value 130Hz

Terminal 53 Filter Time Constant 0.25s

Terminal 53 Mode set to Voltage (the default)

Local Control Potentiometer Low Reference 20Hz

Local Control Potentiometer High Reference 68Hz

3.6.1. Power Circuit - Overview

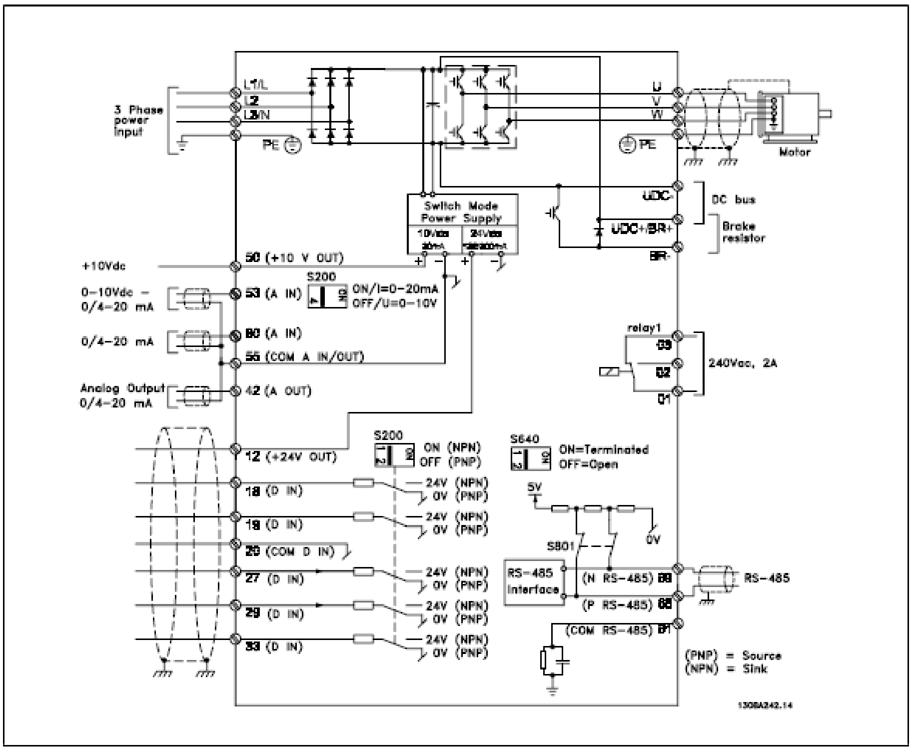


Illustration 3.10: Diagram showing all electrical terminals.

Figure 21

VLT Micro Drive FC 51 Operating Instructions

3. Electrical Installation

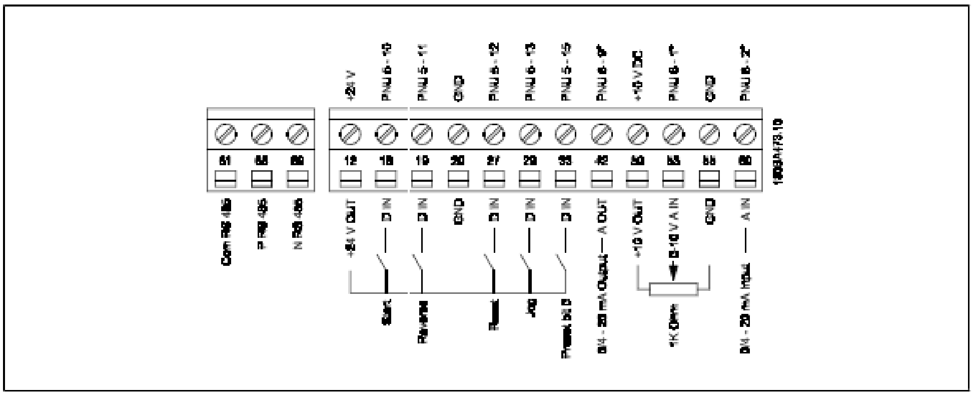


Illustration 3.7: Overview of control terminals in PNP-configuration and factory setting.

Figure 22

Tools Required

1. Laser Optical Tachometer (Optional)
2. Trim Tool for Potentiometers
3. No 2 Philips Head Screwdriver
4. VFD Operation Manual
5. Digital Multimeter

Calibration Procedure

1. Set the VFD to Remote Control.
2. Issue M3 S300 from the MDI in Mach3. The spindle should start with CW rotation at approximately 300 rpm.
3. Overcome the Mach3 bug by pressing the Spindle Speed Reset button.
4. Using the multimeter, monitor the Analogue control voltage.
5. Adjust the calibration potentiometer on the PWM Converter board until the spindle speed is 500rpm.
6. Enter 300 into the "S" DRO Box and press enter. The spindle speed should be approximately 300rpm. Record the Multimeter Voltage reading.
7. Enter 900 into the "S" DRO Box and press enter. The spindle speed should be approximately 900rpm. Record the Multimeter Voltage reading.
8. If necessary, adjust a combination of VFD Settings such as Analogue Low and High Voltage, (the voltages recorded in Steps 6 and 7 will give you clues as to what to try) and the Maximum Frequency Limit.
9. Repeat Steps 6, 7 and 8 until you are satisfied.

Conclusion

I hope you find this document useful. If you have any suggested improvements, please let me know via the Mach3 forum and I will look at making and issuing amendments.