Integrator Information V2.7.15-22-g3231675, 2021-01-22

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Chapter 1

Stepper Information

1.1 Stepper Voltage

What Voltage should the power supply be?

To calculate the voltage needed empirically take a 24 VDC power supply or any power supply that you have on hand that is above the minimum for the drive and hook it to the heaviest loaded axis.

Run that axis and increase the speed until you find the fastest speed that it will run without missing steps with the test voltage.

Using the following formula you can determine your voltage needed. Speed you want ÷ (Speed you got * 0.9) * Test voltage used = Voltage needed Example (300IPM ÷ (150IPM * 0.9) * 24VDC = 53.3VDC Just make sure that the voltage is within the range of your stepper driver.

What Voltage is my Stepper?

Some steppers just have the resistance and current on the tag. Using Ohm's Law R x I = E (Resistance x Current = Voltage) Example 1.1 Ohms x 2.8 Amps = 3.08 Volts

Compute Maximum Voltage vs Inductance

To compute the maximum voltage that you should use depending on the inductance of the motor use this formula. Maximum Voltage = 1000 * SQRT(inductance)

Example a motor that is rated at 1.5mH inductance per phase. 1000 * SQRT(0.0015) = 38.73 Volts MAXIMUM. Example a motor that is rated at 6mH per phase 1000 * SQRT(0.006) = 77 Volts MAXIMUM. Example a motor that is rated 2.5mH 1000 * SQRT(0.0025) = 50VDC MAXIMUM.

Note
Not all motors are created equal. If you use this formula and your motor seems to be excessively hot, turn down the voltage until the temperature is acceptable. Stepper motors are designed to run hot, but there's no need to stink up the place with fried insulation. Many motors are rated to withstand an 80 C temperature rise. For my own purposes, I limit the temperature rise to 60 C.

Compute Value and Wattage of Current-Limiting Resistors

Note: For L/R systems only.

This is a basic application of Ohms Law for a series circuit. Your resistor must drop the difference in voltage between the voltage at which your stepper is rated and your supply voltage:

Resistor voltage drop = Supply voltage - stepper rated voltage

Applying Ohms Law, divide by the rated current to get the resistance:

Resistor value = Resistor voltage drop / stepper current

Finally, and very importantly, you need to know how much wattage you will be dissipating as heat, which your resistors must be rated to handle:

Resistor wattage rating = Resistor voltage drop * stepper current

For example: Steppers rated at 2.5V @ 5A, with a 26V power supply

Resistor voltage drop = 26V - 2.5V = 23.5V Resistor value = 23.5V / 5A = 4.7 Ohms Resistor wattage rating = 23.5V * 5A = 117.5 Watts

1.2 Stepper Motor Speed

Among the things that slow down a stepper motor are: Coil Inductance, drive voltage, resonance, decay mode, microstepping, and the clocking limitations introduced by using the main thread to drive through the parallel port. Here at the beginning I would like to discuss what the implications are for using stepper motors instead of very high speed (and high cost) servo systems.

1.3 Stepper Torque

What will be consuming the torque of the system? If allthread is used for the leadscrew, it will consume a lot of the torque applied. ACME threaded leadscrews will consume less, but a ballscrew will consume nearly none of the available torque. Acceleration and deceleration will use some of the torque until the axis reaches the speed that is set. For high speed moves like to and from the tool changer, these are the only drains on the torque. When you start cutting, the hardness of the material along with the cubic inches per minute that is being removed and the sharpness of the tool affect the torque requirements.

Let's start with a system with a standard 200 step per revolution stepper motor running in full step mode. Let's choose a motor that will need 100uS per step if it is to maintain full torque. If it drives a 20 thread per inch all thread leadscrew, it will require 4000 steps per inch, giving ¼ of a thousandth of an inch resolution. This requires .4 seconds per inch, which is 150 Inches Per Minute (IPM). If this motor is sized to provide a lot of torque for cutting, then when doing high speed moves, the motor can be driven faster, into the region where the torque decreases. This system in practice might be suitable for 300 IPM high speed moves without losing steps. For most hobby uses this is quite fast.

The most torque will be needed when you are cutting a large amount of metal with a large bit, as in shell milling. Wood milling requires less force per cubic inch per second than most metals, but the torque is still needed most when making a heavy cut. When making a heavy cut, the spindle power, and the strength of the tool will probably limit the maximum speed of the cut. I've rarely seen a machine tool cutting at more than 25 IPM, though some videos on YouTube show a router cutting MDF at a pretty good clip. For most stepper motor systems the speed used for cutting will be slow enough that the stepper motor will be putting out it's full torque during cutting, even if it's not fast at full speed.

Tormach machine tool maker has a PDF on the design of their PCNC1100, and they describe the design decisions made for that machine. I find it worth quoting them about speed and power.

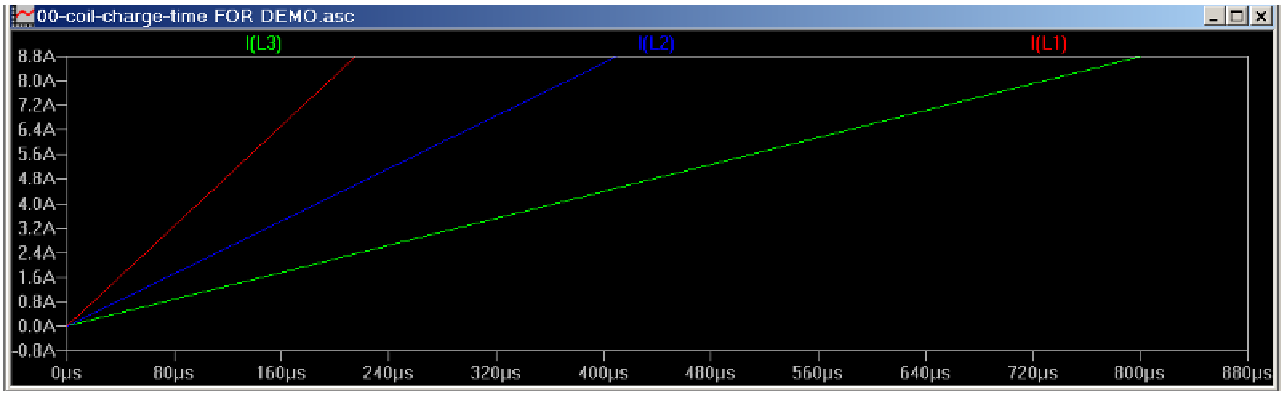
"A 1.5 hp CNC mill with 65 IPM rapids and no tool changer is ludicrous in a production environment, where minutes per piece are crucial. However, in prototype development, where run time is a tiny fraction of setup time, those extra minutes are simply not relevant."

I believe 65 IPM rapids are easily attainable with careful selection of stepper motor components, so I believe steppers are useful for most of us.

1.4 Coil Inductance

Probably the most limiting factor in the ultimate speed of a stepper motor system is the inductance designed into the stepper motor. If you wind a 2 milliHenry coil using 18 guage wire you'll need about 3x times more turns if you use an air core than if you use an iron core. In a stepper motor the structure of the motor requires an iron core to get 200 steps per revolution. with air core coils you might get 20 steps per revolution.

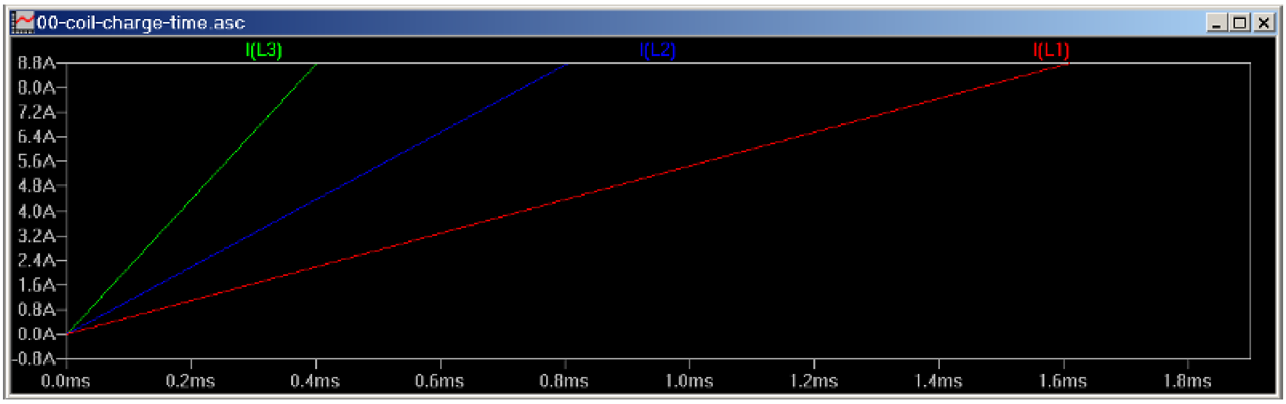
Because of the structure of the stepper motor, the lowest inductance I have seen quoted for a stepper motor is around 1 mH (milliHenry) per coil, while many rate 12 mH or higher. In the graphs below you will see plots of charge time for a 2mH (red), a 4mH (blue), and an 8mH (green) coil charged from a 90Volt supply.



By 80 uS (microseconds) the 2 mH coil has achieved 3.2 Amps. At that same time, the 8 mH coil has only achieved about 0.9 Amps. If the stepper motor is rated at a certain torque at 3 Amps, but it only gets to 0.9 Amps it would seem like you have a little less than 1/3 of the rated torque at 80 uS per step, but it's even less than that, since it only starts exerting that 1/3 torque at the 80 uS mark. At 40 uS it may only be delivering 1/6 of the full rated torque.

1.5 Drive Voltage

Below is a graph of a 2 mH coil charged from a 12V supply (red), a 24V supply (blue) and a 48V supply (green).



If you are using the same 3A motor, it takes about 150uS for a 48V supply to bring this motor up to 3A. It takes the 24V supply about 300uS to achieve the same current level. The 12V supply takes about 4 times as long as the 48V supply. Most switch mode IC stepper motor controllers limit the supply voltage you may use. The Allegro A3977 which is a great bipolar stepper motor controller chip has limits at 2.5A and 35V. The unipolar Sanken SLA7062M limits you to 3A and a 46V supply. Usually the insulation in the stepper motor can handle more voltage than 46, so with a discreet transistor solution you may be able to use 80V to 90V for your supply. 90V should allow your stepper motor to charge in about ½ the time that it would take a 45V supply. In case a suitable discreet option is available to you, there are plenty of 80 to 90V supplies available for free. An old 100Watt stereo amplifier will have bipolar supplies over +-40V giving a differential of over 80V. You can use one half of this supply for the SLA7062M, and a lower power amplifier could have a power supply suitable for the Allegro A3977. In the users manual for the Geckodrive G540 which is a complete system with four stepper motor controllers and inputs for limit switches, etc.; when discussing the selection of stepper motors says:

"Never use a power supply voltage greater than 32 times the square-root of the motor inductance expressed in milli-Henries (mH)" That would limit the power supply to 45 volts for a 2mH stepper motor used with this controller, which is not a terrible limitation.

While I'm talking about the power supply, it's worth noting that a stepper motor controller that uses a linear current regulator (IE the LiniStepper) would put the full 6A load on the power supply continuously. That would tax the power capability of most audio amplifier power supplies. A switching regulator only draws from the power supply for brief amounts of time, so a stepper motor that draws 3A at 2 volts per coil, would draw 3A x 2V = 6 Watts per coil or 12 Watts. At 48 volts 12 Watts would only require .25A. Three such motors would require 75A. This is well within the limits of a 100W per channel audio amplifier power supply. If you over rate your power supply by a factor of 2, you should be safe, except that the capacitors of an audio amplifier are not designed to take the peak currents that switching regulators draw, so having an additional capacitor rated for switching supplies would be necessary. A commercial switching stepper motor controller may have the high frequency capacitor built in.

1.6 Resonance

Resonance is a little gremlin that tries to hide in your machine, and eat your torque. Usually it can only eat your torque at a certain speed. The trouble is, if that speed is below your system's top speed, you can never get past it to your top speed. If you put a weight on a spring, and pull the weight down then let go, the weight will oscillate up and down at a particular speed. If you double the stiffness of the spring, it will oscillate twice as fast. If you cut the weight in half, it will oscillate twice as fast. Anything in your machine that flexes is one of those springs. If it's stiff enough, the oscillation (resonance) will be fast enough that you will never excite it. You will never lose torque to that resonance. If you can't make that part stiff enough, there are other techniques to reduce the effects of the resonance.

Rubber Couplings. # Friction. # Loosely coupled weights.

Rubber couplings are often used to reduce the resonance. A short piece of rubber hose coupling your stepper motor to your leadscrew can help a lot.

The friction in an allthread leadscrew can damp out a resonance, but it also uses up some of your torque all the time.

1.7 Decay Mode

To understand decay mode, and it's effect on a stepper motor, I found the data sheet for the Allegro A3955 (a 423kB PDF) very informative. Allegro has a patent on a mixed decay mode that gives us the best of both worlds. If the decay is slow, then when the current in the coil needs to be reduced, it doesn't reduce the current quickly enough to match the commanded current level, if the decay mode is too fast, the motor performs quickly, but it can get noisy, and some power gets wasted in eddy currents that normally wouldn't have to.

1.8 Microstepping

The benefits of microstepping include:

increasing the resolution of a given motor or system # reducing noise in a stepper motor system and # it may reduce or eliminate a resonance in the system.

Microstepping shouldn't affect the step motor speed much because of coil charging since while you are increasing the steps per revolution, each step now has to change the coil current a smaller amount. With a fast controller microstepping should only be a small percentage slower than full stepping. Where microstepping can slow the system down is by bumping into the limitations of the parallel port earlier, at lower RPM.

Microstepping does have a limitation though. Let's consider a stepper motor which draws 707mA through each coil when full stepping, and therefore providing full torque for each step. If it is microstepped at 4X microstepping, the current levels for each coil will step through a sequence of 0.0 mA, 382 mA, 707 mA, 924 mA, and finally 1000 mA. 4X microstepping gives torque as if you were running a motor designed for 707 mA at 382 mA full step. That is about 0.54 times the full torque. Jeramé Chamberlain of Nippon Pulse America put out 2 PDFs on servicing stepper motor systems, and here is a portion of his list of the torque for different microstepping modes:

MICROSTEPS	% FULLSTEP TORQUE
1	100%
2	70.17%
4	38.27%
8	19.51%
16	9.80%

Some lists have full stepping and half stepping at full rated torque, assuming that when only one coil is driven, you can increase the current by 1.414 and still pump the same power into the motor, but since that power would be localized in just one coil, it's best not to use the full 100% torque at half stepping, unless you reduce current in the motor, and the extra current doesn't create a field large enough to degauss the permanent magnets.

When you choose microstepping, though you get extra resolution, it comes at the cost of torque AT that resolution. If there is too much static friction for this much torque, the motor may pile a few microsteps together before it provides enough torque to break the static friction. Then, the machine may move 2 or 3 microsteps before stopping again to wait. If the machine has low friction, but is cutting a heavy cut that requires lots of torque, the stepper motor's position may get a few microsteps behind the commanded position.

When making square cuts, like cutting the outside of a square housing, though the machine may get behind the commanded position in the middle of the cut, the machine will decelerate to 0 before making a change of direction at the corner. At this really low speed, the low torque may be able to catch up to the commanded position before changing direction. Even a poorly tuned servo system can get behind while doing a heavy cut, yet it may not be noticed on rectangular shapes since it can catch up in the corners. Where this may cause problems is when cutting out a continual circular pocket or post. In this case being behind the commanded position can make the inside diameter smaller than commanded, or the outside diameter larger than commanded. If you are doing art, the smoothness of the cut may be more desirable than the absolute accuracy. In this case microstepping may be the right choice.

The crux? Be aware of the liabilities as well as the benefits of microstepping before you choose to use it. A cogged belt reduction may be more useful than microstepping in some instances.

1.9 Force Calculations

This is a spreadsheet to calculate force for steppers or servos. Mechanical Spreadsheet

1.10 Parallel Port Limitations

If you are running a stepper system from a parallel port, the latency test is the first thing you need to run. Be aware that on board video can cause an otherwise fine motherboard to have terrible latency, but a cheap external video card usually fixes that.

Now let's suppose you have a great latency reading of 6000 nS, or 6 uS. This should allow you to run a main thread at 10uS. Lets further assume your stepper motor controller accepts quadrature as it's input, which allows one step per thread, or one step per 10 uS. We are ignoring the signal timing requirements of the stepper controller for now. At 10uS per step, if you have resolution of .001 inch per step, theoretically you can step an inch in 10 mS. That's 100 inches per second or 6000 inches per minute. WOW! That parallel port shouldn't be any limit at all! Well, not so fast. .001" resolution is not that great, let's cut it down by a factor of 4. 250 micro inches per step seems usable. Now we're down to 1500 IPM. Still seems very fast! But we're still not done running into the wall physics puts in front of us. Let's consider the change in speed we need as we approach this 1500 IPM which occurs at 10 uS per step. Consider this table:

MICROSECONDS PER STEP	10	20	30	40	50	60	70	80	100	200
% CHANGE IN SPEED	100	50	33.3	25	20	16.7	14.3	12.5	10	5

It is unrealistic to expect a stepper motor to double it's speed from 20 uS per step to 10 uS per step. 50%, 33.3%, 25%, and 20% changes in speed seem to be unrealistic too. At what percent change can your system make the change? I can't answer that. Experimentation is probably the only way to find that answer. This is the reason why an FPGA board often used for servo systems, may be useful for a stepper system. When the resolution at 100 MHz is 10 nS, at 10 uS per step the % change is 0.1%, and realistic to expect a stepper to keep up with.

If our stepper motor can handle a 5% change in speed at high speed, our 6000 nS latency is only good for 75 IPM high speed. At

200 uS per step, a well selected stepper motor, and a stepper controller that works at 40V should allow near full torque at high speed. If you opted for an FPGA board, then the stepper motor/controller combination (or resonance) will be your speed limiter.

1.11 For More Information

For (perhaps) more information than you ever wanted to know about stepper motors, search the web for "Jones on stepping motors". A generous soul has given a great tutorial on all aspects of stepping motor operation.

This page is for step and direction timing of stepper drives.

Please add to this list using the stepconf wizard format and in nanoseconds so it will be uniform.

Some boards have know issues see the troubleshooting hardware page

If your unsure about your drive timing start high like 10000 for each and test. remember that signal conditioning and opto-isolation can increase timing requirements. That's why you need to know the timings for a driver board, not just the step translator chip that is contains.

Also notice that some controllers step on the falling edge some on the rising edge. This matters as it will change the timing and will be hard to trace. make sure LinuxCNC follows what the controller expects.

Note 1 if an asterisk precedes the name then the values are not confirmed. If you can confirm the values please do…

Times listed are in nanoseconds (ns). Multiply microseconds (us) by 1000 to get nanoseconds (ns)

Manufacturer	**Model**	**Step Time**	**Step Space**	**Direction Hold**	**Direction Setup**	**Steps on**	**Spec Sheet**	
Chinese Blue Boards	TB6560 CNC Stepper Motor Driver Controller Board	150000	150000	150000	150000	Falling Edge	http://hyu68.com/-cp8.htm	
Gecko	201	500	4000	20000	1000	Falling Edge	http://www.geckodrive.com/-support/-motor-control-manuals/-stepper-drives/-g201-rev-16.html	
Gecko	202	500	4500	20000	1000	Falling Edge	http://www.geckodrive.com/-support/-motor-control-manuals/-stepper-drives/-g202-rev-15.html	
Gecko	203v	1000	2000	200	200	Rising Edge	http://www.geckodrive.com/-support/-motor-control-manuals/-stepper-drives/-g203v-rev-7.html	

Manufacturer	Model	Step Time	Step Space	Direction Hold	Direction Setup	Steps on	Spec Sheet
Gecko	201x	500	3000	20000	1000	Falling Edge	http://www.geckodrive.com/-support/-motor-control-manuals/-stepper-drives/-g201-rev-16.html
Gecko	212	500	4000	20000	1000	Falling Edge	http://www.geckodrive.com/-support/-motor-control-manuals/-stepper-drives/-g212-rev-15.html
Gecko	213v	2000	1000	200	200	Rising Edge	http://www.geckodrive.com/-support/-motor-control-manuals/-stepper-drives/-g213v-rev-7.html
Gecko	320	3500	500	200	200	Rising Edge	http://www.geckodrive.com/-support/-motor-control-manuals/-dc-servo-drives/-g320-rev-7.html
Gecko	320x	1000	2500	200	200	Rising Edge	http://www.geckodrive.com/-support/-motor-control-manuals/-dc-servo-drives/-g320x-rev-10.html
Granite Devices	VSD-E/XE Evolution	125	125	125	125	Rising Edge	http://granitedevices.fi/-assets/-files/vsd-e_160_manual.pdf
Granite Devices	VSD-E/XE DualDC	150	1850	150	800	Rising Edge	http://granitedevices.fi/-assets/-files/vsd-e_160_dualdc_manual.pdf

Manufacturer	Model	Step Time	Step Space	Direction Hold	Direction Setup	Steps on	Spec Sheet	
JVL	SMD41	500	500	2500	2500	Rising Edge	http://www.jvl.dk/-files/pdf/-lb043gb.pdf	
JVL	SMD42	500	500	2500	2500	Rising Edge	http://www.jvl.dk/-files/pdf/-lb043gb.pdf	
Linistepper Open Source	RULMS1	30000	100000	4000	4000	Rising Edge	http://www.piclist.com/-techref/-io/-stepper/-linistep/-index.htm	
Linistepper Open Source	THB6064	2300	2300	4600	1000	Rising Edge	http://www.piclist.com/-techref/-io/-stepper/-THB6064/-index.htm	
*Motion Control	MSD542	>1500	2000	2000	2000	Rising Edge	http://www.motioncontrolproducts c2/-uploads/-msd542%20datasheet.pdf	
Parker	OEM750	200	300	0	200000	Rising Edge	http://www.compumotor.com/-manuals/-OEM750/-OEM750_Entire_Rev_B.pdf	
ST	L297	?	500	4000	1000	Rising Edge	http://www.st.com/-stonline/-books/-pdf/docs/-1334.pdf	
Xylotex	XS-3525/8S-3	2000	1000	200	200	Rising Edge	http://www.xylotex.com/-XS3525V202.pdf	
Xylotex	XS-3525/8S-4	1000	1000	200	200	Rising Edge	http://www.xylotex.com/-XS3525V400.pdf	
Lin Engineering	Silverpak 17D/DE	20000	20000	200	200	Rising Edge	http://www.linengineering.com/-site/-products/-pdf/-SilverPak17D_DE-manual.pdf	
Hobbycnc	Pro Chopper Board	2000	2000	2000	2000	?	http://www.hobbycnc.com/-products/-hobbycnc-pro-chopper-driver-board-kits/	
*Routout	2.5amp Stepper Driver	200	1000	1000	?	?	http://www.routoutcnc.com/-2-5ampdriver.pdf	
*Intelligent Motion System	IM483	1000	1000	1000	1000	Rising Edge	http://www.imshome.com/-im483.html	

Manufacturer	Model	Step Time	Step Space	Direction Hold	Direction Setup	Steps on	Spec Sheet	
Keling	4030	5000	5000	20000	20000	?	http://www.	
Keling	6852	1750	1750	10000	10000	Rising Edge	http://www.kelinginc.net/kL-6852.pdf	
Sherline	8760	1000	6000	24000	24000	?	http://www.sherline.com/	
Burkhard Lewetz	Step3S	6000	15000	?	5000	?	http://www.lewetz.de/download/ibstep3se.pdf	
Parker Compumotor	Zeta 4	200	200	?(200)	?(200)	Rising Edge	http://www.compumotor.com/manuals/ZETA/ZETA_Rev_A_Entire.pdf	
www.cncdrive.com	Dugong	1000	2500	1000	1000	?	http://www.cncdrive.com/content/dugong.htm	
www.cncdrive.com	DG2S-08020	1000	2500	1000	1000	?	http://cncdrive.com/DG2S_08020.html	
Wantai Motors	DQ542MA	5050	5050	500	500	?	http://www.wantmotor.com/ProductsView.asp?id=257&pid=82	
Leadshine USA	Digital DM422 40V 2.2A	7500	7500	20000	5000	Rising Edge	http://leadshineusa.com/UploadFile/Down/DM422m.pdf	
Leadshine USA	Digital DM556 50V 5.6A	2500	2500	10000	5000	Rising Edge	http://leadshineusa.com/UploadFile/Down/DM556m.pdf	
Leadshine USA	Digital DM856 80V 7.0A	2500	2500	10000	5000	Rising Edge	http://leadshineusa.com/UploadFile/Down/DM856m.pdf	
Leadshine USA	Digital DM870 80V 7.0A	2500	2500	10000	5000	Rising Edge	http://leadshineusa.com/UploadFile/Down/DM870m.pdf	
Leadshine USA	Digital DM1182 150VAC 8.2A	2500	2500	10000	5000	Rising Edge	http://leadshine.com/UploadFile/Down/DM1182m.pdf	
Leadshine USA	Digital EM402 40V 2.2A	10000	2500	10000	5000	Rising Edge	http://leadshine.com/UploadFile/Down/EM402d_P.pdf	
Leadshine USA	Digital EM503 50V 4.2A	2500	2500	10000	5000	Rising Edge	http://leadshine.com/UploadFile/Down/EM503d_P.pdf	
Leadshine USA	Digital EM705 70V 7.0A	2500	2500	10000	5000	Rising Edge	http://leadshine.com/UploadFile/Down/EM705d_P.pdf	

Manufacturer	Model	Step Time	Step Space	Direction Hold	Direction Setup	Steps on	Spec Sheet
Leadshine USA	Digital EM806 80V 8.2A	2500	2500	10000	5000	Rising Edge	http://leadshine.com/-UploadFile/-Down/-EM806d_P.pdf
Leadshine USA	Analog M415B 40V 1.5A	1500	1500	8000	5000	Rising Edge	http://leadshineusa.com/-UploadFile/-Down/-M415Bm.pdf
Leadshine USA	Analog M542 50V 4.2A	1500	1500	8000	5000	Rising Edge	http://leadshineusa.com/-UploadFile/-Down/-M542V2m.pdf
Leadshine USA	Analog M752 75V 5.2A	1500	1500	8000	5000	Rising Edge	http://leadshineusa.com/-UploadFile/-Down/-M752m.pdf
Leadshine USA	Analog M880A 80V 7.8A	1500	1500	8000	5000	Rising Edge	http://leadshineusa.com/-UploadFile/-Down/-M880Am.pdf
Leadshine USA	Analog M860H 80VAC 7.2A	1500	1500	8000	5000	Rising Edge	http://leadshineusa.com/-UploadFile/-Down/-MA860Hm.pdf
Leadshine USA	Brushed servo DCS303 30V 15A	2500	2500	10000	5000	Rising Edge	http://leadshineusa.com/-UploadFile/-Down/-DCS303m.pdf
Leadshine USA	Brushed servo DCS810 80V 20A	2500	2500	10000	5000	Rising Edge	http://leadshineusa.com/-UploadFile/-Down/-DCS810V1m.pdf
Leadshine USA	Brushed servo DCS810S 80V 20A	1000	1000	7000	5000	Rising Edge	http://leadshineusa.com/-UploadFile/-Down/-DCS810Sm.pdf
Leadshine USA	Brushless servo ACS306 30V 15A	2500	2500	10000	5000	Rising Edge	http://leadshine.com/-UploadFile/-Down/-ACS306hm.pdf
Leadshine USA	Brushless servo ACS606 60V 15A	850	850	6700	5000	Rising Edge	http://leadshineusa.com/-UploadFile/-Down/-ACS606m.pdf
Leadshine USA	Brushless servo ACS806 80V 20A	850	850	6700	5000	Rising Edge	http://leadshineusa.com/-UploadFile/-Down/-ACS806m.pdf
Pololu	A4988 Stepper Motor Driver Carrier	1000	1000	200	200	Rising Edge	http://www.pololu.com/-catalog/-product/-1182/

Manufacturer	**Model**	**Step Time**	**Step Space**	**Direction Hold**	**Direction Setup**	**Steps on**	**Spec Sheet**	
Pololu	DRV8825 Stepper Motor Driver Carrier	1900	1900	650	650	Rising Edge	http://www.pololu.com/-catalog/-product/-2132/	
cnc4you		2000	8000	5000	5000	Rising Edge	http://cnc4you.co.uk/-resources/-CW5045.pdf	

Chapter 2

Best Wiring Practices

The following information was provided by a machine builder to aid other machine builders when planing the electrical part of their machine build.

2.1 Electrical Noise

Electrical noise comes from a couple of things. First is EMI which stands for Electromagnetic Interference. EMI is caused by current flowing through wires. The second is electrical mechanical noise cause by physical switches bouncing when they open or close. Both of these conditions can cause you problems with the daily operation of your CNC machine. The mechanical noise can be dealt with pretty easily, but the EMI noise on the other hand requires a little work to help reduce and prevent it. The guidelines that follow are some things that you can do to reduce this problem. Before we get to the list of things to do, let's first discuss a little more what EMI is.

EMI as I stated above is caused by current running through a wire, but there is a little more to it. When current runs through a wire a magnetic field is created. As the current builds the magnetic field gets stronger. Then when the current ceases to flow through the wire the magnetic field collapses. This in itself isn't too bad, but if this magnetic field happens to cross another wire it will induce a voltage across it. This is how a transformer works. It uses a magnetic field in one coil of wire to induce a voltage in another coil of wire. If a wire is able to induce a voltage across another wire that we are using for a signal at logic level voltages, it may drive the voltage level in that wire to some state that the logic circuits reading it cannot understand. To be clear, 5V TTL work on distinctive voltage ranges. An input voltage of 0V to .8V is considered a false or low logic level. A voltage level of about 2V to 5V is read as a true or high level input. If however a voltage somewhere in between the .8V and 2V is on the input then we do not know what the output will be. When an input in this range is given the output could be either a high or a low level and this has to be avoided for a reliable circuit. Knowing the above information we know that a magnetic field crossing our signal wires could drive the input voltage to a TTL circuit into this band resulting in unexpected operation. But this is only half the story.

When current is switched on and off in a circuit we know that it creates a magnetic field but when current is switched on and off repeatedly it is possible to create another kind of noise. If the rate the current is being switched on and off is fast enough, it can generate radio frequencies that can interfere with other equipment nearby. The strength of these radio frequencies again depends on the amount of current that flows through the wire.

Now that we know what EMI is and the effects that it can have let's discuss what we can do about it by giving some general wiring tips.

2.2 AC Line Voltage

The AC that you use can inject noise into your power supplies and other equipment. If you have motors running on the same circuit for example, can create noise on the line if it is running on the same circuit as your CNC components. RF signals can also be superimposed onto AC line voltage. Years ago, this fact was exploited in some home entertainment systems to provide music to a remote speaker over the AC line. In-line filters are made to attenuate (reduce or block) this type of noise from the AC line voltage before it is run into your equipment. AC Line Filters can be found at electronic supply houses. LinuxCNC forum user “lead_injection” recommends Medical Grade filters as they have the lowest leakage current.

2.3 PSU’s (Power Supply Units)

2.3.1 AC Grounds

A typical CNC machine may have a few different power supplies installed and in use on the system. Make sure the AC inputs to your power supplies are properly grounded. Tie them all to the same ground. Many power supplies have a metal case and the case is usually tied to the AC ground as well so keep this in mind when you are fastening them down. In my case I have a metal drawer that I am using, so when I fasten down the power supplies, I need to keep in mind that the AC ground will be attached to this drawer as well.

2.3.2 DC Grounds

There are two trains of thought when it comes to the DC ground. Some folks say that you should ground it to the AC ground and others suggest that you should create a separate isolated ground plane for the DC power. I don’t know if one style is better than another but if you are interested a Google search you can find folks that will defend either side of the argument.

Additionally, many suggest that you keep the ground for any supply providing logic level voltages segregated from any other DC supply to prevent ground loops which could create new additional problems. A ground loop exists when the grounds of two different devices are at different potentials. For example, if the PSU for your drivers were at a different potential than your supply for your logic and you tied them together, you could corrupt your logic signals by a small voltage change. If this difference in voltage is enough to push your signal into the unknown state we discussed above, then your equipment will be unreliable or possibly erratic.

In my controller drawer I have three PSU’s. Two of them are 36VDC and one is a 5VDC. The 36V supplies are meant to run my stepper controllers while the 5V supply will provide power to my BOB (Break Out Board) and TTL signal level voltages. My intention is to give the 36V their own ground plane and to isolate the 5V supply for the logic.

2.4 Stepper Motor Controllers

When wiring the controllers up, the following list should be helpful.

The metal housing of the controller should be grounded. You can verify this with a multimeter set to check continuity. Best practice is to mount your controllers directly to your ground plane. The ground plane as you recall from above is an isolated piece of metal that you will attach the ground from your PSU that supplies your controllers. A simple way of doing this is to use a piece of aluminum plate for the ground plane and mount it to your enclosure using insulated standoffs. Mounting your controllers to this plane allows any noise the controller might generate to be diverted to ground rather than emitted through the air and possibly affecting surrounding equipment.

The controllers that I have experience with have two sets of connectors. They are divided into two groups. The first group is power supply and motor leads. The second group are control signals. When wiring your controllers keep these two groups separated. Run your power and motor leads to one side of the controller and the signal wires to the other if at all possible. Again, using shielded wire will take you a long way in avoiding extraneous noise.

2.5 DC Supply wires

When running power to various pieces of equipment in your electronics box, using twisted pairs will aid in negating noise from neighboring wires. The twist in the wire creates a canceling effect on any magnetic field that passes across them. For additional protection use twisted wire that is housed in a shielded jacket. This type of wire typically has a metal foil or braid wrapped around the wire along with a stranded wire that runs beside it. The foil or braid will absorb the magnetic field that a neighboring wire produces as current runs through it. For best results, attach the stranded wire to the DC ground. Doing this will prevent the field from passing beyond the shielding to affect the wires contained in the cable. When grounding the shield wire, only ground at one end. Grounding the shield wire at both ends can create a loop that can effectively negate the ground allowing noise to be injected back into the wire.

When making power connections to the controller use a twisted pair of wires. You can twist them yourself, but make sure you have at least one twist per inch of wire. For best protection use a shielded twisted pair and attach one end of the shield wire to your grounding plane. The piece of aluminum plate your controllers are mounted to.

When making connections to the motors, use shielded cable. These wires carry the most current and will emit a lot of magnetic radiation. Be sure to ground the shield wire to the ground plane.

When making signal connections to the controller (The step and direction pins) use a twisted pair to make the connection. Category 5 Ethernet cable is cheap and contains four twisted pairs. This makes excellent signal wire. You can strip the housing back enough that you can run two pair to one controller and another two pair to a second controller. You can also buy Ethernet cable with a shield. If you ground this shield, be sure to ground it to the PSU that supplies your logic signals and not to the power plane for your stepper controller and its PSU.

2.6 Variable Frequency Drives (VFDs)

VFDs are used to drive spindles and work by varying the frequency of the AC going to the spindle. VFDs are great noise producers. If at all possible locate your VFD in a separate enclosure or cabinet to reduce the risk of it injecting noise into your other wiring. Recommended wiring for the VFD is foil braid or copper tape shielded wire and observing good grounding practices. A PDF document from Belden on the topic can be found at the following URL.

http://www.mc-mc.com/Portals/1/articles/WP-VFDCablingPractices.pdf

2.7 Wire Selection and Use

Wire comes in many types, sizes and configurations. Wading through all the wire available is a monumental task of its own, but for our purposes we only have a look at the types of wires suitable for wiring a CNC controller. Additionally, how the wire is to be used can have some affect on the overall system. What follows are some tips that may prove helpful.

1. Shielded Wire.

There are basically three types of shielded wire. One has a bare wire braid that surrounds the wire inside, and the other has metal foil that surrounds the wire inside. And lastly, there is both a braid and metal foil. All of these are designed to prevent noise from being injected into the wire enclosed. The type of shielded wire you will select will depend on the amount of noise you are trying to combat. A brief discussion of each follows.

a. Foil Shielded Wire

Foil shielded wire has a thin metal aluminum foil that is usually bonded to a film of plastic that surrounds the wire. The enclosed wire is usually 100% covered and that is good. Foil shielded wire can be difficult to use, especially when trying to attach a connector to the shielding in order to ground it. For this reason, you will usually find a bare metal stranded wire enclosed that you can make a connection to. Of the three types of shielded wire, this is the least effective.

a. Braided Shielded Wire

Braided Shielded Wire has a metal braid that surrounds the wire. It is more bulky than the foil shielded wire and does not provide 100% coverage. It typically covers 70 to 95% covering depending on how tight the braid is made. The braid is typically made of tinned copper wire. Because copper is a better conductor than aluminum and it's bulky size it works better to shield the wire than the foil shielded wire. It should be noted that this type of shielded wire will cost more than the foil shielded wire above. Of the three types this one is more effective than foil shielded wire, but less effective than the next one discussed.

a. Multi Shielded Wire

For very noisy environments a wire that contains both foil wrapped wire and a braid will provide the most protection. As you can guess, of the three types this is the most expensive.

2.8 Routing Wire

There are two types of routed wire. Wire that is stationary and wire that gets moved as the machine runs. Along with this, we must consider the effects of neighboring wires to the wire being routed may have. The following recommendations were given by forum member lead_injection.

2.8.1 Routing Movable Wires

Any wire that will be moved about in normal operation of the CNC falls into this category. For example, the wires that run from your controllers through cable management and then to your motors.

If you are flexing your cables, use high flex rated cable (IGUS). This may get pricey for 4pair STP (Shielded Twisted Pair) type cables.

If running cables in a cable track/carrier tie them down at both ends of the cable track. If not, ratcheting can occur and fatigue the cable prematurely.

In a cable track/carrier observe the neutral axis idea. Have the wire run as close to the neutral axis as possible. Make sure the wire is not in tension in the longest neutral axis situation.

2.8.2 Routing Stationary Wires

Running different signal classes (high voltage and low voltage) in metal conduit may make the noise worse. Separate by as much distance as possible and if they have to cross, cross them at 90 degree angles.

Avoid wiring loops coming off of devices - they are great antennas for receiving noise, or great antennas for transmitting noise. Run wires along the ground plane.

2.9 Signal Wires

The wires that are used to transmit logic signals are the most susceptible to noise interference. The reason for this is the low level voltages that are used to convey the information. The following will prove helpful in keeping your signal wires clean.

Isolate the PSU for your signal wires from the rest of the system. Keeping the power supply isolated will prevent your other supplies from interfering with it.

Use twisted pairs to carry your signals. For best results use both wires and do not share a common ground for two or more signals. Use a pair of wires for each signal. Using shielded wire is best. When grounding the shield wire, ground to the logic PSU.

Shielded Twisted Pairs (STP) are most beneficial to differential signals. If you add the noise to both signals, the common point is not affected - the magnitude of the difference is maintained.

2.10 Stranded Wire

Wire comes in two forms, solid conductor and stranded. Both have their ups and downs. Stranded wire is pretty common in cables because it is more flexible. When using any stranded wire keep the following things in mind.

1. Terminate the ends

Little wires hanging off the end of your cable can create problems. They can cause shorts when wired next to other wires in close proximity or to the boards they are connected to. They can also act like a little antenna that will help them emit any noise they may be trying to generate. There are several ways that you can terminate them.

Twist and solder the ends. Tinning the wires in this manner makes then easier to insert in the set screw connectors and binds all the little wires together preventing them from fraying apart.

Use crimp on ends. Crimp on ends like spade connectors or bootlace ferrules also work very well. It is best to not to tin the end before crimping them. Tinning the wires could allow them to loosen over time. Attention to detail and the proper selection of the crimped end will form a quality mechanical connection.

Be careful of the amount of insulation you strip from the wire. Stripping too much insulation off will lead to exposed wire that something can short against. If you do simply trim off the extra wire.

2.11 Control Signals

When a limit or home switch is engaged, or a probe has made or broken contact, we use this signal to signify the event has taken place. Typically this is done by using input pins on the parallel port. The signal voltages used on the port are in the 3 to 5 volt range depending on the type of port you have. It only takes a small noise injected onto the signal wires to put it in that unknown voltage area we discussed above, resulting in an unknown TTL state. If after careful wiring and planning you are still having these kind of issues, there are a couple of things you can do to fix the problem.

Higher control voltages. If instead of using the logic PSU to supply the voltage for the detection circuit you used a larger PSU, for example a 12 or 24V supply to the input side of a mechanical relay or SSR (solid state relay), the control circuit would be less affected by noise. In turn, the mechanical relay or SSR would turn on or off the control signal to your parallel port or breakout board allowing you to keep these small control voltages in short runs and contained in your wiring cabinet. In addition you may be able to find opto-isolators or opto couplers that will work on higher input voltages that will switch the lower TTL voltages to the port. A search on Jameco, Mouser or other electronics supplier should turn something up.

Higher control current. If you are using pull up resistors on your inputs, you can use a smaller valued resistor to increase the current draw and reduce the chance of a false signal. Keep in mind the additional current load on your PSU. You can calculate the current load with a judicious application of Ohm’s Law.

2.12 Mechanical Noise

Mechanical Noise happens when mechanical contacts open and close, as in a switch or relay contacts. As they open or close they will bounce against each other creating a rapid state change in the circuit. The electronics monitoring the change in state, the opening and closing of the contacts, can detect these quick changes. Sometimes it doesn’t matter, but more often than not, you don’t want this condition to interfere with the operation of your machine. For example, it will generate errors when probing. However, like I mentioned above, this situation is pretty easy to remedy.

1. Debouncing a switch with hardware.

Debouncing a switch can be done with the addition of some hardware to the signal circuit. There are ICs (Integrated Circuits) like Motorola’s MC14490 that are designed to do just this thing, but they can be difficult to find. A simple method of debouncing a SPST switch uses an RC network (sometimes coupled with a diode to increase the speed) as a delay into a Schmitt triggered inverter allowing it to compensate for the time it takes the switch to settle down. If you are interested in this method, you can find more information on the subject by visiting the following URL:

https://electrosome.com/switch-debouncing/

Additionally a great video on debouncing a SPST switch can be found here:

https://www.youtube.com/watch?v=tmjuLtiAsc0

2.13 Debouncing a switch with HAL

The hardware abstraction layer (HAL) of LinuxCNC has a debounce component. The debounce component has a single input pin and a single output pin. Its job is to look at the input and to send the output after a programmed delay time. The debounce HAL component will be covered in a separate tutorial when we create a touchoff plate for the CNC machine. More information can be found for the debounce component by visiting the following URLs:

http://linuxcnc.org/docs/html/hal/rtcomps.html#sec:Debounce http://linuxcnc.org/docs/html/man/man9/debounce.9.html

2.14 Documentation

Documenting your wiring cannot be over stressed. With power feeds, motor leads, signal wire and everything else you stuffed into your your wiring compartment, you will be grateful that you documented your wiring. A year after you completed your CNC wiring and you want to add something, or some trouble arises, you will have your documentation to fall back on.

So, what should you document? The list that follows probably should be the minimum you hang onto and if you think you should note or save something else, you probably should.

2.14.1 Hardware Documentation.

At a minimum, make sure you save any documentation you have for your hardware in a safe place. Stepper controllers, Break out Boards, Power Supplies, PID controllers, individual components if they apply, Servo Controllers, etc. Although it takes a little more room, I print all the electronic documentation for the stuff I have and keep them in a binder in plastic sheet protectors. This binder is divided into sections based on the type of hardware or documentation I am keeping.

2.14.2 Wiring Schematics

As you wire your CNC, make sure to draw up a schematic that you can reference later. The schematic does not have to be all that neat, but you must be able to pick it up a year later and understand what you have done. Be sure to annotate your schematic with any additional information that will help remind you of what you made. Keep a copy of your schematics in your documentation folder so it does not get lost. If you keep things electronically, scan your schematics and save it with the rest of your documents. If you don't have a scanner, you can take a digital picture and save it to your computer.

2.14.3 Label your wires

Take the time to label your wires. When you start bundling wires, it is hard to look at them and know for sure what is what when you go back to modify or change something a year later. Label your motor wires with the joint or axis they run, label your signal wires so you know what they do. The idea here is to make it easy to identify a specific wire or set of wires you have in your controller.

2.15 Additional Information

2.15.1 LinuxCNC and Machine Related Questions

Additional Information and help can be found by using the LinuxCNC forums. If you are not a member of these forums, I encourage you to join. Please visit:

http://linuxcnc.org/index.php/english/forum/index

The folks there are very helpful, have loads of experience and are willing to share some insights.

2.15.2 Cable and Wire Harness Assemblies

Publication IPC/WHMA-A-620 covers the Requirements and Acceptance for Cable and Wire Harness Assemblies. This publication describes acceptability criteria for producing crimped, mechanically secured, or soldered interconnections and the associated lacing/restraining criteria associated with cable and harness assemblies. It is not the intent of this document to exclude any acceptable procedure used to make the electrical connection. A 2002 version of this document can be downloaded from the following URL.

http://www.gartechenterprises.com/downloads/IPC-A-620.pdf

2.15.3 Understanding EMC (Electromagnetic Compatibility) Phenomena

A publication from Groupe Schneider goes into depth about what Electromagnetic interference is and how to design your system with it in mind. This is a great document is you want to know the what and why of electromagnetic interference. It discusses in detail, cables, grounds, types of interference, chassis connections, filters and more. A very good source of information to those who want to know more on the topic. You can download a copy of the 200+ page PDF from the following URL:

http://www.engineering.schneider-electric.dk/Attachments/ia/instal/electromagnetic_compatibility_install_guide.pdf