Manual del Integrador
V2.10.0-pre0-5521-g8502ed4582

# Índice general

Capítulo 1

Información del sistema

1.1. Modos de operación

Los motores a pasos operan energizando y des-energizando secuencialmente varias bobinas que envuelven un rotor, de tal manera que el eje es forzado magnéticamente a girar en pasos discretos. Son muy comunes pasos entre 0.9 y 1.8 grados, dando 400 - 200 pasos por revolución completa del eje.

En la vida real, nada puede cambiar entre un estado y otro sin tiempo de retardo en absoluto. En el caso de un motor a pasos, la corriente que pasa por cada bobina, y por ende el campo magnético que jala al rotor para cada paso de rotación, toma algo de tiempo para surtir efecto. Esto debido a que la bobina tiene inductancia (expresada en Henrios, abreviados con la letra H), la cual tiene una tendencia natural a resistir el flujo de una corriente rápidamente cambiante. Mayor inductancia en una bobina resulta en un tasa más baja de cambio de corriente, y por lo tanto una velocidad más baja de expansión y contracción del campo magnético.

El toque máximo que puede alcanzar un motor a pasos es cuando el motor queda estacionario con un devanado energizado. Esta figura puede citarse en una ficha de datos de motor a pasos como el *torque/par de retención*. Mientras la tasa a la cual cada bobina es energizada y des-energizada se incremente para inducir rotación en el eje, se reduce el tiempo en que cada bobina puede ejercer su plena atracción magnética en el rotor, reduciendo así el torque general. La relación entre velocidad y torque es en gran parte inversamente proporcional.

En el ejemplo de abajo, se muestra el tiempo de carga de las tres bobinas cuando el escalón de voltaje aplicado va de 0 V a 40 V. Mientras las tres bobinas pueden alcanzar fácilmente el límite completo de corriente de 5 amperios (A), el tiempo que toma varía entre cada bobina. La bobina de 4 mili-Henrios (mH) (línea azul) toma el doble de tiempo en alcanzar la corriente completa que la bobina de 2 mH (línea verde), y su vez la bobina de 8 mH (línea roja) toma el doble que la primera:
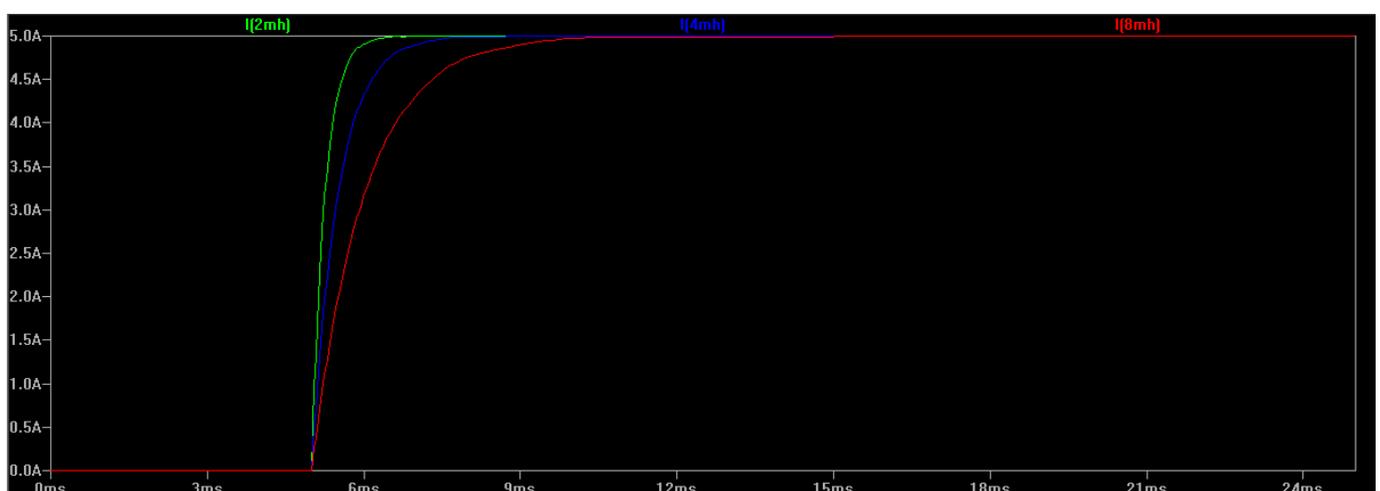
Si la velocidad a la que se aplican cambios de paso a las bobinas es significativamente mas baja que el tiempo de ascenso, es fácil ver que los devanados tienen menos tiempo para alcanzar la atracción magnética total en el rotor, y por lo tanto se restringe el torque máximo. En el ejemplo de abajo la bobina de 2 mH puede alcanzar el límite total de 5 A antes de quitar el voltaje de paso, pero las bobinas de 4 mH y 8 mH no pueden:
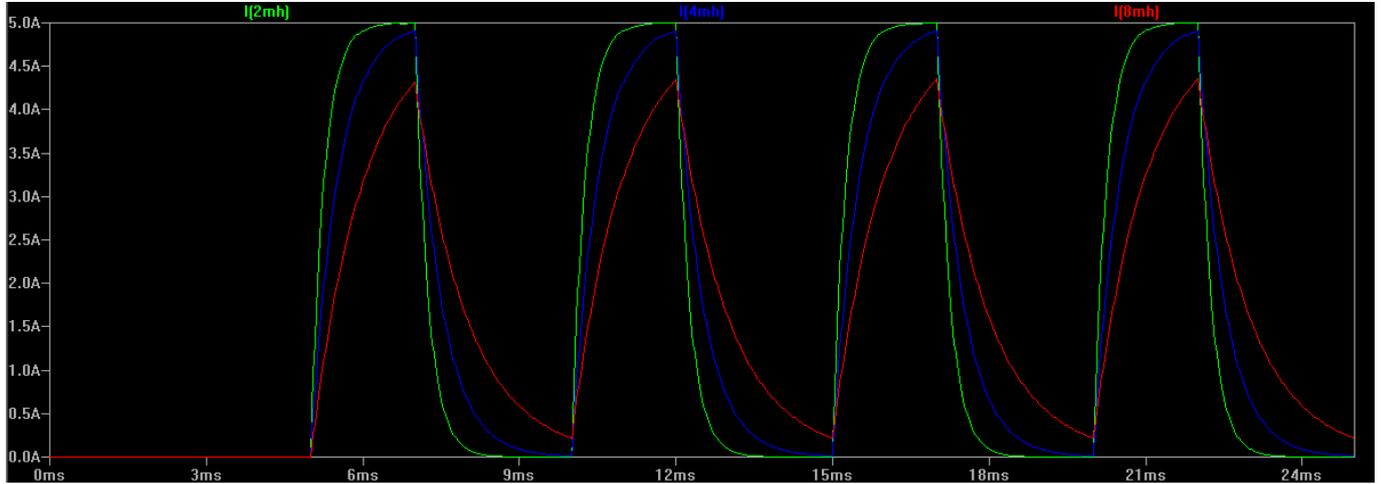
El método aceptado para mejorar la velocidad del motor manteniendo el torque es incrementar la velocidad a la que el campo magnético en las bobinas del motor puede expandir y colapsar. La forma más fácil de conseguirlo es incrementado el voltaje suministrado para forzar a que la corriente en cada devanado suba y baje más rápidamente. Un tiempo de magnetizado más corto equivale a velocidades de pasos más altas, mejorando el torque a altas velocidades; ambas cosas son obviamente deseables en un sistema CNC.

Usando el mismo ejemplo de antes, pero incrementando el voltaje de paso a 80 V, se puede ver que las tres bobinas ahora pueden alcanzar muy fácil el máximo de 5 A:
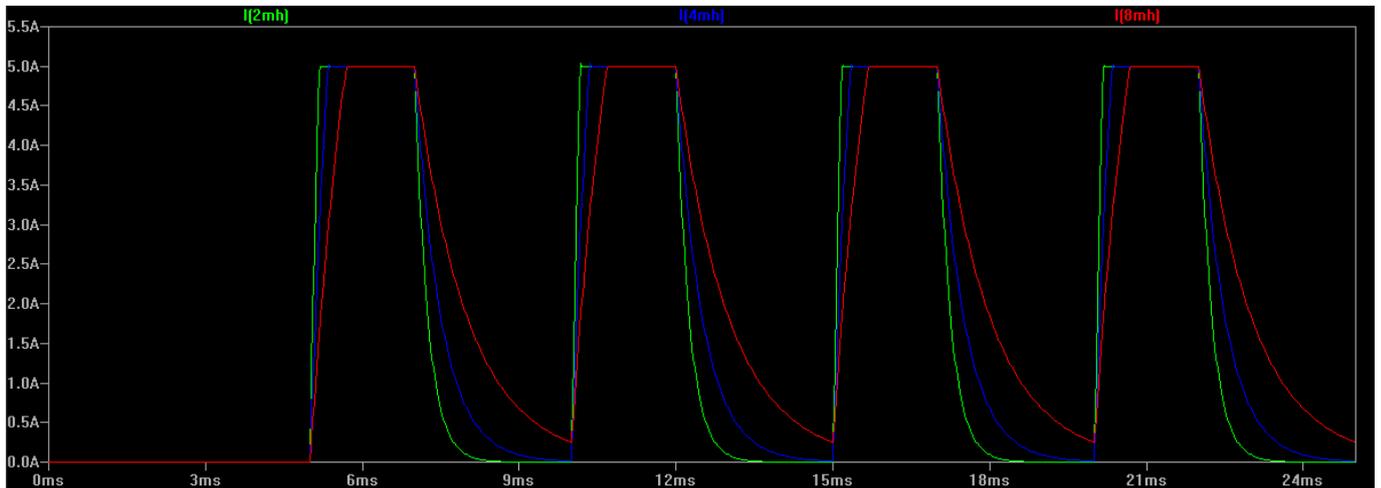
No obstante, es necesario procurar la administración de un voltaje de conducción más alto, ya que un voltaje mayor incrementará la corriente que fluye en cada bobina con un correspondiente incremento en la temperatura del devanado. Un aumento excesivo de temperatura en el devanado puede llevar a eventual sobrecalentamiento y falla del motor.

En la mayoría de los sistemas CNC basados en motores a pasos el voltaje suministrado al controlador de pasos es muchas veces más grande que el voltaje del motor mismo. Un motor a pasos típico NEMA23 puede tener una tasación de tan solo un puñado de voltios, pero la fuente de poder y el controlador podrían operar a 48 VDC o más.

Casi todos los motores a pasos modernos en el mercado actual son del tipo de corriente constante. Esto es, que la corriente aplicada en cada devanado es fija sin importar cuánto voltaje se aplique. La mayoría de los controladores logran esto monitoreando la corriente drenada por los devanados del motor y encendiendo y apagando las salidas con una frecuencia muy alta para mantener esta corriente. Dependiendo de cómo se usen los controladores, incluso podría ser posible escuchar un silbido de alta frecuencia en los motores cuando están sin movimiento. A este tipo de controladores también se les conoce como *controladores de helicóptero*.

1.2.   Eligiendo una fuente de poder de motor de pasos

Si bien un voltaje mayor se relaciona directamente con más velocidad y torque, resulta obvio que haya un límite en el cual un aumento de suministro de voltaje ya no será benéfico. La primer limitante al voltaje máximo de la fuente de poder es probablemente la cantidad que puede soportar el controlador en sí. Este valor debe encontrarse en la ficha de datos del controlador, y exceder este voltaje resultará en la destrucción del controlador. Idealmente el voltaje de la fuente de poder debe elegirse con un margen del alrededor del 10 % por debajo del mencionado límite máximo de voltaje. Por ejemplo, si un controlador tiene una tasación V_{max} de 80 VDC, el voltaje de máximo de la fuente de poder debería limitarse a 72 VDC.

Como se mencionó arriba, un exceso en el voltaje suministrado al motor conlleva un aumento excesivo de calentamiento de los devanados del motor, lo cual puede llevar a la eventual falla del motor por sobrecalentamiento. Una ecuación usada normalmente para dar pauta en la determinación del voltaje máximo, para prevenir el aumento excesivo de calentamiento, es tomar la raíz cuadrada de la inductancia de devanado señalada en la ficha de datos del motor (expresada en mili-Henrios) y multiplicarla por 32. Por ejemplo, elegir un motor a pasos con una inductancia de bobina del 4 mH resultará en un voltaje máximo de fuente de poder de 32 x SQRT(4) = 64 VDC.

Muchas hojas de especificaciones de motores a pasos también proporcionarán curvas de velocidad/-torque; a menudo graficadas con diferentes voltajes de suministro. Estudiando las gráficas se puede determinar que incrementar el voltaje suministrado en un factor de 2, no resultará en una mejora correspondiente en velocidad/torque del mismo grado. Si hay poco que ganar al correr un motor a pasos a 64 VDC, esto sugeriría reducir la fuente de alimentación a los 32 VDC propuestos que también ayudarán a minimizar el aumento de calentamiento en los devanados del motor.

El otro factor a considerar es la corriente nominal de la fuente de poder. Esto se basa en la corriente nominal de devanado del motor y ya sea que los devanados estén en serie o en paralelo, ambas disposiciones deberían estar en la ficha de datos del motor. Un buena regla general es dimensionar la corriente nominal de la fuente de poder a 2/3 de la corriente de fase nominal del motor a pasos si los devanados están en paralelo, o 1/3 de la corriente nominal si están conectados en serie. Entonces, para un motor a pasos nominado a 4 A en paralelo, la fuente de poder debe tener una corriente nominal de por lo menos 2.7 A, o 1.3 A si se conecta en serie. La corriente total nominal del sistema completo entonces será la suma de todas las corrientes requeridas por los motores a pasos.

1.3.   Resonancia

Las resonancia de motor ocurre cuando la velocidad a la que se aplican lo pasos a los devanados iguala a la frecuencia natural del motor mismo. Aplicar pasos a esta velocidad por un tiempo prolongado resulta en una caída dramática de torque, y el motor podría parar o incluso girar en direcciones aleatorias. Algunas hojas de datos de motores a pasos proporcionan gráficas de la relación torque/velocidad y muestran una tendencia donde podría haber resonancia. Debe considerarse que este pico de resonancia es solo para el motor; en cuanto se acople el motor a otros componentes (p. ej., instalado en un sistema CNC) podría alterarse la frecuencia de resonancia, e incluso, podrían introducirse múltiples resonancias nuevas.

Existen varios métodos para ayudar a controlar los efectos de resonancia, todo ellos con diferentes grados de complejidad, efectividad y efectos secundarios:

- Los micropasos pueden ayudar a reducir la resonancia al usar cambios de paso más pequeños en la corriente entre cada paso. Estos cambios de paso mas pequeños provocan menor zumbido en el motor y los devanados , y por lo tanto hay menor excitación en el punto de resonancia.

- Un método muy básico para reducir la resonancia es asegurarse que el motor nunca opere a una frecuencia particular por un período sostenido, acelerando y desacelerando siempre que se atraviese el pico de resonancia.

- Incrementar la carga inercial amortiguará las resonancias indeseables al costo de algo de torque y potencialmente algo de precisión. Se pueden usar montajes elastoméricos, acoplamientos de eje o soportes de rodamientos.

- Los controladores de motores a pasos más avanzados pueden tener la habilidad de conmutar entre modos de pasos para administrar el pico de resonancia a ciertas velocidades de operación. Otros sistemas existentes colocan carga eléctrica en los devanados, lo cual tiene un efecto similar a la amortiguación mecánica de arriba.

1.4. Micropasos

Un motor a pasos que opera con cada devanado energizado por completo de manera secuencial opera en modo de paso completo. Esto es, la resolución de rotación máxima posible para ese motor es la misma que el número de pasos completos para el fue fabricado (p. ej. 200 pasos por revolución para un motor de 1.8 grados/paso). Cuando se energiza cada devanado el rotor gira por completo de un tope al siguiente.

Se puede obtener una mayor resolución de rotación de un motor a pasos dando micropasos, donde la corriente conducida a cada devanado puede en esencia *enramparse* de pasos intermedios discretos. Esto provoca que el rotor transicione gradualmente por cada tope de rotación en lugar de dar saltos completos de un paso a otro.

Normalmente, los micropasos se dividen en múltiplos de 2 (4x, 8x, 16x, 32x, etc.). Por ejemplo, un controlador configurado para micropasos 4x dividirá cada paso entre cuatro niveles discretos de corriente en los devanados del motor, por lo que ofrecerá una mejora de resolución rotacional por un factor de cuatro. Esto significa obviamente que en una interfaz de control paso/dirección típica se necesitará generar cuatro veces mas pulsos de paso para hacer que el motor se mueva lo mismo que en el modo de operación de paso completo. Para hacer que el motor gire a la misma velocidad, la tasa a la que se necesitan aplicar los pulsos al controlador también debe ser cuatro veces más rápida.

A velocidades de rotación bajas, los micropasos resultan en realidad en un torque ligeramente mayor que en paso completo. Esto debido a los menores cambios de corriente entre pasos intermedios, resultando en menor desperdicio de energía excitando la resonancia natural del motor. Sin embargo, a mayor incremento en las RPM el torque tiende a caer a la misma razón que en paso completo.

Sin embargo, el continuar incrementando el grado de micropasos eventualmente llevará a algunas limitaciones de la vida real. La generación de pulsos de paso, particularmente cuando se usa el puerto paralelo, tiene una frecuencia limitada. Esto limitará inevitablemente la velocidad máxima de pasos que se le pueda ordenar al controlador a dar. Con grados altos de micropasos esto resultará en inaceptablemente bajas RPM del motor.

Tasas excesivamente elevadas de micropasos no tienen beneficio real si la precisión resultante es muy baja para ser mecánicamente útil. Un motor de 1.8 grados por paso corriendo a 16x micropasos es teóricamente capaz de 0.1125 grados por paso. Acoplado a un tornillo de avance de 20 hilos por pulgada resultará en una resolución de posicionamiento de 0.000016" o 0.0004 mm. En realidad es increíblemente difícil conseguir tal fineza de grados de control. Todos los componentes en un sistema CNC tendrán tolerancias y contra-fuerzas (holgura mecánica en tornillos de avance, flexión en pórticos, descentrado de husillo y herramienta de corte, fricción estática en el motor a pasos mismo, error de retención en motor a pasos, etc.) que se traducirán en pequeñas cantidades de resolución completamente insignificantes. En la práctica, no tiene mucho caso hacer micropasos a tasas mayores

que 4x u 8x en una máquina CNC equipada con tornillos de avance. En algunos casos podría incluso ser más benéfico correr a menos grados de micropaso e incluso a paso completo y operar el motor a pasos con un engrane reductor para obtener las ganancias de resolución y torque necesarias.

1.5. Bucle abierto y cerrado

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.

Capítulo 2

Tiempos de motores a pasos

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 Contro-ller Board	150000	150000	150000	150000	Falling Edge	https://hyu68.com/-cp8.htm	
Gecko	201	500	4000	20000	1000	Falling Edge	https://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	[https://www.geckodrive.com/support/-motor-control-manuals/-stepper-drives/-g202-rev-15.html](https://www.geckodrive.com)	
Gecko	203v	1000	2000	200	200	Rising Edge	[https://www.geckodrive.com/support/-motor-control-manuals/-stepper-drives/-g203v-rev-7.html](https://www.geckodrive.com)	
Gecko	201x	500	3000	20000	1000	Falling Edge	[https://www.geckodrive.com/support/-motor-control-manuals/-stepper-drives/-g201-rev-16.html](https://www.geckodrive.com)	
Gecko	212	500	4000	20000	1000	Falling Edge	[https://www.geckodrive.com/support/-motor-control-manuals/-stepper-drives/-g212-rev-15.html](https://www.geckodrive.com)	
Gecko	213v	2000	1000	200	200	Rising Edge	[https://www.geckodrive.com/support/-motor-control-manuals/-stepper-drives/-g213v-rev-7.html](https://www.geckodrive.com)	

Manufacturer	Model	Step Time	Step Space	Direction Hold	Direction Setup	Steps on	Spec Sheet	
Gecko	320	3500	500	200	200	Rising Edge	https://www.geckodrive.com/support/-motor-control-manuals/-dc-servo-drives/-g320-rev-7.html	
Gecko	320x	1000	2500	200	200	Rising Edge	https://www.geckodrive.com/support/-motor-control-manuals/-dc-servo-drives/-g320x-rev-10.html	
Granite Devices	VSD-E/XE Evolu-tion	125	125	125	125	Rising Edge	https://granitedevices.fi/-assets/-files/-vsd-e_160_manual.pdf	
Granite Devices	VSD-E/XE DualDC	150	1850	150	800	Rising Edge	https://granitedevices.fi/-assets/-files/-vsd-e_160_dualdc_manual.pdf	
JVL	SMD41	500	500	2500	2500	Rising Edge	https://www.jvl.dk/-files/-pdf/-lb043gb.pdf	
JVL	SMD42	500	500	2500	2500	Rising Edge	https://www.jvl.dk/-files/-pdf/-lb043gb.pdf	
Linistepper Open Source	RULMS1	30000	100000	4000	4000	Rising Edge	https://www.piclist.com/-techref/-io/-stepper/-linistep/-index.htm	
Linistepper Open Source	THB6064	2300	2300	4600	1000	Rising Edge	https://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	https://www.motioncontrolp c2/-uploads/-msd542%20datasheet.pdf	
Parker	OEM750	200	300	0	200000	Rising Edge	https://www.compumotor.co manuals/-OEM750/-OEM750_Entire_Rev_B.pdf	
ST	L297	?	500	4000	1000	Rising Edge	https://www.st.com/-stonline/-books/-pdf/-docs/-1334.pdf	
Xylotex	XS-3525/8S-3	2000	1000	200	200	Rising Edge	https://www.xylotex.com/-XS3525V202.pdf	
Xylotex	XS-3525/8S-4	1000	1000	200	200	Rising Edge	https://www.xylotex.com/-XS3525V400.pdf	
Lin Engi-neering	Silverpak 17D/DE	20000	20000	200	200	Rising Edge	https://www.linengineering site/-products/-pdf/-SilverPak17D_DE-manual.pdf	
Hobbycnc	Pro Chop-per Board	2000	2000	2000	2000	?	https://www.hobbycnc.com/ products/-hobbycnc-pro-chopper-driver-board-kits/	
*Routout	2.5amp Stepper Driver	200	1000	1000	?	?	https://www.routoutcnc.com 2-5ampdriver.pdf	
*Intelligent Motion System	IM483	1000	1000	1000	1000	Rising Edge	https://www.imshome.com/-im483.html	
Keling	4030	5000	5000	20000	20000	?	https://www.	
Keling	6852	1750	1750	10000	10000	Rising Edge	https://www.kelinginc.net/-kL-6852.pdf	
Sherline	8760	1000	6000	24000	24000	?	https://www.sherline.com/-	
Burkhard Lewetz	Step3S	6000	15000	?	5000	?	https://www.lewetz.de/-download/-ibstep3se.pdf	
Parker Compu-motor	Zeta 4	200	200	?(200)	?(200)	Rising Edge	https://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	?	https://www.cncdrive.com/-content/-dugong.htm	
www.cncdrive.com	DG2S-08020	1000	2500	1000	1000	?	https://cncdrive.com/-DG2S_08020.html	
Wantai Motors	DQ542MA	5050	5050	500	500	?	https://www.wantmotor.com/ProductsView.asp?id=257&	
Leadshine USA	Digital DM422 40V 2.2A	7500	7500	20000	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-DM422m.pdf	
Leadshine USA	Digital DM556 50V 5.6A	2500	2500	10000	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-DM556m.pdf	
Leadshine USA	Digital DM856 80V 7.0A	2500	2500	10000	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-DM856m.pdf	
Leadshine USA	Digital DM870 80V 7.0A	2500	2500	10000	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-DM870m.pdf	
Leadshine USA	Digital DM1182 150VAC 8.2A	2500	2500	10000	5000	Rising Edge	https://leadshine.com/-UploadFile/-Down/-DM1182m.pdf	
Leadshine USA	Digital EM402 40V 2.2A	10000	2500	10000	5000	Rising Edge	https://leadshine.com/-UploadFile/-Down/-EM402d_P.pdf	
Leadshine USA	Digital EM503 50V 4.2A	2500	2500	10000	5000	Rising Edge	https://leadshine.com/-UploadFile/-Down/-EM503d_P.pdf	
Leadshine USA	Digital EM705 70V 7.0A	2500	2500	10000	5000	Rising Edge	https://leadshine.com/-UploadFile/-Down/-EM705d_P.pdf	
Leadshine USA	Digital EM806 80V 8.2A	2500	2500	10000	5000	Rising Edge	https://leadshine.com/-UploadFile/-Down/-EM806d_P.pdf	
Leadshine USA	Analog M415B 40V 1.5A	1500	1500	8000	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-M415Bm.pdf	
Leadshine USA	Analog M542 50V 4.2A	1500	1500	8000	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-M542V2m.pdf	
Leadshine USA	Analog M752 75V 5.2A	1500	1500	8000	5000	Rising Edge	https://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	https://leadshineusa.com/-UploadFile/-Down/-M880Am.pdf
Leadshine USA	Analog M860H 80VAC 7.2A	1500	1500	8000	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-MA860Hm.pdf
Leadshine USA	Brushed servo DCS303 30V 15A	2500	2500	10000	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-DCS303m.pdf
Leadshine USA	Brushed servo DCS810 80V 20A	2500	2500	10000	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-DCS810V1m.pdf
Leadshine USA	Brushed servo DCS810S 80V 20A	1000	1000	7000	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-DCS810Sm.pdf
Leadshine USA	Brushless servo ACS306 30V 15A	2500	2500	10000	5000	Rising Edge	https://leadshine.com/-UploadFile/-Down/-ACS306hm.pdf
Leadshine USA	Brushless servo ACS606 60V 15A	850	850	6700	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-ACS606m.pdf
Leadshine USA	Brushless servo ACS806 80V 20A	850	850	6700	5000	Rising Edge	https://leadshineusa.com/-UploadFile/-Down/-ACS806m.pdf
StepperOnline	Digital DM860T v1.0 80VA-C/110VDC 7.2A	5000	5000	5000	5000	Rising Edge	https://www.omc-stepperonline.com/-download/-DM860T.pdf
StepperOnline	Digital DM860T v3.0 80VA-C/110VDC 7.2A	5000	5000	5000	5000	Rising Edge	https://www.omc-stepperonline.com/-download/-DM860T_V3.0.pdf
Pololu	A4988 Stepper Motor Driver Carrier	1000	1000	200	200	Rising Edge	https://www.pololu.com/-catalog/-product/-1182/
Pololu	DRV8825 Stepper Motor Driver Carrier	1900	1900	650	650	Rising Edge	https://www.pololu.com/-catalog/-product/-2132/

Manufacturer	Model	Step Time	Step Space	Direction Hold	Direction Setup	Steps on	Spec Sheet	
cnc4you		2000	8000	5000	5000	Rising Edge	https://cnc4you.co.uk/-resources/-CW5045.pdf	

Capítulo 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.

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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:

debounce(9)

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.