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Chapter 1

Stepper Information

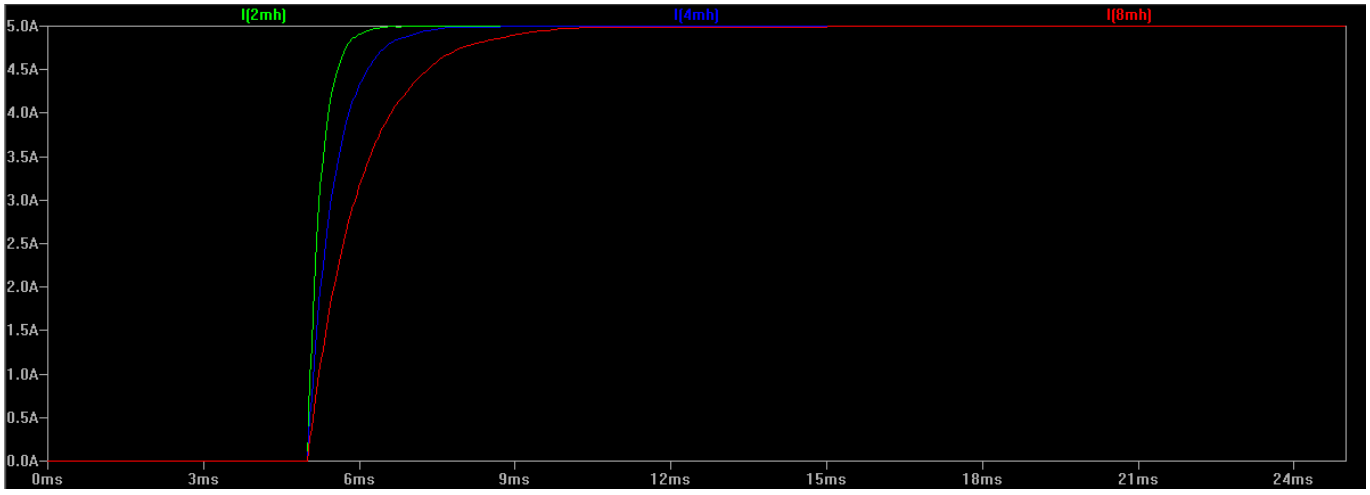
1.1 Stepper Motor Operation

Stepper motors operate by sequentially energising and de-energising several coils surrounding the rotor in such a way that the shaft is magnetically forced to rotate around in discrete steps. Steps of 0.9 - 1.8 degrees are quite common, giving 400 - 200 steps per full revolution of the shaft.

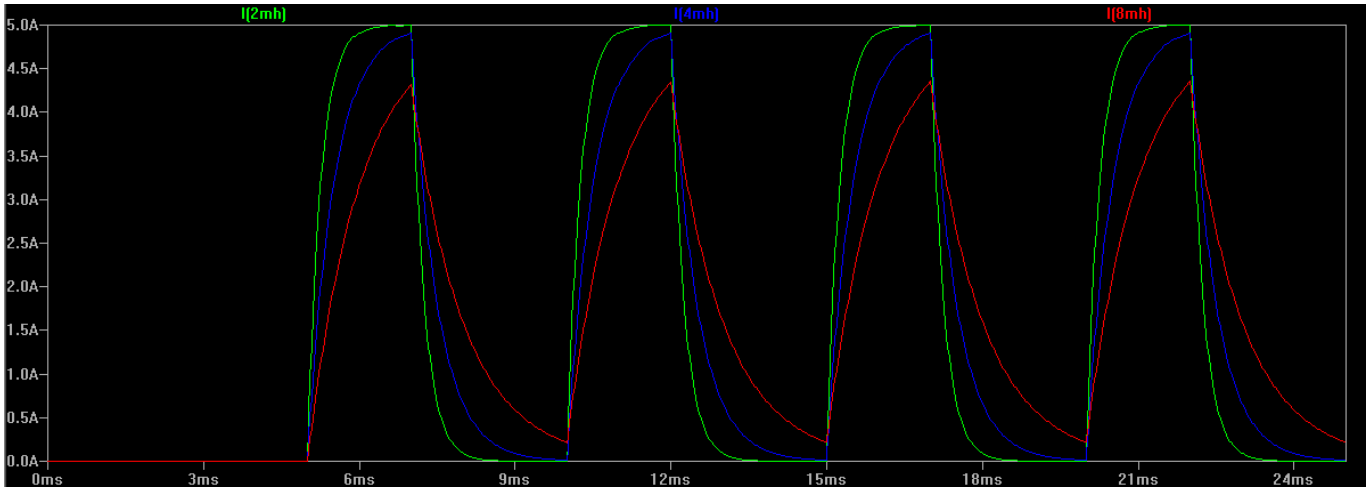
As in real life, nothing can change from one state to another with absolutely no time delay. In the case of the stepper motor, the current passing through each coil, and thus the magnetic field that pulls the rotor around to each step of rotation takes some time to take effect. This is due to the coil having inductance (expressed in Henries, abbreviated to the letter H) which has a natural tendency to resist the flow of a rapidly changing current. More coil inductance results in a slower rate of current change and thus a slower rate of magnetic field expansion and contraction.

The maximum torque that the stepper motor can achieve is when the motor is stationary with one winding energised. This figure may be quoted on a stepper motor datasheet as the *holding torque*. As the rate at which each coil is energised and de-energised increases to induce rotation in the shaft, the time that each coil can exert its full magnetic attraction on the rotor reduces, thereby reducing the overall torque. This relationship between speed and torque is largely inversely proportional.

In the below example, the charging time for three coils is shown when the applied voltage is stepped from 0 V to 40 V. While all three coils can easily reach the full current limit of 5 amps (A), the time taken varies for each coil. The 4 milli-Henry (mH) coil (blue trace) takes twice as long to reach full current than the 2 mH coil (green trace), and the 8 mH (red trace) coil takes twice as long again:

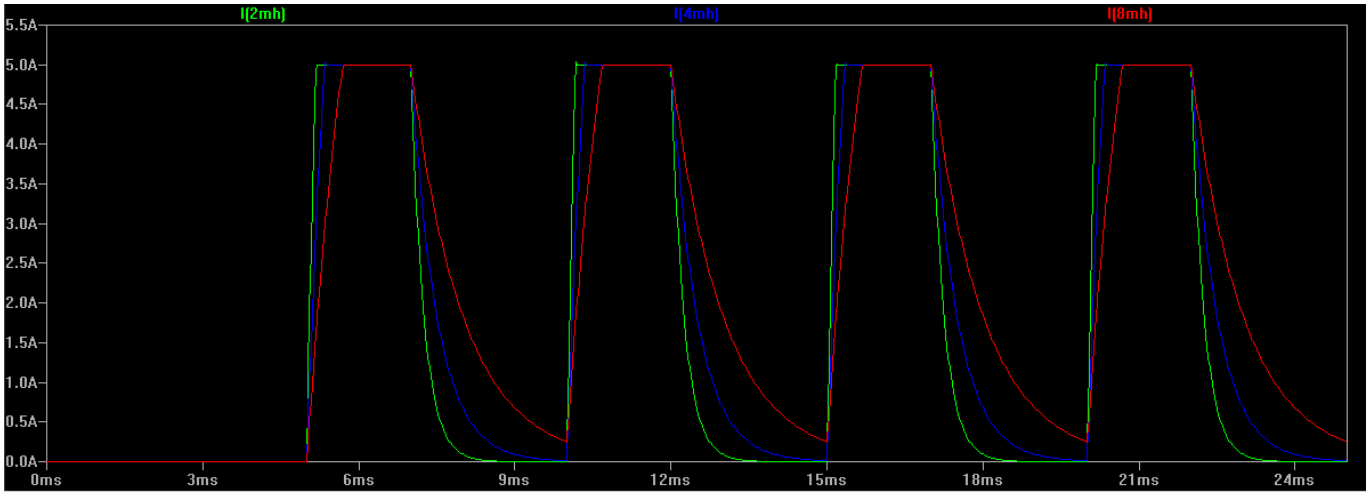


If the rate at which step changes are applied to the coils is significantly shorter than the rise time, it's easy to see that the winding has less time to attain full magnetic attraction on the rotor, and thus maximum torque is curtailed. In the below example the 2 mH coil can achieve the full 5 A limit before the step voltage is removed, but the 4 mH and 8 mH coils cannot:



The accepted way of improving motor speed while maintaining torque is to increase the speed at which the magnetic field of the motor coils can expand and collapse. The easiest way to accomplish this is to increase the supply voltage to force the current in each winding to rise and fall much more rapidly. A quicker magnetising time equates to faster step rates while improving torque at higher speeds, both of which are obviously desirable in a CNC system.

Using the same example as above, but increasing the step voltage to 80 V it can be seen that all three coils can now reach the 5 A maximum quite easily:



However, careful management of a higher drive voltage is required, as a higher voltage will increase current flowing in each coil with a corresponding increase in temperature of the winding. Excessive temperature rise in the winding will lead to eventual overheating and failure of the motor.

In most stepper-based CNC systems the voltage of the supply feeding the stepper driver is several orders of magnitude greater than the voltage of the motor itself. A typical NEMA23 stepper motor may have a rating of only a handful of volts, yet the power supply and driver could be operating at 48 VDC or more.

Nearly all modern stepper motor drivers on the market today are constant-current types. That is, the current being applied to each winding is fixed irrespective of how much voltage is being applied.

Most drivers accomplish this by monitoring the current being drawn through the motor windings and rapidly switching the outputs on and off at a very high frequency to maintain this current. Depending on the drivers being used, it may even be possible to hear this high frequency whistling in the motors themselves when stationary. Because the voltage is rapidly switched on and off to maintain the winding current at an approximate fixed value, these types of drivers are also known as *chopper drive*.

1.2 Selecting a Stepper Power Supply

While a higher voltage is directly related to more speed and torque, obviously there comes a limit where increasing supply voltage is no longer beneficial. The first limitation to the maximum power supply voltage is likely to be what the stepper driver itself is capable of withstanding. This value should be provided in the datasheet for the stepper driver, and exceeding this voltage will result in the destruction of the driver. Ideally the power supply voltage should be chosen with a degree of headroom that falls under this maximum voltage limit of around 10%. If, for example a stepper driver has a V_{max} rating of 80 VDC, the maximum power supply voltage should be limited to 72 VDC.

As mentioned above, excessive motor supply voltage also leads to excessive heat rise in the motor windings, which can lead to eventual failure of the motor through overheating. A commonly used equation for providing a guideline in determining the maximum voltage to prevent excessive heat rise is to take the square-root of the winding inductance quoted in the motor datasheet (expressed in mill-Henries) and multiply by 32. For example, choosing a stepper with a coil inductance of 4 mH will result in a maximum power supply voltage of 32 x SQRT (4) = 64 VDC.

Many stepper motor datasheets will also provide speed/torque curves, often plotted using different supply voltages. By studying the graphs it may be determined that increasing the supply voltage by a factor of two will not result in a corresponding improvement in speed/torque by the same degree. If there is little to be gained in running a stepper motor at 64 VDC, this may help in narrowing down the proposed power supply to 32 VDC which will also help minimise excessive heat rise in the motor windings.

The other factor to consider is the current rating of the power supply. This is based from the motor's winding current ratings and whether the motor windings are wired in series or parallel, both of which should be listed in the motor's datasheet. A good rule of thumb is to size the power supply current rating at 2/3 of the rated phase current of the stepper motor if the windings are in parallel, or 1/3 of the rated current if wired in series. Thus, for a stepper motor rated at 4 A wired in parallel, the power supply needs to have a current rating of at least 2.7 A, or 1.3 A if wired in series. The total current rating of the complete system is then the sum of all stepper motors' current requirements.

1.3 Resonance

Motor resonance occurs when the rate at which the steps are applied to the windings matches the natural frequency of the motor itself. Applying steps for a prolonged period of time at this rate results in the torque dropping dramatically, and the motor may stall or even rotate in random directions. Some stepper motor datasheets provide plots of the torque/speed relationship and show a dip in the graph where resonance is likely to occur. It should be noted that this resonant peak provided in the datasheet is only for the motor itself - as soon as the motor is coupled to other components (i.e., installed in a CNC system) the resonant frequency may be altered, or even multiple new resonances introduced.

Several methods exist to help control the effects of resonance, all with varying degrees of complexity, effectiveness and side effects:

- Microstepping can help reduce resonance by using smaller step changes in current between each step. These smaller step changes cause less ringing in the motor and windings and thus cause less excitation at the point of resonance.

- Ensuring the motor is never operated at a particular frequency for a sustained period is a very basic method of reducing resonance, always accelerating or decelerating through the resonant peak.
- Increasing inertial load will damp unwanted resonances at the expense of some torque and potentially some accuracy. Elastomeric motor mounts, shaft couplings or bearing mounts can be employed.
- More advanced stepper motor drives may have the ability to switch between stepping modes such that the resonant peak is managed at certain rates of operation. Other systems exist to place electrical load on the windings, which has a similar effect to mechanical damping, above.

1.4 Microstepping

A stepper motor operating with each winding being fully energised in a sequential fashion is operating in full-step mode. That is, the maximum rotation resolution possible for that motor is the same as the number of whole steps that motor is manufactured to perform at (e.g., 200 steps per revolution for a 1.8 degree/step motor). As each winding is energised the rotor clocks around fully from one detent to the next.

Additional rotational resolution from a stepper motor can be obtained by performing microstepping, whereby the current being driven into each winding can essentially be *ramped* in discrete intermediate steps. This then causes the rotor to gradually straddle across each rotational detent rather than making the full jump from one step to the next.

Microstepping is commonly performed in multiples of 2 (4x, 8x, 16x, 32x etc). For example, a drive set to 4x microstepping will divide each step into four discrete current levels in the motor windings, thus affording an improvement in rotational resolution by a factor of four. This obviously means that for a typical step/direction control interface there will need to be four times as many step pulses generated to make the motor move the same amount had it been operating in full-step mode. To make the motor rotate at the same speed the rate at which pulses need to be applied to the drive also needs to be four times as fast.

At low rotational speeds, microstepping actually results in slightly higher torque than when full stepping. This is due to the smaller changes in current between intermediate steps resulting in less energy being wasted exciting natural resonances in the motor. As RPM increases however, torque tends to fall off at a similar rate as full stepping.

However, continuing to increase the degree of microstepping will eventually lead to some real-life limitations. Step pulse generation, particularly when using the parallel port, is limited in frequency. This will inevitably limit the maximum speed at which the drive can be commanded to step at. With high degrees of microstepping this will result in unacceptably slow RPM of the motor.

Excessively-high rates of microstepping have no real benefit if the resultant accuracy is too small to be mechanically useful. A 1.8 degree per step motor running at 16x microstepping is theoretically capable of 0.1125 degrees per step. Coupled with a 20 TPI leadscrew this should result in a positional resolution of 0.000016” or 0.0004 mm. In reality it is incredibly difficult to achieve such fine degrees of control. All components in the CNC system will contain tolerances and countering forces (backlash in leadscrews, flex in gantries, runout in the spindle and cutting tool, static friction in the stepper motor itself, stepper detent error , etc.) that will render such small amounts of resolution completely meaningless. In practice, microstepping at rates in excess of 4x or 8x on a CNC machine fitted with leadscrews serves little purpose. In some cases it may even be more beneficial to run at lower degrees of microstepping or even full steps, and operate the stepper motor through a gear reduction to obtain the necessary resolution and torque gains.

1.5 Open and Closed Loop

In the simplest CNC systems employing stepper motors, the host computer and/or stepper driver receives no feedback from the motor that it has achieved the desired outcome when commanded to begin stepping. The assumption by the software, driver and end user is that the motor operated correctly and the axis has moved to the expected new position. A system operating in this fashion is said to be running in *open loop*, where the device at the end of the signal chain (the stepper motor) does not provide any indication to the device at the start of the chain (the computer) that the target was reached.

A further enhancement to the basic stepper motor is to run the system in a *closed loop*. This is achieved by equipping the stepper motor with a rotary encoder whose positional signal is returned back to a device higher up in the signal chain. In this way the motors' actual position can be compared to the expected position at all times, and the drive parameters adjusted in real time to ensure that the motor does not fall behind. This enables closed loop stepper systems to be able to achieve better speed and torque performance than open loop systems, due to the system constantly compensating for any deviation to the stepper's performance under varying loads.

Basic systems operating in this fashion may only close the loop between the motor and the driver, leaving the software on the host computer out of the loop. The software issues step/direction pulses to the downstream driver as it would normally when running in open loop. In these situations the drivers usually include an alarm output which signals the software to halt when the load placed on the stepper becomes too great for the driver to compensate without losing steps.

More advanced implementations of closed loop operation bring the encoder signal all the way back to the host computer, but require that a much higher hardware and software overhead be installed to manage the encoder feedback and calculation and delivery of drive compensation.

Chapter 2

Stepper Timing

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 Con-troller 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	

Manufacturer	Model	Step Time	Step Space	Direction Hold	Direction Setup	Steps on	Spec Sheet	
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	
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	

Manufacturer	Model	Step Time	Step Space	Direction Hold	Direction Setup	Steps on	Spec Sheet
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
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

Manufacturer	Model	Step Time	Step Space	Direction Hold	Direction Setup	Steps on	Spec Sheet
*Motion Control	MSD542	>1500	2000	2000	2000	Rising Edge	http://www.motioncontrolpr c2/-uploads/-msd542%20datasheet.pdf
Parker	OEM750	200	300	0	200000	Rising Edge	http://www.compumotor.co 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 Engi-neering	Silverpak 17D/DE	20000	20000	200	200	Rising Edge	http://www.linengineering.c site/-products/-pdf/-SilverPak17D_DE-manual.pdf
Hobbycnc	Pro Chop-per 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
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	?	https://www.sherline.com/-
Burkhard Lewetz	Step3S	6000	15000	?	5000	?	http://www.lewetz.de/-download/-ibstep3se.pdf
Parker Com-pumotor	Zeta 4	200	200	?(200)	?(200)	Rising Edge	http://www.compumotor.co manuals/-ZETA/-ZETA_Rev_A_Entire.pdf

Manufacturer	Model	Step Time	Step Space	Direction Hold	Direction Setup	Steps on	Spec Sheet
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&
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
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

Manufacturer	Model	Step Time	Step Space	Direction Hold	Direction Setup	Steps on	Spec Sheet
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/
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 3

Best Wiring Practices

3.1 Electrical Noise

Electrical noise in a system is caused by Electromagnetic Interference (EMI), where signals appearing in one electrical circuit interfere with an adjacent circuit, either through electromagnetic induction, electrostatic coupling or conduction. EMI can cause problems with the daily operation of a CNC machine, and can manifest itself in various ways such as false triggering of limit switches, prematurely interrupted tool probing operations, corruption of a serial data link to a VFD or erratic behaviour of the CNC control systems and software.

When current passes through a conductor a magnetic field is created. As the current increases the magnetic field gets stronger, and then collapses again when current ceases to flow. If this alternating magnetic field happens to cross another conductor it can induce an unwanted voltage into it, which presents itself as noise.

There are several methods that can be employed to minimise the effects of EMI in any electrical system. The most effective of these is obviously to prevent the noise from occurring in the first place. In reality the method of controlling the effects of EMI is usually by applying measures to prevent noise from contaminating wanted signals in the CNC system.

3.2 Ground, Earth and Common

Confusion can arise when using terms such as earth, ground and common. In some cases they may be used to describe the same thing; that being the point in an electrical system to which all voltages are referenced to. For the purpose of this article, the terms *earth* and *ground* refer to the point at which the incoming mains supply is earthed to, whereas *common* is the return or negative terminal on a DC supply. In some cases it is permissible to ground the common on a DC supply, thereby making the negative terminal on that supply the same potential as the incoming AC earth, but for the purposes of this discussion the terms *earth* and *common* must be made distinct from each other to avoid confusion.

3.3 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 the purposes of this article it is only necessary to consider the types of wires typically used when wiring a CNC controller. Additionally, how the wire is to be used can have some effect on the overall system. What follows are some tips that may prove helpful.

3.3.1 Single Conductor Wire

Wire comes in two forms: solid conductor and stranded. Solid core wire is generally cheaper than stranded, but more likely to break if used in applications where repeated bending is expected. Fortunately, the prevalence of stranded wire on the market means that its use should be encouraged wherever possible.

Wires should be terminated such that all strands in the conductor are neatly and securely located into the mating receptacle. This may be accomplished by either twisting the strands together before inserting in the termination, or using a compression crimp such as a spade or bootlace terminal. Care should be made to ensure that no strands of wire end up outside the termination to prevent accidental shorting with adjacent terminations.

If using a compression crimp on the bare wire, avoid soldering the strands together before crimping. Crimping the lug onto a soldered wire can result in the lug working loose over time as the soldered strands lose their compressibility once the crimp has been applied. For this same reason, soldered wire should not be installed in a terminal block where the screw stud bites directly onto the wire when tightened.

When stripping the wire ready for a termination, only remove the minimum amount required to keep the termination covered when complete. Stripping too much insulation off will expose some of the wire that something can short against.

The circuit that the wire is intended for should also be considered; the voltage the circuit operates at and the amount of current it carries have a bearing on the choice of wire to be used. The thin insulation on a piece of recycled CAT5 ethernet cable is insufficient to withstand the voltages that can appear at the output terminals of a Variable Frequency Drive, nor is the cross sectional area of the conductor sufficient to carry several amps of current without overheating and potentially causing a fire. Conversely, while it is perfectly permissible to wire a limit switch circuit using 2.5 sqmm cable, it creates needless bulk in the wiring loom. Consult any manufacturer's documentation and your local country's electrical wiring codes for minimum suggested wire gauges for power and control requirements.

3.3.2 Shielded Wire

There are two 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. The type of shielded wire selected will depend on the amount of noise you are trying to combat.

Foil Shielded Wire Foil shielded wire has a thin aluminum or copper foil that is usually bonded to a film of plastic that surrounds the wire. The enclosed wire is usually 100% covered. Attaching the foil to earth can be difficult, especially if the foil is constructed from aluminum or laminated to a plastic backing material. For this reason, it is usual to find a bare metal stranded wire enclosed inside the cable which is in contact with the foil for the full length of the cable. This is called the drain wire and is used to make the connection to earth with.

Braided Shielded Wire Braided shielded wire has a woven copper braid that surrounds the wire. It is more bulky than foil and does not provide 100% coverage, but is more flexible than foil shielded types. Coverage is typically 70% to 95% depending on how tight the braid has been constructed. Despite the lower coverage of braided shield, the effectiveness is greater than foil shielding due to the increased bulk of the braid, and copper being a better conductor than aluminum.

For very noisy environments, a further subset of the above two shielding methodologies may be employed, whereby both braid and foil shielding is used simultaneously. Individual wires in a multi-conductor cable may also be shielded along with an overall shield being applied to the entire cable jacket.

3.4 AC Line Voltage

The incoming mains AC that powers the CNC system can pick up and carry noise into the power supplies and other equipment. For example, if the incoming supply is also used to feed large motors, electrical noise may be generated on the line feeding the CNC components. Although most modern electronic devices feature built-in mains filtering to help minimise the susceptibility to mains-borne interference, the custom and modularised nature of a CNC system can mean that components used come from a wide variety of sources with differing degrees of inherent noise immunity.

Inline filters may be installed on the incoming mains supply feeding the CNC control system to help reduce any induced noise. Running the CNC system from a different mains circuit to any large electrical sources of noise may also help minimise any potential sources of mains-borne interference.

□□
Be aware that in many countries, the installation and alteration of mains circuits can only be carried out by licensed electricians.

3.5 Power Supply Units

3.5.1 AC Ground

A typical CNC machine may have several different Power Supply Units (PSUs) installed in the system. Any device powered from the incoming mains designed to be earthed must be properly and permanently terminated to mains earth. Ideally this should be made to the same point in the system, which may be a threaded post or bolt, a copper/brass termination strip or a large metallic mounting plate within the control enclosure.

The prevalence of high-frequency switchmode PSUs used in CNC systems increase the likelihood of RF noise being coupled from them to adjacent circuitry. Many of these PSUs have a metal case which, if connected to mains earth, will help screen the coupling of high frequency EMI into other electrical components.

From a safety standpoint, it is important that these mains earth connections also be mechanically strong and unlikely to break free, and the wire used has a cross-sectional area sufficient to carry the anticipated fault current should a short to earth occur. It is also imperative that mains earth is never used as a current-carrying conductor for other components in the system. Earth shall be used for one purpose only: safety earthing.

Note also that the colour of the jacket used to make a termination to earth may be prescribed by the wiring code for your country, and the conduction of other unrelated signals in that same wire colour may be prohibited.

3.5.2 DC Common

Commoning of a DC PSU is somewhat dependent on the electrical operating requirements of the CNC system. For example, a stepper motor driver operating with a 24VDC motor supply and a 5V logic supply may have optically-isolated signal input lines which provide complete electrical separation of the driver’s input and output circuitry for safety and noise immunity purposes. Tying the stepper motor and logic control supply commons together in this case may have a detrimental impact on the operation of the system.

In general it makes most sense to keep the commons of the various DC PSUs used in the CNC system separate from each other, and separate from the AC mains earth unless there is a specific requirement

to tie them together. In most cases the common points of the heavy-duty power sections of the CNC system (eg, stepper motor or servo motor drivers, spindle motors etc) will be segregated from common points of the electrically-sensitive sections of the CNC (control interface boards, limit switches, tool probe circuitry etc) to prevent cross-contamination of the two systems.

Should it be necessary to connect several common points of different PSUs together, or to connect a common of a PSU to AC main earth, it should be done at a single point only and as close to the common terminal of the PSUs as possible.

In CNC machines where the hardware drivers and interfacing circuitry are pre-assembled, the decision as to which DC commons are tied where is usually taken out of the hands of the end user.

3.6 DC Supply Feeds

In situations where a DC circuit is run with the common point disconnected from the mains earth (ie, the supply is *floating*), it can be helpful to run DC supplies using twisted pairs of wires, whereby each pair of wires in the circuit (eg, the positive and negative leads) is physically twisted together in a helix pattern. The twist in the wire allows both conductors to share the same *real estate* as closely as possible. Any EMI that passes across them will therefore be largely canceled as both conductors will receive the same degree of EMI. For additional protection use twisted wire that is housed in a shielded jacket with the shield terminated to mains earth.

Note however that twisted pairs of wires are less effective at combating the effects of EMI if one of the two wires is referenced to mains earth, as the conductor at earth potential is less able to be influenced by EMI than the un-earthed conductor. In these instances the twisting of the wires has less of an impact on the overall noise immunity, and shielded cable will be intrinsically more effective at reducing noise pickup.

3.7 Signal Wires and Control Lines

The wires that are used to transmit logic signals to and from various peripherals in the CNC (eg, stepper motor controller inputs, axis limit switches etc) are the most susceptible to noise interference. The reason for this is the low level voltages that are used to convey the information. When a limit or home switch is engaged, or a tool probe has made or broken contact, this signal is used to signify the event has taken place. Typically this is done by using input pins on the computer interface card or parallel port which, dependent on the application, may be signaled using as little as 3.3V. Evidently a 2V noise spike has the potential to corrupt the validity of a signal if the useful range is only 0-3.3V.

If possible, isolate the common point of the PSU supplying the logic peripherals from the rest of the system. For example, keeping the common of the low voltage power supply isolated from the common of the stepper motor supply will reduce the chances of large currents flowing in the stepper motor return line contaminating the common of the low voltage supply.

If the controller uses differential signaling, use twisted pairs to carry the signal. Shielded cable is preferred when the control lines are single-ended, or if the distances traversed are long or through electrically hostile environments. When grounding the shield in the cable, terminate to the mains earth.

If the controller and interfacing devices can withstand higher control signals, consider altering the wiring and power supply requirements to use a bigger voltage for signaling (eg, 12V or 24V). The same 2V EMI noise spike that could corrupt a 3.3V limit switch signal will be far less likely to cause issues with a limit switch operating with a 24V signal.

3.8 Stepper or Servo Motor Drivers

The metal housing of the driver should be connected to the local mains earth in the CNC system. Some driver enclosures will indicate a specific terminal as being the earthing point, in which case this point must be connected to earth via a dedicated wire.

Control and power wiring should be segregated as much as possible. Route signal input wires well away from power supply and motor drive output lines.

It is recommended to run both driver input and motor output wiring in shielded cable with the shield terminated to mains earth. The shield on the input lines helps reduce the amount of interference they can receive, while the shield on the output lines reduces the amount of noise they can radiate.

3.9 Variable Frequency Drives

If at all possible the Variable Frequency Drive (VFD) should be mounted in a separate enclosure or cabinet to reduce the risk of it radiating noise into adjacent wiring. If the VFD enclosure is metallic it must be earthed as per any recommendations in the manufacturer’s documentation.

Because the VFD is a high power, high frequency electronic switching device, the output is notoriously prone to EMI radiation, and it is advisable to run the VFD output to the connected motor in a shielded cable, with the shield terminated to mains earth.

3.10 Routing Conductors

3.10.1 Routing Movable Wires

Any wire that will be moved about during normal operation of the CNC falls into this category. For example, wires running from stepper drivers through a cable management system (drag chains) and then to the stepper motors mounted on a movable gantry. Cables and wires operating in these circumstances should be rated for extra flexibility. This precludes the use of solid-core wires and cables, as the constant flexing will lead to fatigue and eventual failure of the conductors.

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. Care should also be taken to ensure that mechanical rubbing of conductors against other parts of the machine is prevented.

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.

3.10.2 Routing Stationary Wires

As discussed earlier, running different signal classes (high voltage and low voltage) in proximity to each other has the tendency to exacerbate EMI interference. Separate conductors by as much distance as possible. If two conductors must cross over each other make the crossing as close to a 90 degree angle as possible.

Avoid long loops of excess wire at any peripheral devices - they are great antennas for receiving or transmitting noise. Where possible, run wires in close proximity to large earthed structures. If the controller enclosure features a large metallic back plate that is earthed, secure all control wiring against this surface as much as possible while wiring between two points.

3.11 Mechanical Noise

Very few mechanical switches (eg, an axis limit switch or tool probe input) will close or open perfectly when operated. More often than not the switch contacts will physically bounce against each other several times within a very short space of time when operated. This may be interpreted by the machine controller as multiple operations of the same signal when in reality only one clean state change was expected. Sometimes it doesn't matter, but in many circumstances it is desirable to ensure that any state change is as *clean* as possible and does not interfere with the operation of the machine. This is accomplished by debouncing.

Debouncing is achieved by permitting a state change on a mechanical switch to only register with the controller after a fixed period of time to allow any bouncing in the switch contacts to settle. Time delays of 5-15 milliseconds are usually sufficient. This can be done with the addition of some hardware to the signal circuit or in software within LinuxCNC.

3.11.1 Hardware Debouncing

Several schemes exist to implement debouncing of switches and relay contacts with hardware, ranging from the addition of a single capacitor across the signal and common lines, to dedicated debouncing integrated circuits such as the MC14490 or MAX6818. Several hardware debouncing schemes can be found via the link below:

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

3.11.2 Software Debouncing

The Hardware Abstraction Layer (HAL) of LinuxCNC includes a debounce component. This component has a single input pin and a single output pin. Its job is to monitor the input and to send an output after the input has activated for a programmed delay period. More information can be found for the debounce component by visiting the following page:

link:../man/man9/debounce.9.html

3.12 Documentation

The importance of documenting the installed wiring and components cannot be over-emphasised. Should the user want to modify the CNC system further down the track, or if trouble should arise that needs correcting, then complete and concise documentation of the wiring and equipment can save many hours of head scratching and frustration.

3.12.1 Hardware Documentation

At a minimum, make sure to save any documentation associated with the installed hardware in a safe place. Stepper controllers, break out boards, power supplies, VFDs, interfaces and controllers, servo and stepper drivers and any associated device settings are all critical components of the system and their documentation should be kept at hand for easy reference.

3.12.2 Wiring Schematics

As the CNC machine is wired, make sure to draw up a schematic that can be referenced to later. The schematic does not have to be all that neat, but it should be understandable in such a way that it could be easily interpreted at a later date, ideally by anyone who may need to service the equipment. Include details such as wire colours used, pin numbers, part numbers and any other notes that will help explain particular details not immediately apparent from first glance at the schematic.

3.12.3 Wiring Identification

Take the time to identify each wire in the system. When a bundle of wires has been cable-tied in place it can be very difficult to look at them and know for sure which wire goes where. Label the motor wires with the joint or axis they are associated with, or identify each signal wire so that it is easy to identify what that signal does. It will also help if this information is transferred to the wiring schematics.