-- SheetCNC.co.uk --
Spindle, Control and Power Systems

A Guide to
Fitting-Out a
Home-Built CNC Mill/
Router

Contents

WARNING

This document is provided free in the hope that it may be useful but without any warranty whatsoever.

While this document uses SheetCNC as a worked example, it does not form part of the assembly instructions of SheetCNC. No warranty whatsoever is given about the suitability of the procedures or the third-party equipment described in this document.

This document uses example components to work through the process of commissioning a typical CNC Mill/Router installation. Where specific components are named or described, this in no way guarantees that those components are correctly specified for use in your specific application nor that they are safe and legal to include as part of an electrical or workshop installation. Such named components are to be considered only as examples for the purpose of illustrating typical connections and setup required of a working CNC machine. The methods of cabling and connection are an overview only and may exclude any safety and protective components or setup that may be required, whether by law or by accepted good practice. System builders must employ components, wiring, and construction methods that meet the needs of their particular installation and which are legal and sufficient for the intended use of their machine.

Some parts, particularly high-voltage wiring and components, may need to be installed by a Competent Person within the meaning of the law. More information (for UK installers) can be found at hse.gov.uk/electricity .

While every care has gone into producing this guide, the reader must not assume that it is correct and complete. SheetCNC.co.uk accept no responsibility for losses incurred due to errors or omissions in this document. The constructor should verify that their own installation is safe and correct by reference to the instruction manuals supplied with their third-party equipment, by reference to independent expert sources and/or by commissioning any necessary expert installation and/or inspections.

Before powering-up any CNC machine, even if only for testing, take suitable precautions to protect yourself and others from injuries and health hazards. Such precautions - which include PPE and guarding - are the responsibility of the machine owner/operator and are *not* covered in our documentation.

Introduction

This guide is an overview of setting up third-party electronics and parts for SheetCNC or other 3-axis CNC mill/routers.

This guide also covers CAD/CAM software choices.

Key Parts of the System

The essential components and software required to complete a bare-bones SheetCNC machine are:

- Stepper-motor drivers
- Break-out board
- Power supply
- Spindle and VFD
- Coolant pump
- Machine controller
- CAD software
- CAM software

In addition, you will need some means of dust extraction.

Fixing and wiring the components is covered in this document. Typically, it will take a competent builder just a few hours to complete.

An overview of installing the machine controller software is given. Step-by-step configuration is covered in detail. These steps are likely to take a couple of hours.

Choice of CAD and CAM software is covered. CAD is a personal choice and is largely left to the builder to choose. CAM options are currently limited but the main contenders are listed. The installation and configuration of CAD and CAM require little time in themselves, but installation will be followed by an extended learning curve for most users as they master the programs, particularly the CAD. See also *Clever Cuts* for a guide to first using CAD, CAM and the machine controller.

Axes Convention

The axis convention with 3-axis CNC mills/routers is that the X axis runs from left to right in front of the operator, while the Y-axis runs along the machine away from the operator.

Due to its large bed SheetCNC is best operated from a controller located adjacent to one long side of the table. Standard convention for axis-naming therefore means that SheetCNC - and this guide - use the convention that travel along the longest axis is the X axis and travel along the short axis is the Y axis. Vertical motion is the Z axis.

The builder may, of course, choose instead to position the controller at the end of the table. They may then prefer to use the convention that X is across the gantry and Y is along the table.

Home Positions

Note the 'home' positions of each axis. These are:

- X-Axis: The gantry positioned with its back (that side of the gantry opposite to the spindle) touching the home stop. When homed, the gantry will be standing wholly over the long MDF extensions that carry the steel X-runners beyond the end of the plywood bed.
- Y-Axis: The spindle carrier touching the right side of the gantry as viewed from the back of the gantry.
- Z-Axis: The spindle raised almost to its limit. There is generous excess mechanical range built-in to the Z axis, so anywhere within a few millimetres of the visible physical limit serves fine as the home position.

Note the coordinate directions of each axis:

- The X and Y axes count their position as a positive distance from home, where home is zero.
- The Z axis convention is that upwards is a positive motion, and also that home is zero. Therefore the Z axis counts any position *lower* than home as a *negative* distance. There are no valid Z axis positions higher than home, so all Z positions will be negative values.

There are no home switches nor end-stop switches installed on SheetCNC. There is little benefit in adding the complexity: end-stop switches only come into play if the machine malfunctions; home switches on X and Y axes are redundant because these axes can be accurately and quickly homed manually; the Z axis home position does not provide useful input to the program because the cutting height depends on where the cutter is positioned in the chuck, rather than solely on the position of the axis.

Of all possible detection devices that could be installed, the most useful addition is a tool touch-off probe to enable the machine controller to precisely locate the tip of the tool relative to the Z axis. A suitable touch-off probe is described in the third part of the documentation *Clever Cuts* and we strongly recommend following those directions to construct one.

Positioning the Electronics

For best operation, the machine controller (the computer, screen, keyboard and mouse that will operate SheetCNC) should be positioned on a desk or other working surface within reach of the home positions of the X and Y axes and part-way along the long side of the machine for easy observation of the Z axis during homing and touching-off. The other electronics also need to be close by the machine controller.

Workshop Safety

When fitting-out and using a home workshop, the following safety practices should be considered as an absolute minimum:

- Potential fire and other risks should not be sited between occupants of the workshop and their escape route.
- Firefighting equipment should be provided and located in such a way that a user will not have to move towards a hazard and/or away from their escape route in order to access the equipment.
- It should be possible to isolate an electrical appliance from the mains supply even if the appliance has malfunctioned in such a way that it cannot be approached. For example, by siting the mains consumer unit near to the door of the workshop.
- Any CNC equipment should be able to be stopped in an emergency by a person who might become entrapped in the machine, for example by provision of suitably-placed emergency stop switches. See also *Build Manual*.
- Sufficient suitable PPE should be provided and the need for that PPE should be notified to all workshop users.
- A risk assessment should be carried out, mitigation strategies devised and written-up, and the resulting document made available to all users of the workshop.

The financial outlay is not great nor does it take much time to assess risks and adapt the workshop as necessary to incorporate these practices.

Personal Protective Equipment (PPE)

A note on sourcing PPE.

Out of all the PPE we buy and use at SheetCNC.co.uk, our favourites are:

- Full-face flip-up visor with browguard, by Axminster. Especially suitable for spectacle wearers who cannot easily wear protective goggles.
- Disposable foam ear-plugs, by Howard Leight. Widely available in boxes of 200 pairs. Useful especially against the constant mid-level noise from dust extraction equipment.
- Howard Leight Sync Stereo Ear Defenders. Little more expensive than a quality pair of regular ear defenders, these have the added benefit of also being stereo headphones. Plug them into any MP3 player or phone equipped with a 3.5mm jack for podcasts and music while you work.
- Powercap IP (impact protection rated) by JSP. Lightweight faceshield and bump-cap that both protects against the possibility of eye injury and provides the wearer with clean, filtered air. Unlike most dust-masks this device works well for bearded users. Widely used by hobby and professional woodworkers.

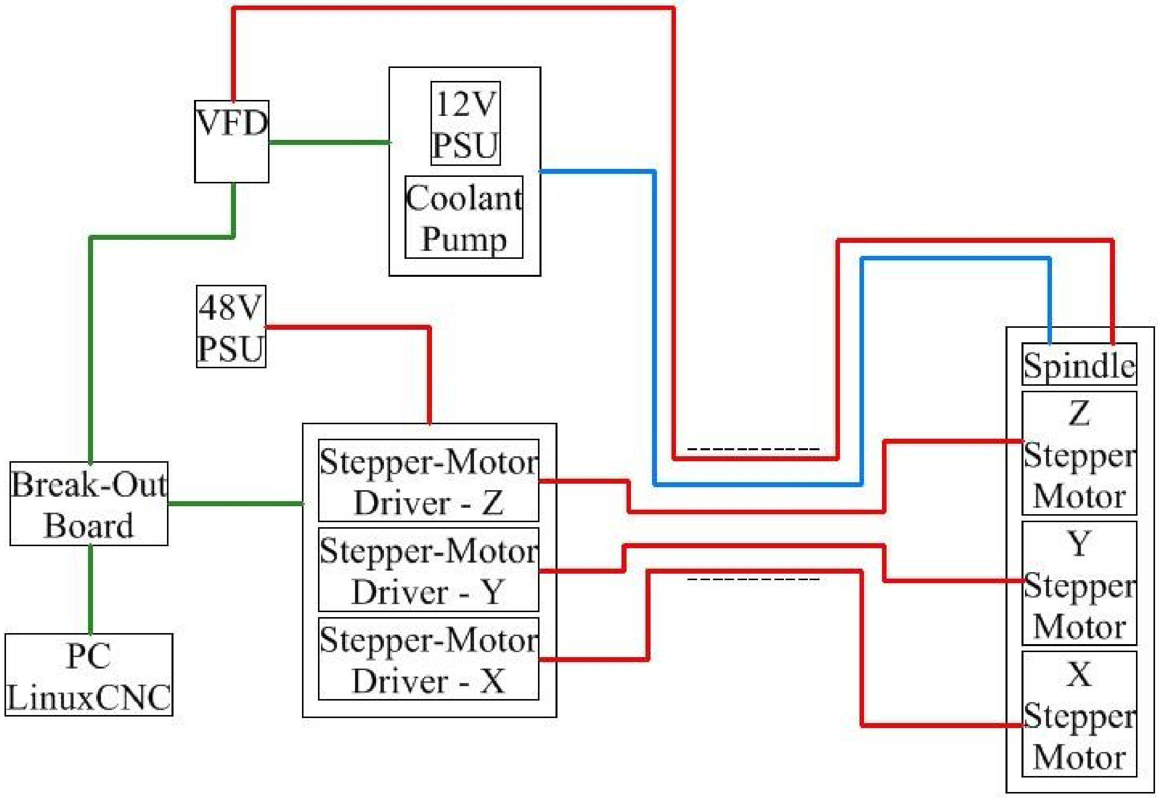
Tip: The useful lifetime of a visor can be greatly extended by application of wax. Lightly rubbed onto the surface and polished off with a soft cloth, the wax hugely improves the view through a lightly scuffed visor. Check that the wax is inert and has no ingredients that will weaken the plastic or be unpleasant or harmful to breathe. Particularly avoid aerosol wax/polish that may contain solvents. Do not use any visor that is so damaged or stained that it significantly restricts vision.

Replace a visor if scratches are more than superficial or if it is weakened in any other way.

Overview of Cable Runs

The following diagram gives an overview of the cable/pipe routes which will be required when setting up a typical 3-axis CNC machine.

The layout will aid in planning the location of the various components. Mains power is not shown.



Routes are colour-coded: Green:signal Blue:coolant Red:high-power

The components on the right of the diagram are fitted to the CNC machine itself. Cables run to these components are usually bundled, taking care to keep the spindle power cable isolated from the stepper cables to prevent noise transmission. The bundled cable run must allow sufficient freedom of movement for the machine to operate.

The remaining components are usually grouped together around the operator's console. The PC (and if manual spindle control is used also the VFD) must of course be accessible to the operator.

Break-Out Board, Stepper-Motor Drivers, PSU

This section describes the basic wiring to power the stepper motors on the three axes of SheetCNC.

A break-out board is a component that connects the parallel port of a desktop PC to one or more stepper-motor controllers.

A stepper-motor driver is a component that converts electronic signals coming from the break-out board into a high-current output which powers a stepper motor on one of the SheetCNC axes.

A PSU is a power supply unit that converts mains (240V AC) electricity into a smoothed 48V DC supply for the stepper motor drivers.

SheetCNC requires one break-out board, three stepper-motor drivers, and one PSU.

Stepper Driver Required Specifcation

For an 8' or a 4' SheetCNC machine, the stepper drivers must be set as follows:

- X and Y Drivers:
  - Current 4.2A
  - Half-current: Inactive, so that full current is supplied even when the axis is static.
  - Microstepping: 5000 steps per turn (25 microsteps per 1.8 degrees)
- Z Driver:
  - Current 2.8A
  - Half-current: Active, so that only half-current is used when the axis is static.
  - Microstepping: 800 steps per turn (4 microsteps per 1.8 degrees)

Other machines will require different values. Never exceed the rated current of the motors.

On most drivers, changing the setup switches during operation will have no effect until after the power to the driver is cycled.

Note: Stepper drivers vary in quality markedly. Some have such poor performance that they are unable to reliably drive the X and Y axes when making deep cuts, or are unable to drive the Z axis at high speed. The result will be that an axis fails to follow a commanded move when making aggressive cuts.

The only satisfactory solution to poor quality drivers is to source better drivers - at least for the X and Y axes. Sourcing genuinely good quality stepper drivers is not easy - the generic M542 type is built to widely varying specifications and with a wide variance in quality. We suggest, if sourcing from an ebay, to use only a seller who specialises in electronics and/or CNC and who has a long track record of excellent feedback.

If the machine exhibits poor axis torques check the length and conductor diameter of the feed cables, the suitability of the PSU and soundness of all the power connections. If these are all fine, then the fault is most likely to be with the driver.

Components

This document assumes the following main components or pin-for-pin equivalents.

Please read the chapter titled *WARNING* before purchasing components or carrying out any electrical work.

Component	Source	Qty	Typical total cost (2016)
M542 Microstepping Stepper Motor Driver or updated variant of similar or better specification. Genuine LeadShine 2M542 if available.	ebay	3	£60 (from international seller) or £150 (from UK)
5-Axis CNC Breakout Board with Optical Coupler (and USB Cable Included). We recommend one specifically labelled “MACH3 Interface Board BL-MACH-V1.1 0302” or an updated variant of similar or better specification.	ebay	1	£4 (from international seller) or £12 (from UK)
48V smoothed DC PSU. 10A (480W) minimum. Widely available. Often sold as 3D printer PSUs. Occasionally sold as LED drivers. If switched-mode type, more power will be required (e.g. 600W)	ebay	1	£50 (from UK)
Parallel Cable DB25 male-to-female. Widely available.	ebay	1	£3 (from UK)
4-core cable 0.75mm^2 E.g. Farnell item CB17120 Shielded may be required (CB17144). See text for details.	cpc.farnell.com and farnell.com	See text	£0.70 - £1.20 per metre
Solid core plastic-insulated instrument wire around 22swg, multiple colours. Stranded wire is equally suitable. Widely available and very cheap to buy as single rolls. Adafruit Hook-up Wire Spool Set is a convenient one-stop purchase, but expensive.	ebay	A few metres each colour	£5-£15
Stranded plastic-insulated low-voltage 2-core 'figure-of-eight' flex around 1mm^2, red and black cores. Widely available	ebay	See text	Trivial
Screw-eyes and fasteners as in the text			Trivial

Make sure to purchase a break-out board that comes complete with USB cable. The cable has an unusual combination of ends which means it is tricky to source separately.

If intending to drive the machine hard, then buy quality stepper drivers. Cheap copy drivers may look identical to the LeadShine, but will likely produce a poor output waveform causing excessive heating of the motors and less powerful performance.

Most PSUs available at reasonable cost will be switched-mode. Buying the highest power available (typically 600W) will reduce chances of the torque dropping off due to high peak demand from the steppers.

Warning

Given that the 48V PSU is a mains device whose low-voltage output is wired to many of the exposed parts of the system we suggest connecting the PSU to the mains via a protective RCD. Take great care with wiring and, if in any doubt, engage the services of a qualified electrician.

Assembly

All the electronic components require passive cooling, so they should be installed in an open-air environment or in a well ventilated case(s). Ensure that any PSU is electrically safe and legal - including for example that the unit is CE marked, that its mains terminals are in an IP-rated enclosure separate from the output terminals, that the unit is suitably earthed and/or insulated, and that there is cable strain-relief provided. Consider installing the PSU inside a ventilated, insulated enclosure if necessary. If in any doubt, consult a qualified electrician to supply and install the PSU.

A straightforward assembly method is as follows:

Fasten the break-out board and the stepper-motor drivers to a 600mm length of 25x150mm planed timber board, leaving them well-spaced to allow for cooling and for easy access to the connections. The terminals and set-up switches of the stepper-motor drivers should be at the top.

Insulating spacer-tubes will be required under the fasteners for the break-out board: short lengths of PVC tubing may serve. Use all the fastening holes and take care not to over-tighten fasteners: the break-out board is delicate.

Fit a couple of screw-eyes to the timber board to serve as strain-relief for cables - the various input and output cables can be cable-tied to them as necessary to prevent connections being tugged loose.

Using the solid-core instrument-wire, connect the components as in Diagram 1. Do *not* connect the 48V PSU to the breakout board.

Using the stranded 2-core flex, connect the output of the PSU to the inputs of the components that are fastened to the timber as in Diagram 1.

In the ceiling, directly above the centre of the machine, fasten a suitable large screw-eye into a strong-point.

In the ceiling, directly above the middle of one X-runner on the machine, fasten a suitable large screw-eye into a strong-point.

In the ceiling, directly above the chosen final location of the stepper-motor drivers, fasten a suitable screw-eye into a strong-point.

Determine the amount of 4-core cable required between each stepper-motor and its respective stepper-motor driver. The cable route is as follows:

> For Y-axis and Z-axis: With the spindle positioned in each corner of the table of the machine, measure the distance from the motors directly to the screw-eye above the centre of the machine, and from there across the ceiling and vertically down to the chosen location of the stepper-motor drivers. Take the maximum and allow an extra couple of metres of slack.
>
> For the X-axis: With the gantry positioned at each end of the table of the machine, measure the distance from the motor to the cable-hole in one end of the gantry, then from the end of the gantry to the screw-eye above the middle of that side of the machine, and from there across the ceiling and vertically down to the chosen location of the stepper-motor drivers. Take the maximum and allow an extra couple of metres of slack.

Cut the cable to length as required, and route it as above, leaving scope for adjustment.

Connect each stepper-motor driver to its length of 4-core cable. 4-pin plugs are supplied with SheetCNC which mate with the 4-pin sockets previously soldered to each motor (see *Build Manual*). Match the colours of the wires in the cable with the colours of the wires on the same pins in the socket. Tip: Unscrew the socket from the machine, insert the plug into the socket, solder the wires to the plug in-situ while matching them colour for colour with the socket wires, then remove the plug and re-fasten the socket to the machine. Don't forget to thread the plug cover onto the cable before soldering.

Run the cables from the motors to the motor controller. Use the provided P-clips and screws to fasten the X motor cable to the back of the gantry, keeping the cable clear of the drive parts.

Fasten the other ends of each cable to the screw-eyes in the board, and install strain relief on the cable as required.

Label each multi-core cable, at each end, with 'X', 'Y', 'Z' as appropriate. A permanent marker is suitable.

Connect each cable to the appropriate stepper-motor driver, as in Diagram 1.

Set the three stepper-motor drivers set-up switches as appropriate to achieve the required specifications. (The settings shown in Diagram 1 will not necessarily match all M542 variants.

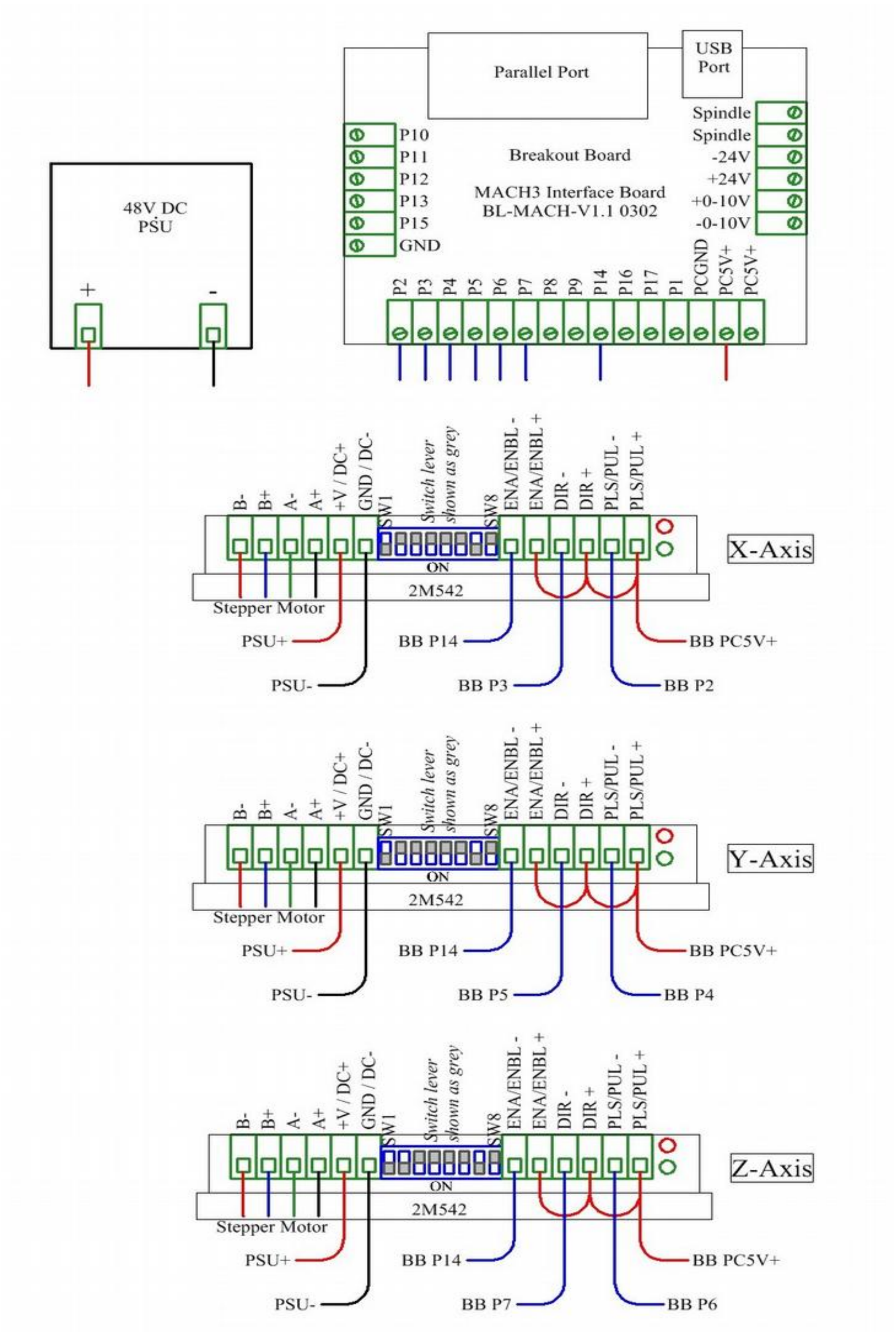


Diagram 1: PSU, Breakout Board and Stepper Drivers. Specific drivers may have their switches and contacts in different locations/orientations to those shown here. Proceed with care and check the driver instruction manual.

Further connections to some of these components will be required in later stages.

Reminder: Do *not* connect the 48V PSU to the breakout board.

Cable Adjustment and Alternative Routing

Adjust the cable runs so that just sufficient of each cable hangs from the ceiling to allow the machine to move to the limits of all axes without tugging the cables. Ensure the cables cannot snag, no matter how the machine axes may move.

Tip: Running the Y axis and Z axis cable to the top of the 600mm vertical stalk attached to the back of the spindle-carrier will help keep them from tangling. A similar stalk on the end of the gantry serves for the X axis cable. Stalk length can be adjusted, if preferred.

If the ceiling of the workshop is particularly low, there will be insufficient room to permit enough slack in the cable in a single fall. In such case the classic solution is to festoon a length of cable along a rail fastened into the ceiling, so that short loop(s) of cable hang down between two or more sliders on the rail. It is best to minimise the number of loops while still keeping the cable clear of the table. Commercial cable festoon systems are available, but there should be little difficulty in fabricating one from a rod and some wire rings. A series of beads or short hollow cylinders threaded around each ring should serve as low-friction rollers.

Ensure that cables are safely clear of any other fixtures in the workshop, particularly lighting and heating fixtures.

Allow that further services must be brought to the machine via the same route, including flexible dust extraction duct, coolant feed and return, power for the spindle, and emergency stop switch cabling.

Be aware that the cables from the stepper-motor drivers to the stepper motors can pick up interference which may be transferred back to the drivers causing unexpected motions of the axes. In the rare event that this occurs it may be necessary to use shielded 4-core cable with the shields earthed at their driver ends. Shielded cable is heavier and less flexible, so in the first instance it is better to try to eliminate the interference rather than change the cables. The spindle power cable (below) will be shielded, for this very reason.

Spindle, VFD, Cooling

The spindle is a combined 3-phase motor and chuck. It spins the cutter.

The VFD is a special type of power supply unit which drives the spindle at user-variable speed.

The spindle requires a circulation of water coolant. A simple pump and reservoir generally suffice.

Components

Please read the chapter titled *WARNING* before purchasing components or carrying out any electrical work. We have suggested the ebay stockist cncmotorshop to supply the VFD and spindle as, in our experience, they are fast and reliable, stock reasonable quality products, and they provide clear setup instructions.

Components	Source	Qty	Typical cost
2.2kW Water-cooled spindle with ER20 chuck. 4-bearing type. Genuine Huan-Yang brand VFD inverter (may be confused with cheaper but very similar-looking inverters)	ebay, UK seller cncmotorshop reliably supplies 4-bearing spindles with Huan-Yang brand VFDs	1	£160-£185
3-core shielded cable 0.75mm^2 E.g. Farnell item CB17140	cpc.farnell.com and farnell.com	See text	Trivial
12V submersible pump and a 12V PSU*	ebay	1	£10-£15
PVC non-braided tubing 5mm ID x 8mm OD or as necessary to fit the pump and spindle - see tips in text.	ebay	See text	£10
5-litre or 10-litre water container with large lid, Preferably clear-walled. Ensure pump fits through the lid opening.	surplus	1	£5
Safety cable	on-line retailer, ebay, or chandler	1	£5-£10
Spanners - The spindle chuck requires a 21mm spanner and a 30mm spanner for fitting and removing cutters. A lightweight pressed-steel 30mm gas cylinder valve spanner is ideal and minimises risk ot cutter damage.	various	1 of each	£5-£10

**We recommend the submersible brushless DC12V / 5W 240 l/hr aquarium pump widely available on ebay, combined with a separate plug-in power module capable of producing 12V DC at 500mA.The 12V supply can alternatively be derived from the 48V PSU, via a DC-DC voltage regulator, if preferred. Avoid windscreen washer pumps: they are noisy and have a short life. Do not use the 24V DC supply from the VFD to operate the pump: it has insufficient capacity.*

Air-Cooling vs Water Cooling - Discussion

Spindles generate heat during operation so require cooling.

Water-cooled spindles are cooled by small quantities of water pumped around channels in their casing. They have the advantage that the cooling generates little noise, is effective at all speeds of the spindle, and is unaffected by dust.

Air-cooled spindles are cooled by a fan attached to the spindle armature which blows air across the windings. They have the advantage that no coolant supply is required. They have the serious disadvantages that the cooling is ineffective at low spindle speeds and dust can accumulate and block the cooling or damage the bearings. Moreover a cooling fan is extremely noisy. Air cooling also creates a dust hazard as the airflow disturbs dust on the table, lifting it into the air.

We absolutely do not recommend air-cooled spindles for any timber-working CNC machine.

Warning

The VFD is a mains device. Take note that the output to the spindle motor is at high voltage and so is dangerous. Be aware that large internal capacitors may remain charged-up, even when the VFD is disconnected from the mains, and may present a shock hazard. Do not work inside the access panels nor on the cable connecting the VFD to the spindle unless the VFD is disconnected from the mains *and is completely discharged*. We suggest connecting the VFD to the mains via a protective RCD, but bear in mind that this will offer limited or no protection against shocks rendered via the capacitative storage in the VFD. The following wiring notes are for general guidance only. Take great care with wiring and, if in any doubt, engage the services of a qualified electrician.

Assembly

Attach the spindle to the machine as described in *Build Manual*.

Fit an appropriate steel restraining safety cable to the spindle, as described in *Build Manual*. An on-line retailer, or a chandler, can make a cable to your specification. The cable should be securely fastened to a strong point on the spindle carrier and another strong-point on the spindle itself.

Position the pump and the VFD close to the break-out board.

Run the shielded cable from the VFD to the spindle via the same route as the Y-axis and Z-axis stepper-motor cables. To prevent damage to the electronics, ensure that this cable is no longer then 15m. Shielded cable is used to minimise risk of interference from the spindle motor cable into the stepper-motor drivers. To achieve proper shielding the cable must be earthed at the VFD end.

Connect the wires inside the shielded cable to the plug that is supplied with the spindle. Connect the other end of that cable to terminals UVW in the VFD, so that plug terminal 1 goes to U, terminal 2 to V, and terminal 3 to W.

Use standard 1.5mm^2 3-core mains flex for the mains supply to the VFD. Live and neutral mains wires should be connected to any **two** of the terminals R S T. Earth should be connected to the earth teminal.

Tips: We think that the spindle body - being metal - ought to be earthed and we achieve this on our machines by connecting the shield of the VFD cable to the spindle body. We connect the other end of the cable's shield to earth. Do not take for granted that the earth symbols on the VFD indicate actual earth points - they may be useful for making earthing connections between various earthing wires but the separate 'earth' points on the VFD are not necessarily connected internally to each other. Do not necessarily believe the many online reports that the fourth pin on the spindle is connected to the spindle chassis for earthing purposes. In our experience it is not. Spindle and VFD specifications are likely to vary, so these notes can be a guide only.

When wiring inside the VFD, route high-voltage wires (the mains cable and the shielded cable) away from the low-voltage wires (all the other wires). Ensure that there is no way for low-voltage wires to make contact with high-voltage terminals, nor vice versa.

The mains cable and the shielded cable **must** be provided with strain relief where they enter the VFD body, so that there is no risk of tugging on the wires where they connect to the terminals.

Run two lengths of the PVC tubing from the pump to the spindle, via the same route as the Y-axis and Z-axis cable. Take care not to pinch or fold the tubing.

Connect the tube ends to the spindle and use the conical nuts provided with the spindle to gently clamp the tube ends in place. Note that the conical nuts may need to be drilled out to about 7.5mm to allow the tube to pass.

At the pump end, connect one tube to the output of the pump after first passing the pipe through a hole in the lid or the topside of the container. Pass the end of the other tube through another hole and fasten it so that the return flow will dribble audibly and/or visibly from the top of the container into the liquid. This provides an indication that the coolant is flowing. Fit the inlet of the pump with a strainer to prevent blockages. Tip: 5mmx8mm tubing can be stretched to fit a pump inlet/outlet up to as much as 9mm dia - simply heat the pipe in very hot water then insert the tip of needle-nose pliers into the pipe and pull the handles apart to enlarge the pipe. Pass the power cable of the pump out through a third hole in the container, ready for connection to the power supply. Fit hose-clamps (or small tie-wraps) to prevent the pipe coming loose from the pump. Position the pump so that the coolant will submerge[*] it.

Fill the container with at least 3 litres of water, mixed with antifreeze (if sited in an unheated building) and corrosion inhibitor. Very dilute vehicle coolant is a combined antifreeze and corrosion inhibitor and should work tolerably well, but check that it is suitable for your specific components. Tip: In use, the heat will be dissipated from the walls of the water container and from the pipe runs and we have found this setup to be quite adequate. If in practice the water becomes too warm then additional heat dissipation will have to be provided such as a coil of copper tubing or a radiator and fan. Note that the cooler that the spindle is maintained, the better the grease in the spindle bearings will perform, and so the longer the life of these expensive components. It is therefore worth investing in reliable cooling.

Using stranded wire, connect the pump to its power supply via the VFD internal relay contacts 'FA' and 'FB' as shown in Diagram 2. Wire the break-out board to control the spindle speed as shown in Diagram 2. Do *not* ever connect the 48V PSU to the breakout board.

Set up the VFD's programmable settings, using the keypad.

Set up the VFD to turn on the coolant pump whenever the spindle is turning by setting CODE PD052 to value 1.

Set up the VFD to respond to the breakout board speed inputs, instead of the front panel buttons, by setting CODE PD002 to value 1. Check also that PD070 is set to 0, specifying 0-10V input.

Set up the VFD to limit the maximum spindle speed to 24000rpm by setting CODE PD072 to 400.

Set up the VFD to constrain the minimum spindle speed to 1260rpm[**] by setting CODE PD0073 to

* Assumes a submersible pump is in use. A non-submersible pump should positioned in such a way that it will *reliably* self-prime. Tip: Submersibles suffer less heating and therefore generally have longer service life.

** PD072, PD073, and the values set in LinuxCNC's configuration are inter-related.

21. This speed is chosen because it is the minimum useful speed of the spindle. Below this speed the spindle would stall if any realistic load were to be applied. Tip: this setting means that the spindle will start to spin whenever the VFD is turned on, even if the machine controller demands zero rpm from the spindle. This has the benefit that the minimum speed can be accurately controlled, reducing risk of stalling when, for example, drilling. It has the apparent disbenefit that the VFD needs to be physically turned off - by using the front panel control - to stop the spindle. However, the main reason for stopping the spindle would be to change the cutter, and this should never in any case be carried out while the VFD is turned on.

If your VFD has a knob on the front panel to control the spindle speed, you must disable it to allow the computer to control the speed. Usually there is a 'jumper' which is inside the VFD just to the right of the rows of terminals. Move that jumper so that it bridges the contacts labelled 'VI' rather than the contacts labelled 'VR'. Your VFD may vary, so check the instructions which came with it.

If your supplier has neither set up the VFD for you nor given any instructions on how to do so, then the following additional settings may be required. Use these with discretion after first checking that they match your spindle specifications:

- PD005 = 400
- PD004 = 400
- PD003 = 400
- PD144 = 3000

There are many other settings which, in our experience, are changed frequently by the VFD maker/supplier. Those which effect spin-up time and torque curves in particular. Consult the VFD manual and check the default settings.

Note: Never turn on the VFD unless the spindle is connected. Never disconnect the spindle while the VFD is powered.

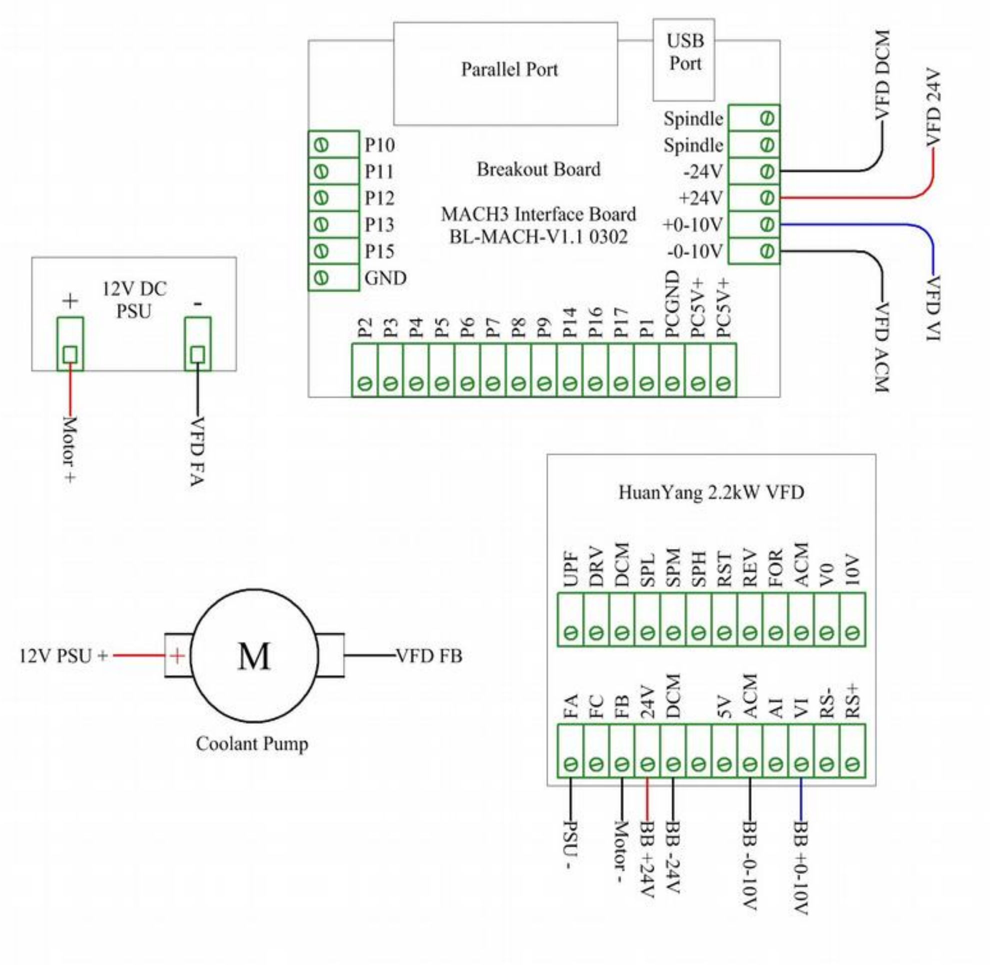


Diagram 2: Breakout Board, PSU, Coolant Pump, and VFD

Reminder: Do *not* connect the 48V PSU output to the breakout board.

Dust Extraction

Dust extraction is essential to prevent fire and respiratory risks. We describe the most basic version of it here that will capture much of the finer dust produced by the machine, leaving the heavier particles to settle on the top of the workpiece. This greatly reduces fine, airborne dust but may not be sufficient to meet health and safety requirements in the environment around the machine. Further dust control - such as ventilation, a dust shoe, and/or PPE - may be required.

Components

Please read the chapter above titled *WARNING* before purchasing components or carrying out any electrical work.

Component	**Source**	**Qty**	**Typical total cost (2016)**
Flexible corrugated spiral-reinforced hose 32mm internal diameter (36mm outside diameter) typically sold as a pond accessory.	ebay	See text	£1.50 per metre (from UK)
Cylone-type dust extractor with 25-litre or 50-litre plastic barrel	ebay - search for 'dust commander cyclone', and 'dust mite cyclone' for examples. For the barrel consider canoe suppliers (frequently stocked as waterproof containers)	1	£12 (from international seller) or £25 (from EU) or £40 (from UK) Barrel about £20 extra.
Powerful vacuum cleaner with HEPA filter.	surplus or s/h	1 or 2 - see text.	Varies - widely available used.
Alternatively an industrial or home workshop dust extraction machine	workshop suppliers such as Machine Mart, Axminster, Screwfix	1	Varies

Warning

Note that domestic type vacuum cleaners are not designed for dust extraction. They may therefore clog or otherwise malfunction and pose various hazards, including fire and the generation of high static charges. A dust extractor based on domestic appliances should not be used unattended. Mitigation should be put in place to deal with the risks, such as frequent checks on the temperature of the appliance, and a means to safely discharge static without causing shock or - in an extreme case - even possible ignition of the dust itself.

Considerations

Noise: Dust extraction is likely to be by far the noisiest element of CNC machining. It is worth giving much consideration to the choice, siting, and containment of the extractor so as to reduce the noise that the operator is exposed to, while also minimising noise nuisance to neighbours.

Airflow: Generally, the higher the airflow through the system the better it will perform. Therefore seek a vacuum that provides high airflow rather than merely high vacuum. A cyclone type vacuum cleaner is likely to provide much better airflow than a bag type. We use Dyson DC-05 cleaners. The specific advantages of this model are: it is widely available second-hand; spares too are widely available; it is extremely powerful yet light weight; the built-in cyclone is so effective that the filters need cleaning only infrequently; the multiple layers of re-usable filters result in clean exhaust air; emptying is a quick and clean process; and the plastic edge on the nozzle can usefully be run around the edges of finished workpieces to neatly remove any slight burrs and to vacuum them away in one operation without scratching the parts.

Safety: Safety features fitted on the vacuum should be checked for correct operation and should never be disabled. In particular, the bypass valve which allows cooling air to reach the motor - should the suction pipe become blocked - is crucial to prevent overheating and fire. Servicing should be carried out more frequently than the cleaner's operating manual indicates.

Additional cyclone: It is possible to use a vacuum cleaner as both vacuum provider and dust collector. However, the volume of particulate produced by the machine - at least when cutting thicker boards - will quickly fill the container of a typical vacuum cleaner necessitating frequent interruptions for emptying. It is better to collect at least the larger dust particles separately and rely on the vacuum cleaner to extract and filter only the finer dust particles. A popular method is to install a simple cyclone dust collector in the duct between the machine and the vacuum. Moulded ready-made cyclones, correctly sized for domestic vacuum cleaners, are now available widely and cheaply.

Assembly

If using a commercial dust extractor, follow the instructions provided for installation and connection to the machine.

If building a dust extractor from components, the following guide may help. There are also many on-line examples of home-built dust extraction equipment which are worth reviewing particularly for the methods that some of the builders use to reduce noise and minimise dust output in the exhaust air.

Begin by installing a length of corrugated hose along the same route as the Y-axis and Z-axis stepper motor cables, so that it reaches from the spindle at one end to the inlet of the vacuum equipment at the other. Keep the duct run as short as possible. Avoid sharp bends in the duct.

The hose should simply push-fit into the plastic elbow previously fitted adjacent to the spindle on the machine (see *Build Manual)*. Enough slack for Z-axis motion should be allowed. At the other end, a suitable adapter may be needed. This can generally be assembled from ABS plastic domestic waste fittings. Tip: Brand *FloPlast* is generally heavier-built than other popular brands.

Cyclone (Dustmaster, Dust Mite, etc) installation is straightforward. Fasten the cyclone to the lid of the barrel ensuring a completely airtight seal - even a small air leak here will cause finer dust to be blown up the cyclone and into the exhaust air. Fit the lid to the barrel, again ensuring a completely airtight seal - the cyclone cannot work if air can leak into the barrel when in operation. Stand the barrel in its chosen location. The cyclone must operate in an upright position so that gravity can extract the dust into the barrel below. Fit the flexible duct from the machine into the side inlet of the cyclone, typically using plumbing fittings to make an adapter. Fit the vacuum cleaner air inlet to the central vertical outlet of the cyclone, again making an adapter as necessary. Ensure the vacuum cleaner is in good operating condition and that all filters are fitted and kept clean.

Be aware that many metal and plastic parts in the duct, cyclone, barrel, or vacuum are likely to charge up with static. These static charges can cause irritating shocks unless they are earthed. In the case of large metal parts - such as metal drums - the shocks can be substantial, even dangerous. Furthermore, the discharge of even modest amounts of static into any machine part - including the chains, rails, motors, and associated cabling - ***will*** cause the machine to make uncommanded movements resulting in loss of touch-off position.

Possible precautions against static include providing a direct path to earth for any metal parts and giving consideration to the possible effects of dust ignition within the extractor, for example by limiting the size of barrel so as to minimise the volume of dust-laden air in the system. Many vacuum cleaners - even metal-cased ones - are not always provided with an earth wire. In the case of double-insulated equipment it may be unsafe to add an internal earth wire. However, an external earthing wire - equipped with a suitable resistance if necessary - permanently clipped from each metal part in the extraction system to an external earthing point should suffice to suppress static. Do not earth sources of static direct to any part of the CNC machine - even if the machine is itself earthed. Always use an independent route to earth for dealing with static.

Typical barrels, as suggested above, are not especially resistant to vacuum. If the extraction inlet becomes blocked, and if there is no bypass route for air to reach the barrel, then the barrel is likely to be seriously deformed by suction. We suggest fitting a reinforcing hoop(s) inside the barrel. We make hoops from two semi-circular pieces of 25mm plywood, which can be push-fit into place.

The dust extraction equipment should be emptied prior to starting cutting operations and the fill level should be monitored during operation. When the cyclone barrel is half-full of dust, it will begin to allow substantial amounts of dust to reach the vacuum, potentially resulting in blockage of filters. So always empty the barrel before it reaches half-full.

Post-Work Cleaning

A second vacuum-cleaner (or the extractor's vacuum cleaner if disconnected from the machine for the purpose) is used for cleaning the table of any cuttings which have not already been extracted via the duct. A neat alternative set-up is to connect a second length of corrugated pipe to the inlet of the cyclone, equipped with a nozzle made from household plumbing parts.

Vacuum the standing particles from the table after the machine has finished working, so that when the workpiece is lifted from the table the minimum possible dust will be disturbed. To that end vacuum not only the surface particles from the top of the workpiece but also those that have accumulated in the pockets and the cut contours of the workpiece and any particles that may have spread onto adjacent parts of the machine. Empty the dust container into a bin outside of the workshop, so that any dust raised in the process of emptying is not breathed in.

We reiterate the warning that domestic appliances are not specifically designed for workshop use. Do not leave them operating unattended, do maintain them frequently, and plan ahead so that equipment and procedures are in place ready to safely deal with any malfunctions which might occur during operation.

Emergency Stop

The machine should be equipped with emergency stop buttons, so that anyone entrapped by the machine can stop it. There are various ways to achieve this. A solution should be engineered specific to your installation. We offer the following notes but we are not in a position to recommend any given design.

The minimum number of stop buttons for SheetCNC would seem to be two - one on each end of the gantry - with the necessary cabling following the path of the X-axis stepper-motor cable. Additional stop buttons may be desirable depending on your particular setup.

The stop buttons could be connected to an isolation relay that chops the mains power to the whole machine when triggered - perhaps with the exclusion of the machine controller which could suffer from being unexpectedly powered down. This has the advantage that all motors - including the spindle - are guaranteed to be powered down. The disadvantage is that the VFD may continue to power the spindle for a short while using stored energy before it stops.

An alternative strategy is to connect the stop buttons to the emergency stop input on the breakout board. This has the potential advantage that the stepper-motors and the VFD can be instructed to brake all motors to a halt immediately. This assumes that such capabilities are built-in to the electronics. It also assumes that all the electronics are functioning properly and will obey the command. A braked stop - if badly executed by the electronics - may result in the motors being held immovable and prevent escape from the machine.

A combination of methods which include a signal to the PC to stop the running program as well as a signal to external equipment to chop the power will be more robust than a single-path system.

It is conventional to wire the switches NC (normally closed) so that an accidental break in the wire triggers the emergency stop. The alternative - NO (normally open) - would mean that a break in the wire will go undetected yet will prevent the stop buttons from having any effect. On the other hand, NC wired stop buttons will fail silently should a short-circuit occur.

Emergency stop buttons should be regularly tested.

Machine Controller

The machine controller is the device which interprets a computer-generated cutting program (colloquially called 'G-Code' after the initial character of the movement commands it contains) and sends appropriate signals to the machine so that it moves the cutting tool to match the program instructions. This guide shows how to use an old, cheap PC as the machine controller.

Other controllers - not necessarily based on PCs - are available.

Components

Please read the chapter titled *WARNING* before purchasing components or carrying out any electrical work.

Item	**Source**	**Qty**	**Typical total cost (2016)**
A desktop PC equipped with a parallel port, a USB port, and a DVD reader. This PC will be dedicated to operating SheetCNC.	ebay or surplus	1	Varies - widely available used or even scrap.
Availability of a home PC that has an internet connection and a DVD writer			N/A

Generally speaking, any old desktop PC from the last 10 years or so is likely to suffice. Check linuxcnc.org for minimum machine specifications. A laptop is *not* suitable.

The PC requires an EPP parallel port to connect to the break-out board. A USB-to-parallel adaptor is *not* a suitable substitute.

Most desktop PCs until quite recently would normally be equipped with a parallel port for connecting to a printer. Some PCs have no visible parallel port but do, in fact, have a parallel port on the motherboard. A parallel port DB25 socket adapter plate can be fitted to the chassis and connected to the motherboard. Such adapters are widely available for a few pounds complete with cable and plug. More recent PCs do not have a parallel port at all. This can be overcome by fitting a PCI-to-parallel card to the PC if the PC has a PCI slot available. Again, these cards are not expensive.

It may be necessary to set up the BIOS so that Linux can recognise and use the parallel port. This is beyond the scope of this document.

An Ethernet port (or wi-fi) is useful for future file transfer, although it is easy enough to work around the lack of Ethernet by using a memory stick.

A USB port is required. It will be connected to the break-out board but does nothing except provide power to the board. No USB communication takes place. While it is unlikely that your PC has no spare USB port, it is worth nothing that the break-out board could possibly, if desired, be powered from a USB type power supply instead, so long as correct adaptors can be found.

The LinuxCNC PC is also SheetCNC's operating console, so it will require a keyboard, a screen, and a mouse.

It is not possible to predict for certain whether a given PC is suitable as a machine controller or not.

However, LinuxCNC's hardware performance requirements are modest so the majority of old desktop PCs that have both a parallel port and a USB port *are* suitable. Age of machine is not a perfect guide but very old machines (15+ years) may not be suitable due to limited performance. Very recent machines (made in the last 6 months) may be unsuitable due to lack of support in Linux for newly-introduced hardware. However, a typical 5- to 10-year old PC will set the buyer back between nothing and £25, so little is lost in the rare event that the PC turns out to be unsuitable. If preferred, consult linuxcnc.org for listings of known good, and known problematic, hardware.

Finally, a PC that appears unsuitable at first may turn out to be fine if minor tweaks are made. For example by disabling or removing as many peripherals as possible such as the sound card. Sometimes an underperforming PC can be be made suitable simply by installing a low-end video card to replace the on-board video hardware. This again is beyond the scope of this document.

Installing LinuxCNC

Please do read this section in full before installing LinuxCNC - even if you're a seasoned Linux expert. There are a few special steps you need to take. Note, particularly, the username that you should use if you wish to make use of our downloadable config files.

Installing LinuxCNC onto the machine controller is reasonably straightforward. While we will try to help by email it is extremely unlikely that we can sort out all OS installation problems remotely. So if you're not a computer wizard now might be a good time to find a geeky friend - or a friend's geeky child - who can handle the setup of LinuxCNC for you. Bear in mind that the Linux scene is huge and is based entirely on free cooperation between strangers so there is a *vast* pool of friendly resource on-line. The answer to almost any issue you are likely to face can be found just by Googling the problem - hundreds of others before you will have faced exactly the same trouble, will have asked the same question online, and will have had it answered by a Linux expert.

Begin by downloading a copy of the latest stable version of LinuxCNC from linuxcnc.org. At time of writing this is v2.7.9. Burn the resulting .iso file to a DVD to create a bootable disk. Plenty of online guidance is available on how to do this. Usually it will be easiest to create the DVD on a familiar home PC, rather than on the machine that is to have LinuxCNC installed onto it.

Note that the next step - installing LinuxCNC onto the PC that is to be used as the machine controller - will destroy the operating system, programs, and data that are on that PC so it is essential to make a copy of anything on that PC that needs to be kept.

Once the DVD has been created, insert it into the DVD reader on the PC that is going to run LinuxCNC. Boot that PC from the DVD drive. This may require changes to the BIOS setup but these are beyond the scope of this document. Follow the on-screen instructions to install LinuxCNC.

Important

When prompted to create a user during the installation, choose the username “sheetcnc” all in lower case and with no spaces. Otherwise our config files will not work for you.

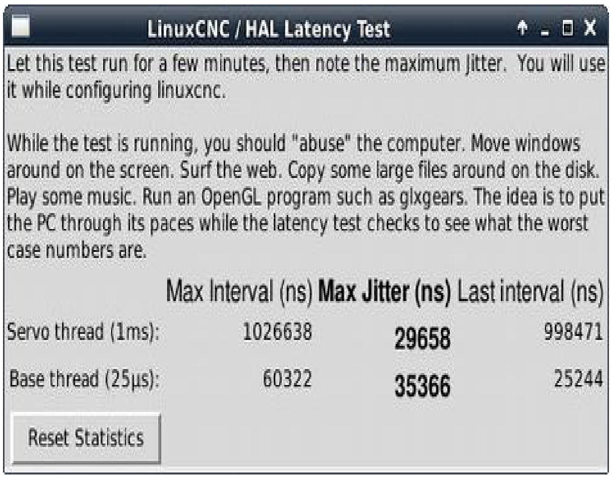
When the installation has finished, boot the PC and log on using the username “sheetcnc”.

Tip: The version of LinuxCNC that's installed by the installer may, in fact, transpire to be an earlier version than the download file claims it to be. But running the system update command (see below) will bring the system up-to-date to the latest version. This is a curious foible of the LinuxCNC distribution.

Test the PC

The very first step after logging on is to test whether the PC has sufficient performance for running LinuxCNC. There is a tool provided in LinuxCNC to do this, called *latency-test* .

To run *latency-test*, simply open a terminal *(Applications->Accessories->Terminal...)*, then type "*latency-test &*" (without quotes) and press <return>. The following window should open.



This program automatically runs a test to measure the performance of the PC.

Follow the instructions given in the window: run a few copies of glxgears (type "*glxgears &*" and press <return> several times in the already-open terminal). Plug in an ethernet connection if available and use IceWeasel to surf the web. Copy large amounts of data from a USB stick onto the hard drive. Do these things simultaneously. A few minutes of putting the PC through its paces like this is sufficient to complete the test.

At the end of the test, take a note of the largest of the two 'Max Jitter' numbers shown in bold by *latency-test*. In this case for example the number is 35366. Tip: A value below 20000 is excellent. A value up to 40000 will produce acceptable performance with the set-up we have provided in our download. If the number is higher that 40000 then either change to a different PC, or remove any hardware from the PC which might be slowing it down, or disable the on-board graphics card and substitute a plug-in video card instead. Then re-run this test.

When testing is finished, and the Max Jitter value has been obtained, close the LinuxCNC/HAL Latency Test. Proceed with setting up LinuxCNC only if the Max Jitter is lower than 40000.

Configure LinuxCNC

In this step, the PC is configured to match SheetCNC's dimensions and stepper-motor drivers.

Expert LinuxCNC users can, of course, set up the configuration using the tool s*tepconf* which is supplied with LinuxCNC. If you wish to do this for your SheetCNC machine but don't know how then our advice is to use our configuration files initially and at least get the system running reliably, before experimenting with modifying the configuration.

The complete configuration for SheetCNC can be downloaded from our website. To use our configuration files requires that you are using the same hardware that we have suggested, including the VFD and spindle, and that you have set it up as suggested above.

To use a copy of our configuration simply download the file 'Configuration.zip' from our website and copy that file (still zipped) onto a USB memory stick. The zip file contains a complete set of LinuxCNC configuration files which are compatible with SheetCNC and are suitable for almost any PC which has a Max Jitter of less than 40000.

Logon to the LinuxCNC machine with the username 'sheetcnc'. *Important: our config files will work* only *for this username.*

Insert the USB memory stick into a USB port on the LinuxCNC machine controller PC.

Open a file browser on the machine controller (the browser is a program called 'Thunar' and can be opened by clicking on the 'filing cabinet' symbol at the bottom of the screen). Navigate to the USB stick and right-click on the zipped file. Choose 'Extract to...' and specify 'Desktop' as the extraction location.

In the file browser, navigate to the Desktop and from there into the new folder 'Configuration.../LINUXCNC-MACHINE'. Copy the files from this folder onto your machine controller piece-by-piece as follows:

- Navigate into the folder 'CopyContentsToDesktop'. Left-click-and-drag the file named 'SheetCNC.desktop' onto the desktop itself, where a copy will be created.
- Navigate into the folder 'CopyContentsToHome'. Right-click and copy the folder named 'linuxcnc'. Then navigate to sheetcnc's home folder (specifically, this is the folder '/home/sheetcnc/'). Right-click in this location, and paste 'linuxcnc' there.

Now carry out the following installation step for the component 'Linear8', which is a useful addon that corrects for errors in the analog LinuxCNC-to-VFD communication:

- In Thunar, navigate to the directory /home/sheetcnc/linuxcnc/components .
- Right-click in Thunar and select 'open a terminal here'. A new window will open.
- In the new window, type 'sudo halcompile --install linear8.comp' . Don't type the quotes. Press return.
- Enter your sheetcnc password when requested. A short installation script should run.

This completes the set-up.

To test the new configuration, double-click on the new icon named 'SheetCNC' which is on the desktop. The LinuxCNC main interface, called 'AXIS' should launch, confirming that LinuxCNC has recognised a valid configuration.

Finally, follow any update instructions offered by the system to make sure the system is running the latest available version of LinuxCNC. Tip: Earlier update notifications which have been skipped can be re-opened by clicking on the red triangle which will be present at the top-right of the screen. It may be necessary to repeat the update process several times, until the system advises that there are no updates available.

This completes the software installation.

Expert users may like to modify our LinuxCNC configurations either by direct editing of the .ini and .hal files, or by using the *stepconf* wizard utility supplied with LinuxCNC. Be aware that *stepconf* will completely overwrite our .ini and .hal files causing loss of the Linear8 module and the special touch-off buttons we have added - so make a backup of the configuration directory before running *stepconf*.

Set Up the Hardware

When all the software installation is complete, shut down the PC and move it to where SheetCNC is installed.

Use a parallel cable to connect the parallel port to the break-out board. Connect the special USB cable from the breakout board to a USB port on the PC.

Ensure the 48V PSU and the spindle VFD are disconnected from the mains. Boot the PC and check that the break-out board powers up from the USB supply - its LED should light.

SheetCNC Test

During testing, SheetCNC will be under the control of the newly set-up PC. It is in the nature of testing that the machine may not perform predictably. Remove any cutting tools from the machine, ensure that all axes are free to move without obstacles, and keep others away from the machine during the tests. Be prepared to stop the machine - by disconnecting the power if necessary - if it malfunctions.

During testing, constantly check for overheating components and stop the test immediately if such become evident. As a guide: Stepper motors may become quite warm - even when stationary - but should never be too hot to hold comfortably. Other components should heat up only marginally. The spindle - when the cooling is operating properly - should be at the same temperature as the coolant in the reservoir and should never be more than tepid to the touch.

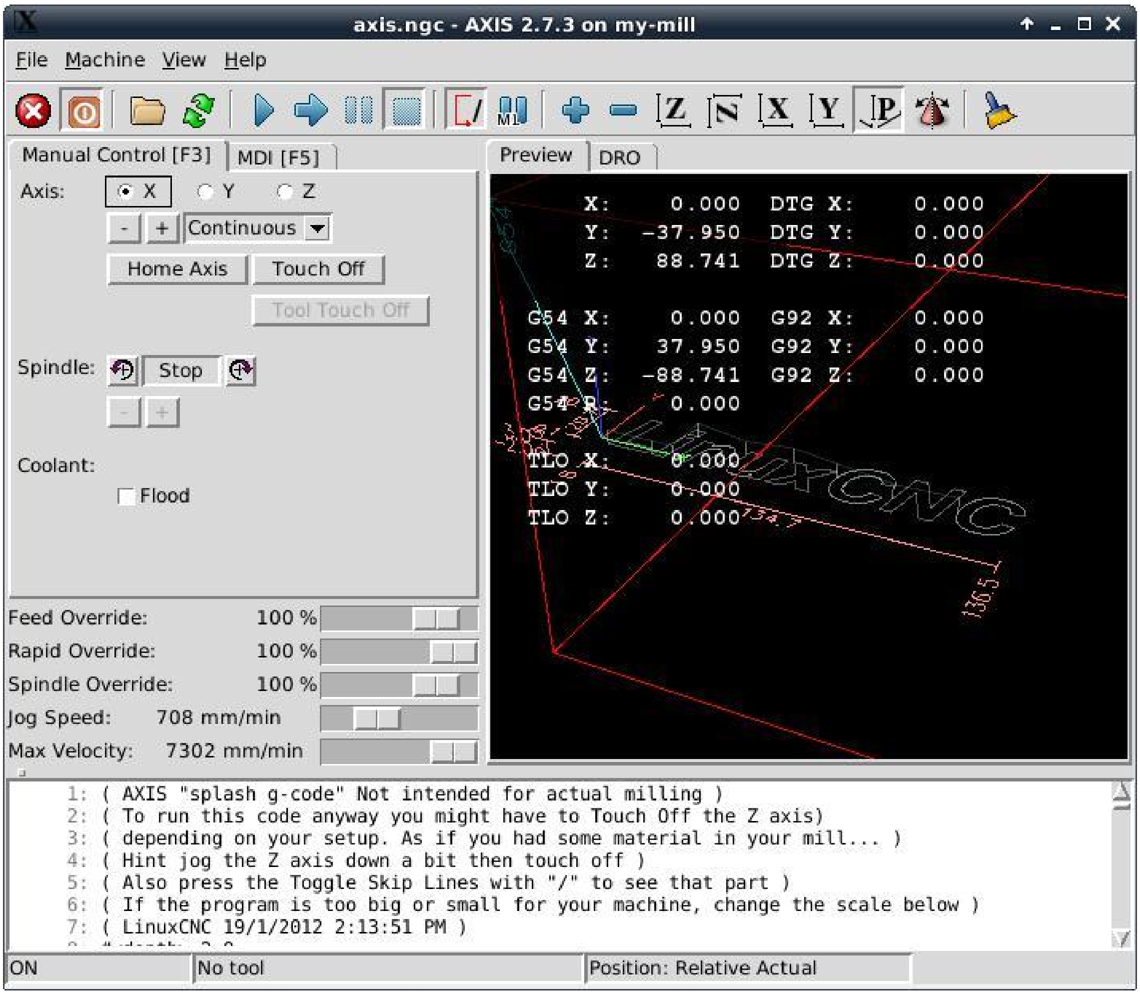
Reference is made to the physical locations of the home positions of the axes. See *Introduction* above for a description of these locations.

Axes and Limits

Begin with everything powered down. Manually move the gantry to the middle of the table and the spindle to the middle of the gantry. Manually wind the z-axis to about half-way up its range of movement. Tip: moving the stepper-motors by hand generates a significant current which feeds into the unpowered stepper-motor drivers. The drivers react by braking the motors, so that intermittent high resistance to motion will be felt. It is therefore best to move the X and Y axes slowly to avoid this.

Power up the 48V PSU and boot the PC but ensure the VFD is disconnected from the mains so that the spindle cannot start.

Double-click on the 'SheetCNC' icon to start LinuxCNC. (More correctly, this icon launches AXIS which is the default display program for the machine controller interface. But for sake of simplicity, we'll just call this interface 'LinuxCNC' in this manual. There is a manual page for AXIS at linuxcnc.org .)



LinuxCNC/AXIS. In this screenshot the Emergency Stop has been released and the power is on.

Before proceeding further, check that the tool table contains reasonable values. The table we supply contains 20 placeholders for tools. See the appendix *Tool Table* for more detail.

When started, LinuxCNC disables the machine much as if a physical emergency stop button has been pressed. To power up the machine first left-click on the 'Stop' button in LinuxCNC (red with a cross, top-left) to disengage it, then click the 'Power' button (orange, next to the emergency stop button). You should hear all the stepper-motors 'clunk' as they lock in position as power is applied to them. If the machine now does anything other than stay stock still, you should click the 'Power' button off again.

If necessary, press <F3> to put LinuxCNC in manual mode.

Assuming all is well, try the axes motions. <Page-Up> and <Page-Down> should move the Z axis up and down respectively. <Left-Arrow> and <Right-Arrow> should move the gantry towards and away from the Home Stop, respectively. <Down-Arrow> and <Up-Arrow> should move the spindle-carrier towards and away from the Y-axis home position, respectively. Do not drive any axis to its limits.

Tip: If none of the axes respond to commands at all, then the likelihood is that the configuration has the wrong address for the parallel port on the controller PC. This can occur if the PC has multiple parallel ports, or if the parallel port is an add-on card, or if the PC has an unusual internal configuration. The port's address is specified in the SHEETCNC.hal file in a line reading "loadrt *hal_palport...”. The correct address of the parallel port can be found from the PC's BIOS. Alternatively the linux command lspci can be used. The .hal file should be updated accordingly, and LinuxCNC (AXIS) should then be restarted.*

If any axis moves in the opposite direction to that expected then shut everything down, power off, and swap over the red/blue wires of that axis's motor where they enter the appropriate stepper-motor driver. This will reverse the direction of the motor.

If any other malfunction occurs then power down and double-check the wiring and the LinuxCNC configuration.

Try the axes movements again, but this time with the <SHIFT> key depressed. The X and Y axes should move at about ten times the speed of their earlier movements. The Z axis should be slightly faster than before.

With all axes stopped try manually pushing the X and Y axes but take care not to distort any parts. The axes should be quite difficult to budge, although it should be possible to overcome the motor holding current - at which point the axis will suddenly appear to become free and will move a substantial distance. If they move easily, possible causes are incorrect maximum current setting for the stepper-motor drivers, faulty drivers, a model of driver that performs microstepping only poorly, or a model of driver that excessively reduces motor holding current. This test of trying to move the axes against the motor holding current is a one-off careful test just to confirm that the motors are set to a high enough torque. The test should not be taken to excess nor should it be repeated unnecessarily as it places considerable strain on the drive parts.

Home the axes, as described in the appendix *Homing The Axes* below. (Tip: Begin by pressing <F2> to power off the stepper-motors.)

Set the Jog Speed to about 1000mm/min. Now try driving the X and Y axes to their limits using the cursor keys. The controller should stop each axis just before it reaches any limit. If any axis does not stop automatically it will impact the end stop and the stepper-motor will be heard noisily trying to drive the axis beyond its limit. The axis will, of course, fail to move as the controller commands so resulting in the controller no longer having an accurate record of where the axis is. In severe cases - such as high-speed collision with the end-stops or continuous attempts to drive beyond the end-stops - machine damage can occur so take care and be ready to stop the machine. Check the configuration (in SHEETCNC.ini) if collisions do occur.

Assuming all is well, test the Z axis limits in a similar way. Bear in mind that the physical lower stop of the Z axis potentially allows the chuck to contact the table, which can damage the chuck or the spindle carrier. So test the Z-axis only when the Gantry is against the Home Stop.

Always take great care to always raise the Z axis to safe clearance before moving the X or Y axes.

Troubleshoot as necessary.

Touching Off and Running a Sample Program

LinuxCNC comes with a sample program (aka a 'G-code' file) preloaded, called axis.ngc . This program can be dry-run as a very simple test of SheetCNC. The program should never be used to cut material because the feeds and speeds are extremely slow and are badly mismatched.

Turn off the VFD. Remove any cutter from the chuck. With the remaining elements of the machine turned on and the axes homed properly, as above, use the cursor keys to move the X axis about 200mm along the table and the Y axis about 200mm along the gantry. Use the <Page-Up> and <Page-Down> keys to position the Z axis to about its mid-position - about 100mm below the home position. Exact positions are not critical.

Before running any program, the controller has to be informed where the material to be cut (the workpiece) is located in relation to the cutting tool. This is called 'touching off'.

Each axis is touched off independently in LinuxCNC. Touching off is allowed only if the axes have previously been homed. So with the axes homed and then re-positioned as above, press 'X' and then <End> to touch-off the X axis. When asked, press <Return> to inform LinuxCNC that the offset is zero for this axis. Similarly, touch-off the Y and Z axes.

The machine controller is now informed that the tool tip is (in theory) just touching the top of the workpiece and that the tool tip is above that corner of the workpiece that is nearest to the home location of the X and Y axes. Clearly, in this simple test case, there is no such workpiece.

Press 'R' to run the program. The program should move the axes through the motions to cut the outline of the letters 'L i n u x C N C'. Note that the test program is designed for very small machines that work v-e-r-y slowly, so all the axes will move only small distances, and at rather slow speeds compared to cutting a real workpiece. Progress of the program can be viewed in LinuxCNC (black frame on the right side of the screen). The view can be panned and rotated using the left and middle mouse buttons. The key 'V' will toggle through various alternate views. The execution of the code can be observed line by line (bottom text frame).

The program can be paused using the 'P' key, and can be resumed with the 'S' key. The program can be stopped by hitting <ESC>.

A paused program can be restarted from where it was paused. It can also be stepped-through one line at a time using the 'A' key.

A stopped program can only be restarted from the beginning.

Spindle Test

Ensure the VFD is powered down. Remove the nut and the collet from the chuck of the spindle. Home the X, Y, and Z axes if not already homed.

Safety eyewear is recommended.

Apply mains power to the VFD. When its display comes up it should show '00000', flashing. The 'Pwr' and 'Rott' lights should be steadily lit, and the 'For' light should be flashing. Press the green button on the VFD control panel. The spindle should start to rotate and a rpm number of exactly '01260' should appear steady on the display. The 'For' light should now be steadily lit. The coolant pump should simultaneously begin to run.

Check that coolant is flowing. A trickle is sufficient. Tip: The spindle will not be instantly damaged through lack of coolant - it takes some minutes to warm up beyond safe temperature.

Check that the spindle is rotating in the correct clockwise direction, if viewed from above, at a slow speed.

Troubleshoot as necessary, checking the VFD settings and the physical wiring.

Hit <F5> to put LinuxCNC in MDI mode. On the MDI tab you can now enter G-code commands to directly control all aspects of the machine. So take care - some commands can damage the machine. Enter the command 'm3 s1350'. The spindle should speed up to approximately 1350rpm, as displayed on the VFD front panel. Enter the command 'm3 s12000'. The spindle should speed up to approximately 12000rpm, which will take several seconds to achieve.

If the speeds displayed on the VFD are very different from the speeds you input, it means that your particular VFD and breakout board have different responses to the ones we used to create the configuration files. Bear in mind that the analogue interface between LinuxCNC and the VFD means that the speed controller will never be perfectly accurate. Errors up to 15% in parts of the speed range are to be expected. If the errors exceed this, contact us for assistance. You may also like to read the README.txt included in the configuration files which describes the Linear8 optional component of LinuxCNC. Linear8 can reduce the spindle-speed errors to virtually nil.

The maximum valid spindle speed is 24000, which you may also like to try.

Enter the command 'm5' to command a spindle-stop. This will bring the spindle speed back down to the minimum again. The spindle will *not* stop rotating - even though 'm5' means 'stop spindle' - because the VFF has been set up with a minimum speed of 1260rpm.

Press the red button on the VFD. The spindle should now slow down and stop. When the spindle has ceased turning, the coolant pump should also cease running.

Troubleshoot as necessary. Tips: For ease of troubleshooting the connection between the VFD and the spindle independently of LinuxCNC, the spindle speed control can be set to manual by setting PD002 to '0' on the VFD's control panel. This then allows the spindle speed to be adjusted via the up and down arrow buttons on the VFD control panel rather than via LinuxCNC. Reset PD002 to '1' before trying to control the VFD via LinuxCNC.

Optional Spindle Start/Stop and Soft Em-Stop

Spindle start/stop is - by default - controlled by the user. Pressing the green button on the VFD starts the spindle. Pressing the red button stops the spindle. The spindle start/stop can instead be placed in the control of LinuxCNC, if preferred.

Software Em-Stop is - by default - enabled only on the F1 button of the computer. The software Em-Stop can, if preferred, be operated via a switch(es) mounted in the machine room and/or on the machine.

These features can be enabled as follows.

On the VFD:

- Run a wire from the VFD's 'DCM' terminal to one of the terminals labelled 'Spindle' on the breakout board above.
- Run a wire from the VFD's 'FOR' terminal to the other terminal labelled 'Spindle' on the breakout board.
- Set the following programmable settings on the VFD:
  - PD001 = 1
  - PD044 = 1
- If your VFD has a knob on the front to control speed, you must disable it by moving the internal jumper from “VO” to “VI”.

On the breakout board:

- Ensure the breakout board is set to use Pin17 to operate the on-board relay (this setting is via a physical jumper on the board and is usually set on by default).
- Connect normally-closed em-stop switches in series between terminal P10 and PC5V+ on the breakout board.
- Connect a 10KΩ resistor from P10 to GND on the breakout board.
- Optionally, connect a 0.1uF ceramic capacitor from P10 to GND on the breakout board to reduce the chance of noise signals being picked up. (But *don't* connect a capacitor from P10 to +5V: if such a capacitor were to fault short-circuit it would render the em-stop inoperable.)

On the LinuxCNC computer:

- Go to the directory /home/sheetcnc/linuxcnc/configs/SHEETCNC . Rename files as follows:
  - Rename SHEETCNC.hal to SHEETCNC.hal.ManualSpindle
  - Rename SHEETCNC.hal.AutoSpindle to SHEETCNC.hal
- Restart LinuxCNC

The changes can be tested by running commands via the MDI tab in LinuxCNC:

- M3S2000 should start the spindle at 2000rpm. The water pump should also start.
- M5 should stop the spindle. The water pump should also stop.

- Operating any of the physical em-stop switches (or pressing F1) should stop the spindle *and* depower the stepper motors *and* stop any running program. Reconnecting the physical em-stop switches should *not* result in the machine or the spindle restarting without further commands from the user.

Note that operating the em-stop signals the VFD to stop the spindle but it does not cause the spindle to brake to a stop - this would require further setting-up of the VFD including the provision of a braking resistor and a signal path to another VFD input which would be set up for em-stop.

Warning

Be aware that giving control of the spindle start/stop to LinuxCNC may increase the risk of the spindle starting unexpectedly due to power spike, software fault, or hardware failure. The spindle may also operate unexpectedly during PC startup and shutdown. Test, and conduct a specific risk assessment, before committing to this option.

Be aware that the described em-stop mechanism operates only via software. A power spike, software fault, or hardware failure may render the em-stop feature inoperable.

The soft Em-Stop described above does not brake the spindle - merely depowers it.

As part of your risk assessment you should consider whether to provide alternative - or additional independent - em-stop features which will function irrespective of other system failures. One option may be to use the NO contacts of the em-stop switches to signal to a backup shutdown method which operates simultaneously.

Bedding-In

Unless your machine runs on precision-ground linear rails then it will need to be run-in for a short while. This allows the bearings and runners of the linear axes to bed-in.

It would be fine to simply allow the machine to bed-in during the first few hours of running it normally. However, this would mean making constant fine adjustments to the bearing tensions which would become tedious. Plus, there would be no guarantee that all areas of the linear axes were bedded-in equally.

To bed-in SheetCNC (other machines will vary but the process will be broadly the same) create a simple G-code program which moves the X and Y axes simultaneously from one limit to the opposite limit, multiple times, at rapid speed.

Before running the program, adjust the bearings so that they are all a smidge over-tight. Not excessively tight because this might damage the parts.

Run the program so that the axes are traversed each way - say - fifty times. Then retighten the bearings a smidge over-tight again and run the program for another 50 traverses. This will complete 90% of the bedding-in process.

A similar program can be run for bedding-in the Z-axis, but take care that the spindle does not strike the bed or foul any other part of the machine.

After the bedding-in programs have finished re-adjust the bearings according to the user manual of your machine (for SheetCNC, see the Build Manual). Then use the machine normally.

Check and adjust the bearing tensions again periodically during normal use until they have fully bedded in.

Cutters

If this is your first CNC machine, you will need to purchase some cutters (aka tools, bits, end-mills) before you can start to use the machine.

The most suitable tools for timber work are single-fluted spiral upcut carbide cutters. While HSS cutters may be preferred for some other materials, we do not recommend HSS cutters for timber work because they will blunt extremely quickly.

Brand-name carbide cutters are extremely expensive at about £30 each. They are easily snapped and it would be a pity to break such a cutter during the first days of learning to use the machine.

We suggest that you confine your initial practice to MDF board and uPVC panelling. This means that, by employing conservative cutting speeds, you can practise using cheap cutters which won't break the bank when you snap them.

When you have practised using SheetCNC so that you are unlikely to break a cutter by mistake, then it will be worth investing in some high quality brand-name carbide cutters.

Tip: Never use straight-fluted cutters. While they are commonly available and very cheap, they are solely intended for use in hand-held routers. Straight-fluted cutters produce poor results because they do not clear chips effectively. They are also *extremely* noisy.

We would suggest buying the following cutters for initial practising with SheetCNC:

1/8” Single-Flute Endmill

1/8” single-flute spiral endmill. They do a lovely job of cutting gears and similar intricate shapes from uPVC board and MDF, and they are cheap as chips.

The specification you are looking for is:

- Single-flute spiral upcut end-mill
- Shank: 1/8” 3.175mm
- Cutting edge diameter CED: 1/8” 3.175mm
- Cutting edge length: 17mm approx
- Overall length: 40mm approx

You will need to buy a collet for these. Look for a reasonable quality ER20 collet made specifically for 1/8” shanks. Alternatively a 4mm collet (i.e. a 4mm down to 3mm collet) will be perfectly fine except that it will be more awkward to set up. Collets are widely available on ebay, but these are likely to be poor quality causing tool run-out so we suggest going direct to a quality supplier, such as Rotagrip, and buying a Vertex collet or similar quality. It may also be worth investing in an additional collet nut, which saves time when switching tools.

These cutters are widely available on ebay in sets of 10 for about £7.50. Commonly the sellers have poor feedback so choose supplier with care. Take care not to purchase equally common ball-ended mills by mistake.

6mm Carbide Endmill

We find that imported carbide cutters vary hugely. But some can be excellent value for money. For example, we have some Chinese upcut 6mm single-fluted carbide tools which produce a superb finish on MDF even when cutting full depth at speeds of 4500mm/minute. Priced at around £25 for a pack of 5 they are something of a bargain and we suggest you track some down for your first experiments with carbide tooling.

The specification you are looking for is:

- Single-flute spiral upcut carbide end-mill
- Shank: 6mm
- Cutting edge diameter CED: 6mm
- Cutting edge length: 25mm or 32mm* approx
- Overall length: 45mm approx

These cutters are frequently sold direct from China on Amazon's website and/or on ebay.

*The 25mm CEL cutters are much quieter than the 32mm ones, but they are somewhat more difficult to source. We strongly recommend the shorter option if it can be found. Longer options (e.g. 42mm CEL) are available. They will be *extremely* noisy on hardwood/plywood/MDF and should be avoided.

Small-Diameter 2-flute Endmill

Plastic - especially HIPS - generate a lot of heat when cut. In the absence of liquid coolant, they therefore require very low spindle speeds to prevent the material melting or binding to the cutter. We recommend obtaining some small, short-CEL, 2-flute, carbide cutters for testing. We have found 2mm and even 1.5mm CED cutters, with CELs of 6mm-10mm, to be ideal for cutting thin plastic sheet. Downcutters are a good option to try as these will greatly reduce the risk of snatching on thin materials.

CAD Software

CAD (Computer Aided Design) software is used to create the drawings which define the items that SheetCNC will cut.

It is normal practice to run the CAD software on a computer separate from the machine controller PC, simply because it is usually easier to create designs in a comfortable environment, rather than in the workshop.

You'll need to install - and learn - a CAD package before you can create stuff on SheetCNC. Here we offer some guidance. See also *Clever Cuts* for tips, tricks, and a getting started guide.

Essential Features

The beauty of 2.5D CAD is that complex shapes can be created from quite simple two-dimensional drawings. These, of course, require a 2D CAD drawing package to draw them. Many of the more recent CAD programs are squarely aimed at 3D work, which means that they operate on cubes, spheres, cylinders and other solid objects but have little or no intrinsic support for two-dimensional line drawings.

Some of the more proficient 3D packages can export 2D drawings of parts of the 3D object - but generally these drawings must still be modified in a good 2D package before they are suitable for CAM. One exception is AutoDesk's Fusion, which is so remarkable that it is covered in a separate section of its own at the end of this chapter.

To be fully useful in 2.5D work a CAD program requires, as an absolute minimum, a comprehensive 2D drawing platform that offers the following:

- Drawing layers
- Drafting tools such as circles, polygons, lines, and perhaps splines
- Tools to explode and join line entities, and to open and close multi-line entities
- Tools to add and subtract 2D objects
- Options to precisely size and orient objects numerically, not just visually
- Options for snapping to elements of the drawing, not just to a grid
- Ability to save drawings to DXF format files, with the essential option to save to older versions of that format, particularly DXF-R14 used by some CAM packages.

Available Software Options

There are many CAD programs available, some of them free. We list a few of the more economic versions here. The list is by no means complete.

AutoDesk

AutoDesk produce the well-known AutoCAD software. This is ubiquitous in offices around the world for 2D, 2.5D, and 3D work of all kinds in all fields. It is complex software and the learning curve is steep. It is also expensive, although AutoDesk do offer their software for free if it is to be used for 'Educational Purposes'. Their definition of this term (available at autodesk.com) is quite wide-ranging and may encompass many home users.

The software is up-to-date and employs all modern concepts including parametrised design.

If you are willing to spend time learning a drawing package in depth, then we recommend AutoDesk with the caveat that, if you later wish to use your CAD skills to set up your own business, you may find that the educational licence limitation combined with the extremely high cost of acquiring a full licence forces you to swap AutoDesk for a different package just at a time when you don't want to be learning a new skillset.

AutoDesk software runs under Windows only.

See also Fusion, below.

TurboCAD

TurboCAD is a widely used, very stable, highly regarded commercial 2D and 3D CAD program. Here at SheetCNC.co.uk it is our go-to hack-a-day 2D drawing package. Like AutoCAD, the learning curve is steep. But wholly unlike AutoCAD it is available for unrestricted use for peanuts. The most recent 'Deluxe' version retails at £85 and half-price offers can often be found. Older versions (commonly TurboCAD Deluxe v20) are available for under £20 including a genuine full unrestricted licence - see Amazon and ebay.

There is plenty of support for TurboCAD beginners. Tutorials abound, the forums are popular and busy, and the manual is comprehensive and detailed.

The 2D drafting tools are impressive, easy to use, and full-featured. One of the beauties of TurboCAD is that, once the 2D toolset has been mastered, it is reasonably easy to transfer those skills to design some basic 3D objects in the same drawing program. This would allow you to explore the 3D abilities of SheetCNC without learning a whole new drafting program.

So if you are on a limited budget but need to create 2D, 2.5D, and - perhaps - 3D drawings for business use and are willing to spend time learning a CAD program in depth then we recommend TurboCAD, with the caveat that it may soon be a little dated: the CAD world - especially for 3D work - is moving on to parametrised designs while TurboCAD has hardly even begun to implement the concept.

Runs under Windows and MacOS. Latest releases run only under recent versions of those operating systems. Can be used on Linux under VirtualBox, but not under Wine.

SketchUp

SketchUp is primarily aimed at 3D design. It is moderately expensive and there is an ongoing annual cost for bug-fixes and upgrades. A free version is available but only for non-commercial use. Runs only on Windows and MacOS.

InkScape

A free program primarily aimed at drawing sketches, illustrations and diagrams, rather than engineering drawing. Potentially it could be used to create CAD drawings and it does have a useful gear-generating plug-in which can be used to export DXF files containing gears. Runs under most operating systems, including Linux.

DraftSight

A commercial 2D CAD program but with a non-commercial 'beta' release available under a free and effectively unrestricted licence for single-user application, with the caveats that the program may contain serious bugs (hence 'beta') and that the licence may be withdrawn at any time by the publisher. Runs under most operating systems, including Linux.

FreeCAD

Free and unrestricted software that can be used for any purpose, including business. The interface is complex and divided into frustratingly separate 'workbenches' which behave like isolated drawing programs in their own right, yet have overlapping functionality. The 2D-drawing workbench lacks layers, making it unsuitable for 2.5D work. Runs under most operating systems, including Linux.

OpenSCAD

Another free and unrestricted offering but suitable only for 3D work. OpenSCAD is popular in the world of 3D printing. Reasonably easy to learn and use yet fully embraces the complexities of parametrised design. Not suitable for 2.5D work.

HeeksCNC

See the entry under *CAM Software*.

QCad

A program that specialises in 2D CAD, potentially making it ideal for 2.5D work. Sadly the free version forbids use of layers, which are essential to CAM processing. However, the pro version is not expensive. Runs under most operating systems, including Linux.

LibreCAD

An old version of QCad, repackaged with a free and unrestricted licence. Development is patchy and there is minimal support available. One for the open source enthusiasts. Runs under most operating systems, including Linux.

AutoDesk Inventor

This a superb package for amateur 3D design. A non-commercial licence is available free. However, it is entirely unsuited to 2.5D work.

OnShape

This is a highly capable 3D online CAD tool. It is free to use, provided that you agree that your designs are publicly and permanently available online. It is entirely unsuited to 2.5D work.

SolidWorks

Another superb 3D drafting tool. It has many of the capabilities of Fusion (see below). The license is costly. We have not used it so are unable to say whether it is suitable for 2.5D work.

AutoDesk Fusion 360

The extraordinary Fusion 360 program from AutoDesk deserves a section of its own.

Fusion is an easy-to-learn, moderately intuitive, 3D CAD package. A commercial license is - for now - free to all users, provided that the business turnover is less than $100,000 annually.

Fusion also incorporates some remarkable CAM facilities, and is able to export 2.5D and 3D G-code *directly from the 3D model*. This means that the user can produce 2.5D G-code without ever having to work with 2.5D drawings.

Our own experience of the CAM elements of Fusion is limited, but one of our customers has been using Fusion exclusively for all their 2.5D and 3D work. They have produced some extraordinary and beautiful items on SheetCNC from their Fusion drawings.

Recommendation

We would *strongly* recommend investigating Fusion as a combined CAD and CAM package, for both 2.5D and 3D use.

If Fusion is judged not suitable, or if a more traditional workflow is preferred, then we recommend either of:

- AutoCAD - for having all the tools required and being bang up-to-date. For being widely used across the industry, and for being free for non-commercial educational use.
- TurboCAD - for having all the tools required and being packaged into a single, simple, works out-of-the-box interface which runs on both Windows and MacOS. For being hugely popular and well supported by tutorials, forums and manuals, and for being very cheaply available on an unrestricted commercial licence.

Unfortunately none of our recommendations will run natively under Linux. If you are a Linux-only household or business, we suggest using a VirtualBox. TurboCAD v19, v20 and v21 run seamlessly under recent releases of VB, and later versions are likely to be similarly well-behaved. Fusion runs tolerably well in a VirtualBox, so long as VB's 3D acceleration is turned off.

CAM Software

CAM (Computer Aided Manufacturing) software is used to convert the CAD drawings into programs that direct a CNC machine, such as SheetCNC, how to move so as to produce the finished work.

The programs created by CAM software are written in G-Code and comprise a series of individual instructions laid out line by line for the CNC machine controller to interpret and to execute sequentially.

It is normal practice to run the CAM software on the same PC as the CAD software.

You'll need to install - and learn - a CAM package before you can create stuff on SheetCNC. Here we offer some guidance. See also *Clever Cuts* for tips, tricks, and a getting started guide.

Types of CNC CAM

There are two distinct types of CAM used for 3-axis CNC milling work: 3D CAM and 2.5D CAM. They each instruct the CNC machine to remove material from the workpiece to produce the finished work. However, they do this in quite different ways:

3D CAM software instructs the CNC machine to follow the contours of the finished object, removing material from all around the object until it is finally revealed. This is much like a sculptor or carver would work, and indeed 3D machining is just as often used to produce artwork as to produce mechanical components.

2.5D CAM software instructs the CNC machine to cut specific holes and pockets into the workpiece, and to cut out outlines from the workpiece. The holes, pockets, and outlines are not necessarily sheer-sided and can have sloping or shaped sides, so that the resulting object is not just a simple 2D shape but instead has 3D elements. This process of applying operations to the workpiece is much like an engineer in a workshop would work, and indeed 2.5D machining is most often used to produce mechanical components, though it is also frequently used for engravings - such as signs - as well.

While SheetCNC can be used for 3D work, this is beyond the scope of this document. The software required for the purposes of this document is a 2.5D CAM package.

Available Software Options

CAM software is available as freeware, as add-on packages for CAD programs, and as stand-alone commercial software. Most freeware is aimed at the 3D market and is unsuitable for 2.5D purposes. Many of the add-on CAM packages for low-cost and free CAD programs are limited and they often cost considerably more than their host CAD package.

Sadly good 2.5D CAM options are few so this is one area where the home machinist will find they are more-or-less forced to purchase commercially licensed software. However, the cost is not prohibitive.

See also Fusion, which is discussed in the CAD section, above.

AutoDesk AutoCAD and Inventor

There are add-in packages from AutoDesk to integrate CAM into their CAD programs.

CamBam

A commercial 2.5D CAM package available to try for free and with no restrictions on that free trial other than that the program will cease to run after it has been started 40 times.

CamBam is hugely configurable and very capable. Of the packages we have tried it has produced the most efficient and neatest cutting paths.

The sheer number of configurable factors in CamBam, combined with its rather clever inheritance-tree concept, can make the program phenomenally complex to set up and use.

CamBam has the significant disadvantage that, if the CAD drawing is slightly changed and then reloaded into CamBam, the user must re-do a lot of work in CamBam before they can re-generate the output. This seriously interrupts the workflow and for this reason we would not immediately recommend CamBam as the best choice for a new user.

CamBam runs only on Windows and - once the evaluation copy has expired - costs £93.

SheetCAM TNG

A commercial 2.5D CAM package. It is available to try for free but with limitations.

SheetCAM is rather less configurable than CamBam and some of the configuration is by analogue sliders rather than numeric data entry, making it feel less precise. The paths generated are sometimes less optimal and lack some subtleties. Even so, SheetCAM is a highly capable package.

SheetCAM has the significant advantage that it integrates into an iterative workflow extremely well: users can create a CAD drawing in another program, import that drawing into SheetCAM to create an output program for SheetCNC, cut that program on SheetCNC, evaluate the resulting work, refine their CAD drawing, and then - crucially - the user can reimport that modified CAD drawing into SheetCAM and immediately create another output program for SheetCNC without being involved in additional CAM work. For this reason we much prefer SheetCAM over CamBam.

SheetCAM TNG runs under Windows and Linux but not MacOS. The evaluation version is restricted to short CNC programs of 180 lines of G-code which is extremely limiting. The licence costs £130.

TurboCAD

TurboCAD offers an add-in CAM package. However, it is costly to licence and has remained undeveloped for many years.

HeeksCNC

HeeksCNC is a CAM program that falls somewhere between commercial software and freeware. Developed by an individual who also runs an active commercial machine shop. Built from open-source (free) software. The program is open-source and freely available on Linux. For Windows users a self-installer can be downloaded for just £10. We occasionally use it for pure 3D CAM work, and it is 2.5D capable too. As a bonus it includes basic CAD features.

PyCAM

PyCAM is freeware. Development ceased several years ago so the program is unsupported. It is aimed at full 3D CNC and users report good results. It is not suitable for 2.5D work. Runs on most operating systems.

Recommendation

Good 2.5D CAM options are very limited and we feel that those who are using traditional 2D CAD have little choice but to trial CamBam and SheetCAM, and ultimately to license one of them. We would favour SheetCAM over CamBam for most users because it allows a much slicker workflow for iterative prototyping.

Some users may wish to trial HeeksCNC.

If designing on MacOS then choices are even further limited. Consider running HeeksCNC or SheetCAM on the LinuxCNC machine controller itself.

We do strongly advise all users to trial AutoDesk Fusion, which may offer a complete - and free - CAD/CAM solution for all their work, both 2.5D and 3D.

And Now...

This completes the guidance we offer for setting up third-party components and software.

We suggest that once you have configured the hardware and installed the software, you should head back to Appendix *Commissioning* in document *Build Manual*. However...

...if you are not yet familiar with CAD and CAM software, or have not previously used a CNC machine, we suggest that you skip *Surfacing the Bed* and instead temporarily fit a spoilboard to the unsurfaced machine and then work through document *Clever Cuts* so that you can practice some of the techniques of CNC design and machining. When you have mastered the basics, you can then remove the temporary spoilboard, and use your new skills to finish commissioning the machine by surfacing the bed.

Appendix: Homing The Axes

To home SheetCNC's axes, follow these instructions:

Click the LinuxCNC orange 'Power' button off. The axes should now be free to move by hand. Move the gantry and the spindle carrier to their home positions. While still gently holding the axes against the X and Y stops, click on the 'Power' button in LinuxCNC. The motors should 'clunk' and the axes should be held firmly in place, perhaps moving a fraction of a millimetre as the motors first engage.

Press the 'X' key on the keyboard followed by the 'Home' key on the keyboard. The machine controller has now stored the current location of the gantry as its home position. It will never try to drive the gantry further backwards than this position. Nor will it try to drive the gantry beyond the furthest limit at the other end of the table which is set by the configuration.

Repeat the homing for the Y axis, using the 'Y' key and then the 'Home' key.

Hold down the 'Page Up' key to drive the Z axis upwards. Release the key when the lead-nut is about 1mm-2mm away from contacting the collar fitted underneath Y-Motor. Home the Z axis in LinuxCNC by pressing the 'Z' key and then the 'Home' key.

All three axes are now homed and the machine is ready to be touched-off.

Tip: It is safe to use the X/Y/Z motors to drive the axes to the home position ready for homing, if preferred, provided that rapids are set to no more than 12000mm/minute and that care is taken not to impact the stops at speed. It is also safe to allow the motors to attempt to drive toward the stops even after the stops have been reached, though it is not advisible to do this excessively. Repeatedly impacting the stops at rapid speeds will wear the machine and ultimately result in damage. Be warned that impacting the stops at high rapid speed *will* cause *immediate* damage to the machine. For this reason, never set a public machine (one in a maker-space for example) to higher rapid speeds than 12000mm/minute. When learning to use a private machine, temporarily set it up to have similarly modest rapid speeds, so that inevitable mistakes do not cause damage.

Powering Down

Tip: Just before shutting down the machine at the end of each day, drive all the axes to their home positions. They will then be ready-positioned at the home positions the next time the machine is started.

This can easily be done by the following sequence of keys:

- Press and hold <Page Up> until the Z-axis is at the home position.
- Press and hold <Shift>, then simultaneously press and hold <Down Arrow> and <Left Arrow> until the X and Y axes are in the home positions.

Appendix: Tool Table

A tool table is a list of tools (cutters). It contains reference data about each tool.

Both LinuxCNC and your CAM program(s) (see *Clever Cuts*) maintain a separate tool table each. In theory, the tool table on LinuxCNC should be kept in sync with the tool table in the CAM program(s). However, LinuxCNC's tool table has little relevance for a machine that has a collet chuck and relies on manual tool changes. So a simple one-off placeholder tool table suffices for LinuxCNC's setup.

The default tool table, supplied with LinuxCNC, has only a few tools in it and - worse - they may have non-zero offsets. Which means that unexpected things can happen when a piece of G-Code is run in the default LinuxCNC setup:

- If a tool is specified in the G-Code but the tool does not exist in LinuxCNC's tool table, then LinuxCNC will not run the program.
- Each tool in LinuxCNC's tool table is given a position/depth offset which LinuxCNC optionally adds to the movements that the G-Code contains. So, if the offsets in the tool table are wrong, and if the G-Code instructs LinuxCNC to add those offsets, then the cuts will be made in the wrong place and/or at the wrong depth.

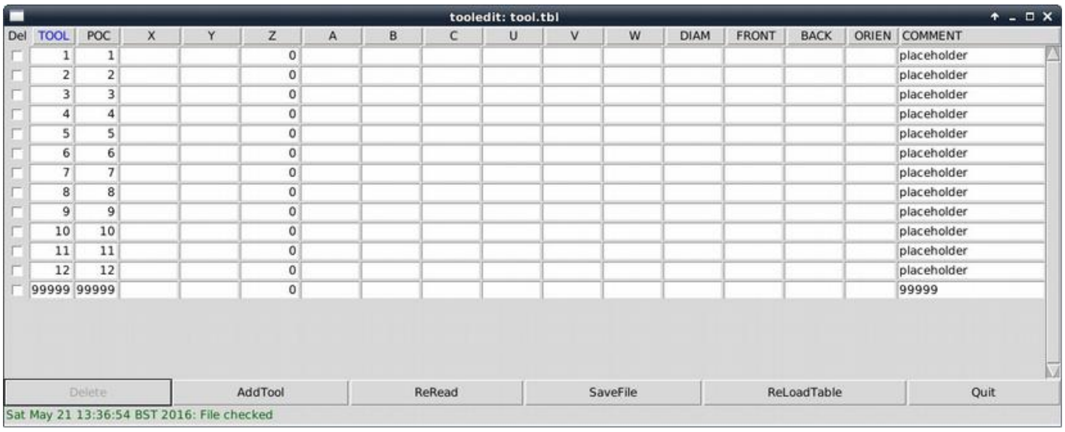
To overcome both these problems, simply create an entry in LinuxCNC's tool table for every tool number ever likely to be needed (say, tools 1 to 50). And specify zero offset for each tool. The rest of the data about each tool are irrelevant.

If you have downloaded the LinuxCNC configuration from our website then it includes a suitable tool table, with placeholders for 20 tools, and there is no need to take any other action unless you intend to specify tools numbered other than 1 to 20.

Procedure

In LinuxCNC select *Menu->File->EditToolTable*

Edit the entries to look like this:



Del	TOOL	POC	X	Y	Z	A	B	C	U	V	W	DIAM	FRONT	BACK	ORIEN	COMMENT
	1	1			0											placeholder
	2	2			0											placeholder
	3	3			0											placeholder
	4	4			0											placeholder
	5	5			0											placeholder
	6	6			0											placeholder
	7	7			0											placeholder
	8	8			0											placeholder
	9	9			0											placeholder
	10	10			0											placeholder
	11	11			0											placeholder
	12	12			0											placeholder
	99999	99999			0											99999

The example shows 12 tools. Add more as necessary.

Click *SaveFile* then *ReLoadTable* to confirm. Then click *Quit*.

In LinuxCNC select *Menu->File->ReloadToolTable*.

Appendix: LinuxCNC Shortcut Keys

It is faster and less error-prone to use keyboard shortcuts, rather than the mouse, to drive LinuxCNC. The following are useful to learn:

O	Open a G-code program.
V	Toggle through the various viewing angles.
R	Run the currently-open program.
<ESC>	Stop a running program. Warning: raise the cutter out of contact immediately.
P	Pause a running program. Warning: don't pause while the cutter is in contact.
S	Resume a paused program. Tip: a *stopped* program cannot be resumed.
F2	Turn off (or on) machine power. Warning: machine will lose all reference positions.
F1	Engage (or release) emergency stop. Warning: machine will lose reference positions.
F3	Switch into manual mode
F5	Switch into MDI mode. Tip: for entering G-code commands by hand.
X	Select X axis for the next operation(s)
Y	Select Y axis for the next operation(s)
Z	Select Z axis for the next operation(s)
<HOME>	Home the selected axis.
<END>	Touch-off the selected axis.

Any of the following can be combined with <SHIFT> for high-speed movement:

<PageUp>	Raise the Z-axis towards its home position.
<PageDown>	Lower the Z-axis.
Left Arrow	Move the X-axis towards its home position.
Right Arrow	Move the X-axis away from its home position.
Down Arrow	Move the Y-axis towards its home position.
Up Arrow	Move the Y-axis away from its home position.

Note that MDI mode disables most of the shortcut keys, with the notable exceptions of ESC, F1, F2, and F3. If keys are not working, try pressing F3 to set LinuxCNC into manual mode.

Take care not to accidentally hit F1 or F2 during a program or between any two programs which are sequentially operating on the same workpiece. If either key is hit then the machine will lose the touched-off position and it will become very difficult to resume work on the same workpiece at the correct offset. In most cases, when this occurs, the job must be scrapped and restarted.

Appendix: Copying G-Code to LinuxCNC

Most users will want to create their designs and g-code on their desktop PC indoors, then copy the g-code to their LinuxCNC machine ready for cutting. A reliable way to transfer files is with a USB stick, but this can get a bit tedious. An alternative is to network the LinuxCNC computer so that files can be read across the home network.

A quick overview of both methods is given here. There is plenty of help online, too.

Transferring G-Code by USB Stick

This is too easy to need describing, right? Wrong! For reasons unknown, the AXIS program is unable to open g-code files directly from a USB stick. A workaround for this is:

- Copy the g-code onto the USB stick from the desktop PC. Eject it.
- Plug the USB stick into the LinuxCNC controller.
- Use Thunar (the LinuxCNC file manager - middle icon on the mini-taskbar at bottom of screen) to copy the file(s) from the USB stick into a folder on the desktop or to some other convenient location.
- Run AXIS and open the files from the copied-to location.

Tip: If the USB stick is removed from the CNC controller (without correctly ejecting it) and is later re-inserted in the CNC controller, it is then advisable to close all instances of Thunar and then reopen them. Otherwise Thunar is likely to incorrectly report a fault with the USB stick.

Transferring G-Code Over the Network

We assume that a network is available which both the desktop PC and the LinuxCNC PC can access. This can be WiFi or wired Ethernet.

Networking LinuxCNC

Setting up and troubleshooting a network is far outside the scope of this document. Help can be found online. LinuxCNC uses the xfce window manager so we suggest including 'xfce' in search terms to obtain the most relevant help. However...

...setting up LinuxCNC for wired Ethernet is generally as simple as plugging a network cable into the Ethernet port and observing the 'connected' icon appear a few seconds later.

... but setting up LinuxCNC for WiFi is likely to be more complex, especially if using an internal PCI wifi adapter. The use of a USB WiFi dongle is likely to simplify matters. The Edimax N150 has been a reasonably reliable performer for us but we offer no guarantees. It costs about £5 from eBuyer and elsewhere. (Beware counterfeit copies.)

To test that networking is working - assuming that your home network has web access - try opening the web browser IceWeasel (which is merely a slightly-modified copy of Firefox) and navigate to a reliable page such as www.bbc.co.uk/news .

Setting Up File Sharing

For LinuxCNC to read shared files across the network requires installation - on the LinuxCNC machine - of cifs / samba. It also requires setting up a share on the source machine and accessing that share on the LinuxCNC machine.

If you're new to networking and/or to Linux, then chances are that gaining access to a network share will involve a good deal of googling (and grumbling) before you get it working.

Here's a starter guide. Networking is a black art, and home networks vary hugely in the way they are set up. So if this guide fails we're not really in a position to help you further, sadly. If you get stuck, we can only suggest that you try google. Or find a local nerd/geek to set up your networking.

To share the folder which contains your g-code:

- On the (Windows) computer which you want to share files from, set up file sharing for the relevant folder. Generally at first it is easiest to share a folder read-only and with guests allowed. It is possible to use password-controlled access, but that's outside the scope of this quick guide.
- Make a note of the share name of the folder, and the network name (and IP address) of the computer.

To set up LinuxCNC so that it can see shared folders:

- Log on to the LinuxCNC machine as normal.
- Start a terminal (2nd icon from the left, on the mini taskbar at bottom of screen).
- Install cifs / samba by typing:
    - sudo apt-get install samba cifs-utils libsmbclient
- This may take some time to run and will probably ask for your agreement before proceeding. We recommend rebooting the LinuxCNC machine after the installation has finished.

LinuxCNC doesn't have a built-in method to access network shares (i.e. there is no “Network” tab in the file manager.) So to make the shared folder visible to applications on the LinuxCNC machine requires mounting it:

- Log on to the LinuxCNC machine as normal, and start a terminal.
- Make a mount point by typing:
    - sudo mkdir /media/myshare
    - sudo chmod 777 /media/myshare
- Make a safe copy of your file system table by typing:
    - cp /etc/fstab ~/fstab.SAFE
- Edit the file system table (beware that a mistake here can seriously disable your LinuxCNC machine):
    - sudo nano /etc/fstab
- At the end of the file, append the following line:
    - <PC>/<share> /media/myshare cifs guest,ro,forcedirectio,uid=1000,iocharset=utf8 0 0
      Where <PC> is replaced by your Windows computer network name and <share> is replaced by the share name on that computer.

- If using the PC's network name doesn't work in the next step, then try modifying the line to:

- //<IP>/<share> /media/myshare cifs guest,ro,forcedirectio,uid=1000,iocharset=utf8 0 0
  Where <IP> is replaced by your Windows computer IPv4 address and <share> is replaced by the share name on that computer.

  - Save and close the file.
  - Mount the shared folder by typing:
    - sudo mount -a
  - Check the folder is available by any or all of the following methods:
    - In the terminal see a list of shared folders by typing: mount
    - In the terminal see the folders in the share by typing: ls /media/myshare
    - Navigate into /media/myshare in Thunar and examine the contents
  - When the share is correctly mounted try using AXIS to open a g-code file that is stored in the shared folder. The shared folder will be found at /media/myshare .

Tip: Don't disconnect the shared folder from the network while LinuxCNC is running a g-code file that is stored there. A common gotcha is allowing the PC on which the shared folder is stored to automatically sleep after a period of inactivity. If there is any risk of LinuxCNC not being able to reliably access the shared file, then *copy* the shared file onto the LinuxCNC machine and run the copy, not the shared file.

Tip: If using the IP address (rather than the Windows computer name) to define the share, it is essential that the Windows machine has a fixed IP address. Most home PCs do *not* have a fixed IP address and for this reason it is preferable to use the machine name, if possible. However, to reliably use the machine name may involve modifying your LinuxCNC 'hosts' file, which - again - is far beyond the scope of this quick guide. Much depends on how your home network is set up.

Appendix: Program Checklist

Prior to beginning any work, the machine should be checked as noted in the Build Manual.

In addition, the following checklist should be run-through before starting each new program on SheetCNC. We recommend mounting a laminated copy beside the machine controller:

Correct Program Loaded ?
Correct Cutter for this Program ?
Cutter Touched-Off in Z ?
Table Clear of Obstruction ?
Sufficient PPE ?
VFD Switched On ?
Coolant Flowing ?
<R> to run program... *Wait for spindle to reach speed...* *<S> to start cutting*