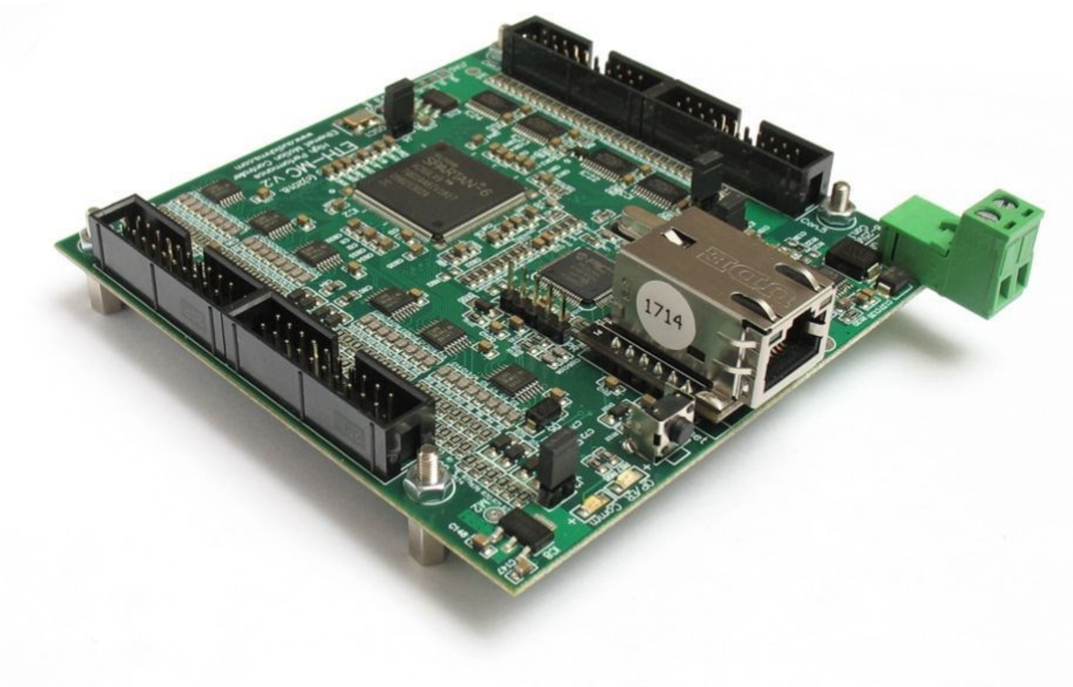
ETH-MC & ETH-BOX

High performance CNC motion controllers based on Ethernet connection



User's manual

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TABLE OF CONTENTS

SAFETY WARNINGS........ 3

1 ETH-MC Motion controller based on Ethernet connection........ 5

1.1 Description........ 5
1.2 Main features of ETH-MC motion controller........ 6
1.3 Technical specifications........ 7
1.4 Installation........ 7
1.4.1 Plugin installation........ 7
1.4.2 Setting up network connection and connection to the computer........ 8
1.5 Software for configuring network parameters of ETH-MC motion controller........ 10
1.5.1 Possible connection problems........ 11
1.6 Automatic firmware update........ 11
1.7 Mach3 software configuration........ 12
1.7.1 Adjusting ports and pins via Ports & pins window........ 12
1.8 ETH-MC configuration dialog........ 13
1.8.1 General setup tab........ 13
1.8.2 Pulse Engine tab........ 16
1.8.3 Input Filter tab........ 17
1.8.4 Special functions tab........ 18
1.8.5 THC options tab........ 20
1.8.6 Synced modes tab........ 20
1.9 Status window........ 21
1.10 ETH-MC controller wiring and input/output connectors pinout........ 22
1.11 ETH-MC motion controller dimensions........ 24

2 ETH-BOX motion controller based on Ethernet connection........ 25

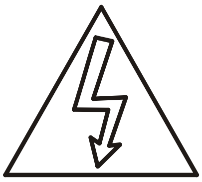
2.1 ETH-BOX motion controller dimensions........ 26
2.2 Connectors arrangement and recommended wiring schemes........ 26
2.3 General purpose digital outputs........ 27
2.4 Opto-isolated inputs........ 29
2.4.1 Non-isolated mode of wiring limit switches to the opto-isolated inputs........ 29
2.4.2 Isolated mode of wiring limit switches to the opto-isolated inputs........ 30
2.5 Differential digital inputs........ 32
2.6 General purpose digital inputs........ 33
2.7 Analog inputs........ 33
2.8 Isolated analog outputs........ 34
2.9 Opto-isolated digital outputs........ 36
2.10 Relay outputs........ 36

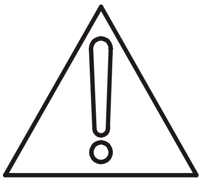
3 Setting up advanced options........ 37

3.1 MPG (manual pulse generator) pendant operation........ 37
3.2 Joystick jog control........ 40
3.3 Plasma system torch height control – THC regulation........ 41
3.3.1 Mach3 THC controls on the main screen........ 42
3.3.2 Configuration for operation with external THC regulator........ 44

3.3.3 Configuring the internal THC regulator ... 48
3.3.4 Input calibration ... 52
3.3.5 Internal THC regulator options ... 53
3.3.6 Custom plasma screen set ... 56
3.3.7 Practical considerations and examples of THC cutting ... 56
3.3.8 THC control – frequently asked questions ... 58
3.4 Rigid Tapping ... 59
3.5 Lathe threading operation – Mach3Turn ... 61
3.5.1 Threading sequence ... 62
3.5.2 ETH-MC(-BOX) motion controller threading options ... 62

SAFETY WARNINGS





When working with ETH-MC & ETH-BOX motion controller there are dangers and risks that can lead to equipment damage and also injuries of people nearby.

For the installation procedure of ETH-MC & ETH-BOX motion controller it is needed to have a high level of knowledge from the fields of electronics, computers and mechanics. It is also necessary to obey safety measures for work with high voltages and mechanical dangers caused by working with heavy, powerful machines.

Voltages above 50VDC can be lethal. If surrounding electronics works with voltages greater than 50VDC, apply prescribed measures for safe operation.

ETH-MC & ETH-BOX motion controller should not be used in places where its failure could impose danger to people safety, great financial loss or any other loss.

When working with ETH-MC & ETH-BOX motion controller it is required to use all necessary precaution measures.

It is recommended to achieve galvanic isolation of the work system from the computer (using opto-isolators or similar). All our drives for step and DC servo motors has opto-isolators on STEP and DIR inputs so for that lines additional isolation is not needed. For other inputs and outputs, depending on equipment used, usage of additional opto-isolators can be necessary.

For usage of ETH-MC & ETH-BOX motion controller it is required to have understanding of the whole system operation and as well to be aware of possible risks when working with tools and machines.

It is recommended to place ETH-MC & ETH-BOX motion controller in a metal enclosure so that it is protected from external influences in case of strong electromagnetic radiation, too high temperature, humidity and similar.

It is necessary to obey safety standards like for example installation of EStop button, limit switches and similar.

It is not excluded possibility that this document contains errors. Thereby the manufacturer does not take responsibility for any damage caused by using ETH-MC & ETH-BOX motion controllers and that is caused as a consequence of obeying or not obeying this user manual.

1 ETH-MC Motion controller based on Ethernet connection

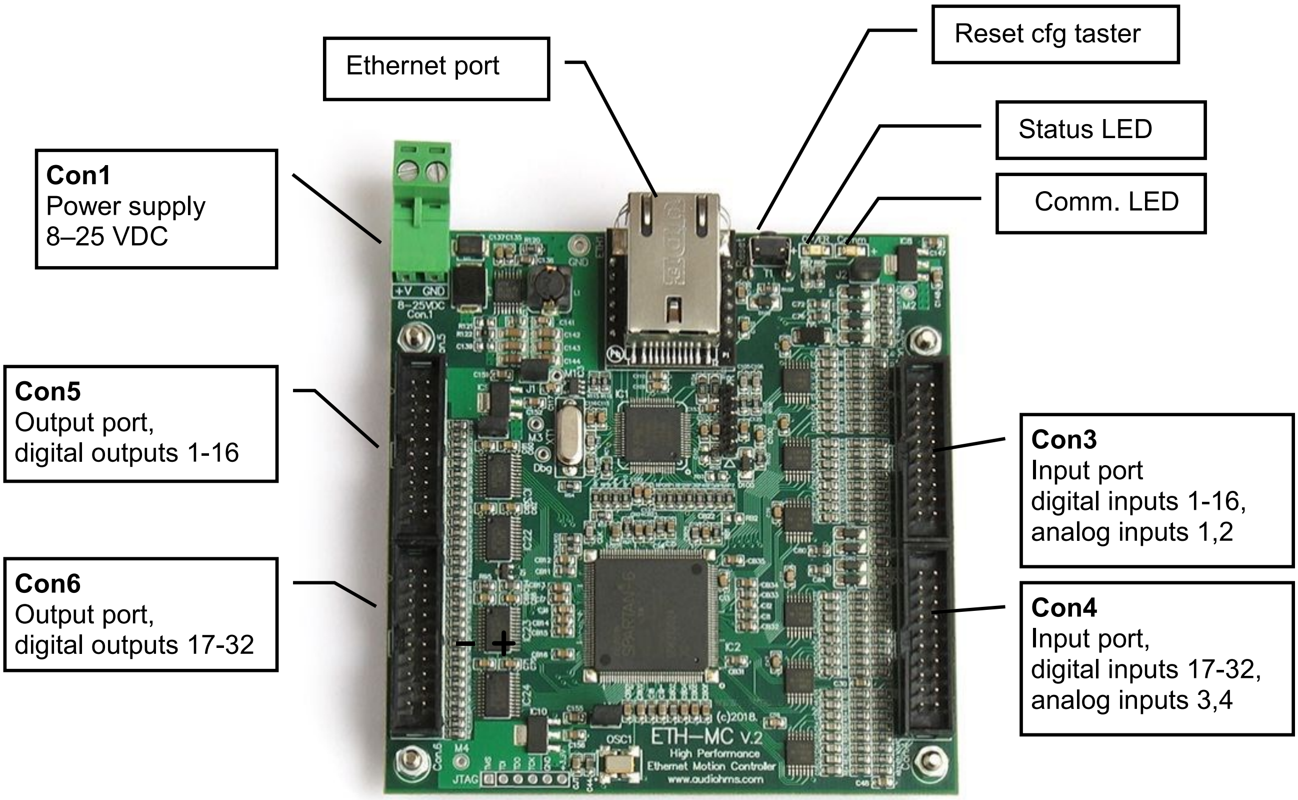


Figure 1.1 ETH-MC motion controller

1.1 Description

ETH-MC (Figure 1.1) is a high performance motion controller for CNC machines designed for use with popular Mach3 CNC control software in Windows XP, Vista, 7, 8, 8.1 and 10 operating systems with 32-bit (x86) and 64-bit (x64) architectures. As an external controller, it brings various improvements in comparison to using Mach3 software with parallel port. ETH-MC motion controller does not require installation of Mach3 LPT driver.

Motion controller ETH-MC with its integrated 32-bit microcontroller and the powerful FPGA chip, takes over all real-time tasks that require precision timing. Therefore, computer CPU is less loaded, so that Mach3 now can work on less powerful desktop, laptop, and even tablet computers.

At the same time, much higher output frequency for the step signal (up to 5 MHz) is achieved and much better quality of the output signal than it is possible with parallel port regardless of performances of used computer.
A large number of functions have been added and many existing have been improved.

The Ethernet connection with a computer is considered to be one of the most robust connection types, so it is suitable for application in difficult industrial conditions. It should be noted that wired Ethernet connection also features galvanic isolation between ETH-MC motion controller and a PC computer.

Mach3 plugin contains integrated latest compatible firmware version, so in case that firmware has to be updated, this process is automatic and easy for the user.

1.2 Main features of ETH-MC motion controller

- Four layer circuit board, FPGA + 32-bit microcontroller
- Ethernet 10/100 Mbit connection
- Advanced smooth trajectory interpolation
- 6 axes + spindle axis, 5 MHz max. step signal frequency, adjustable pulse width
- Available axis output modes: step/dir, cw/ccw, quadrature
- 32 digital inputs, 5 V Schmitt triggers
- 32 digital outputs, 5 V TTL
- 4 analog inputs, 0-5 V
- 7 quadrature encoders reading at 12,5 MHz max, resolution multiplied by 4 in hardware
- All digital inputs and outputs freely remapable
- For all digital inputs and outputs adjustable active state (low/high)
- Hardware feedhold (instantaneous activation, no delay)
- Hardware MPG mode (real-time control, no latency) + all Mach3 MPG modes
- Synchronized motion generation using encoder as feedback (electronic gearing)
- Threading with lathe, encoder based (G32, G76) using Mach3turn;
  advanced, autonomous synchronized motion generation,
  no pullout delay at the end of a cut pass, successive G32 moves can be seamlessly joined in tapered threads...
- Rigid tapping using Spindle encoder as feedback, axis selection, forward/reverse speed adjustment etc.
- THC integrated controller with advanced precision PID regulator (closed loop 1 kHz) and classic Up/Down regulator (for usage with THC voltage sensor connected to one of the analog inputs)
- THC support for external Up/Down controller
- THC acceleration ramped moves, voltage sampling, anti-plunge support, arc detection...
- THC advanced option: Low pass filter, Kerf detect, THC lock from G-code, consumable status...
- Laser PWM output, fast M10/M11, eNp0/eNp1 port commands, PWM gate by M10/M11
- Laser power compensation, adjustable arbitrary curve relation to speed of motion
- Laser 8-bit gray level engraving
- Detailed setup for debouncing for all digital inputs and adjustable digital filters for encoder inputs
- SoftLimits
- Probing function (G31)
- Backlash compensation
- One standard PWM output (for spindle / laser) + two additional PWM outputs (10Hz – 200KHz)
- Shuttle mode, control using MPG or using potentiometer via analog input
- Slave axes
- Spindle index input, adjustable divider
- Charge pump output signals, adjustable frequency (12,5 kHz and 5 kHz)
- Offline mode
- Limits override, auto/manual/external
- Configurable special functions for control via analog inputs or encoders (FRO, SRO, Set User Variable, Set User DRO...)
- Analog Joystick Jog control

1.3 Technical specifications

Function	Description
Connection with PC	Ethernet 10/100 MBit, TCP/IP - data buffer size of about 1 s for stable communication, Auto crossover detection
Number of axes	6 + spindle axis
Number of digital outputs	32
Number of digital inputs	32
Maximum STEP signal frequency	5 MHz (adjustable from plugin for every axis)
STEP pulse width	50 % (or fixed, adjustable from plugin for every axis)
STEP signal output modes	Step&Dir / CW&CCW / Quadrature
PWM outputs	10 Hz – 200 kHz
PWM duty cycle resolution	16 bit
Frequency of signal on Index input	≤ 50 MHz
Pulse width on Index input	≥ 10 ns
MPG/encoders input (x4) frequency	≤ 12.5 M steps/sec
Digital inputs type	Schmitt trigger, 5 V, Pull-up resistors 4.7 kΩ
Digital outputs type	TTL, 5 V
Maximum current on digital outputs	32 mA
Number of analog inputs	4
Analog input range	0–5 V, 10 bits
Charge pump outputs	2
Charge pump frequency	12,5 kHz or 5 kHz
Power supply	8–25 VDC / 0.25 A – 1 A (current draw depends on connected peripherals)

NOTE: Shown specifications are subject to change without prior notice

1.4 Installation

Below is a detailed description of the ETH-MC motion controller installation.

NOTE: ETH-MC motion controller does not require Mach3 LPT driver to be installed nor is uses this driver.

1.4.1 Plugin installation

To install ETH-MC Mach3 plugin, copy supplied file **ethmc_drv.dll** to Mach3 plugins folder (usually "**c:\mach3\plugins**"). Then, start Mach3 and new plugin should be detected (Figure 1.2). Now choose **ETH-MC-plugin** from displayed list of options. Also, optionally turn on option **Don't ask me this again** so that this choice is remembered and not displayed again on next Mach3 startup.

In case that this dialog for plugin selection is not shown, it is possible to initiate it using menu option **Function Cfg's\Reset Device Sel…**

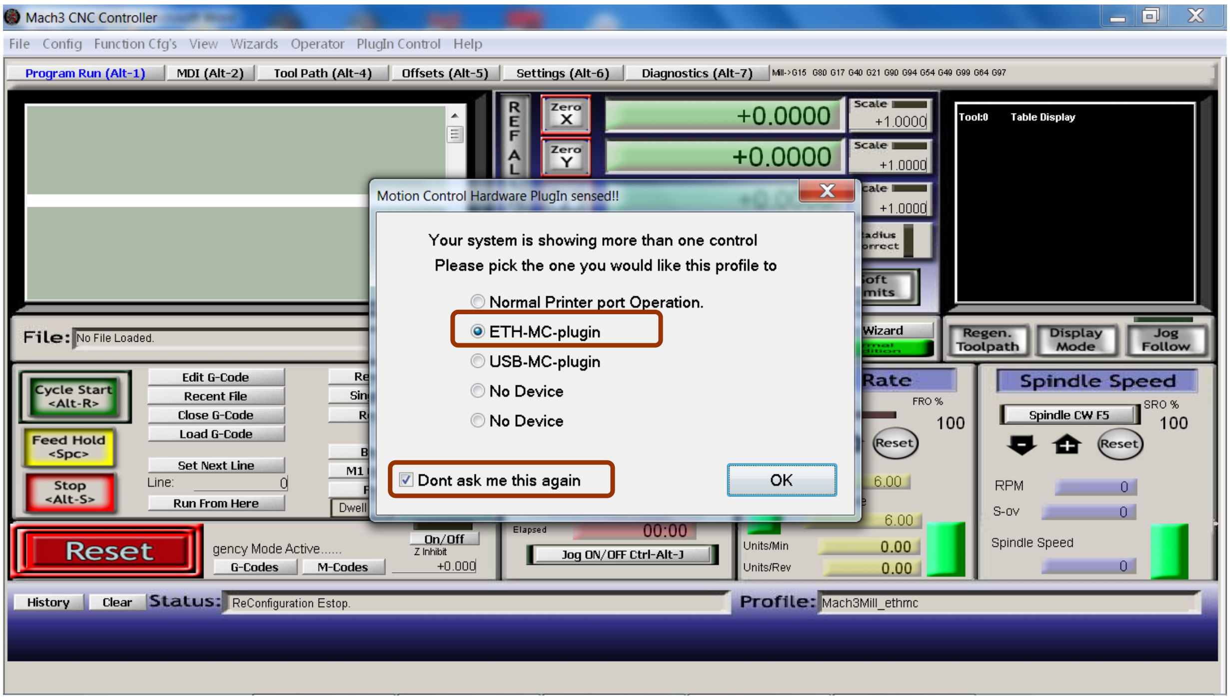


Figure 1.2 Plugin selection

Now it is required to setup network address for the controller that we are connecting with and that is done using configuration dialog Menu/PluginControl/ETH-MC network setup (Figure 1.3). IP address of the ETH-MC motion controller is stored in the EEPROM that is integrated on the controller and this address can be changed if needed by using special application (factory set IP address is 192.168.1.222).

Using dialog box it is possible to enter known fixed IP address of the controller (option By IP address) or controller can be accessed via alias name in form ETH-MC-xxxxxx, where xxxxxx are six hexadecimal digits that represent unique identification number of the controller (option By alias name).

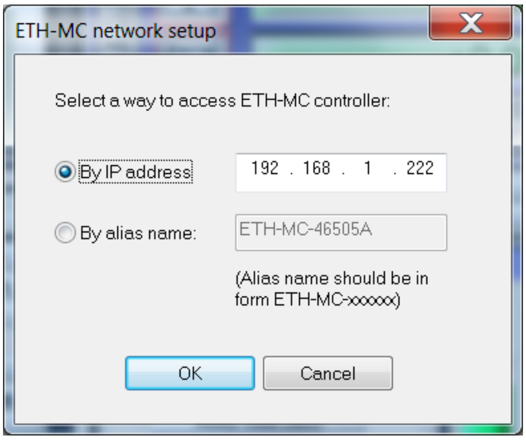


Figure 1.3 Setting up network communication in Mach3

1.4.2 Setting up network connection and connection to the computer

There are two possible options for connecting controller with PC computer:

a) Direct connection of the controller with PC computer using network (UTP) cable and
b) PC computer and controller are connected to the existing network via router.

a) Direct connection of the controller with PC computer using network cable

In this case network consists of only these two devices: PC computer and ETH-MC motion controller. **Described connection method is recommended for most secure operation and best communication performance.**

Ethernet (network) cable that is used for connection of the network adapter on the PC computer and ETH-MC motion controller does not need to be with crossed lines (crossover cable) because ETH-MC motion controller has implemented automatic detection of the Ethernet port and needed mode of operation.

IMPORTANT NOTE: Ethernet module integrated on ETH-MC(-BOX) motion controller provides galvanic isolation between computer and motion controller. Usage of shielded network cable (STP cable) is NOT recommended (Figure 1.4) because in that case galvanic isolation is lost, which in some cases can lead to damage of ETH-MC(-BOX) motion controller and/or computer.

a) b)

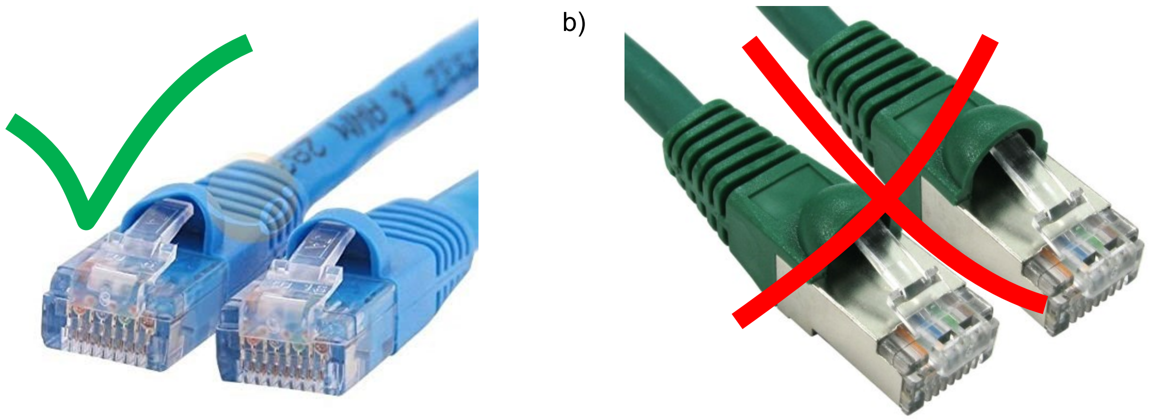


Figure 1.4 Network cable types, a) UTP cable (unshielded) and b) STP cable (shielded)

It is needed to manually specify fixed IP address of the computer and the other network parameters in windows system and that can be done in the following way.

1. Open **ControlPanel/Network and Sharing Center,** then choose **Change Adapter Settings**. In the shown list of network adapters, locate "**LocalAreaConnection**", right click on it, then choose "**Properties...**".

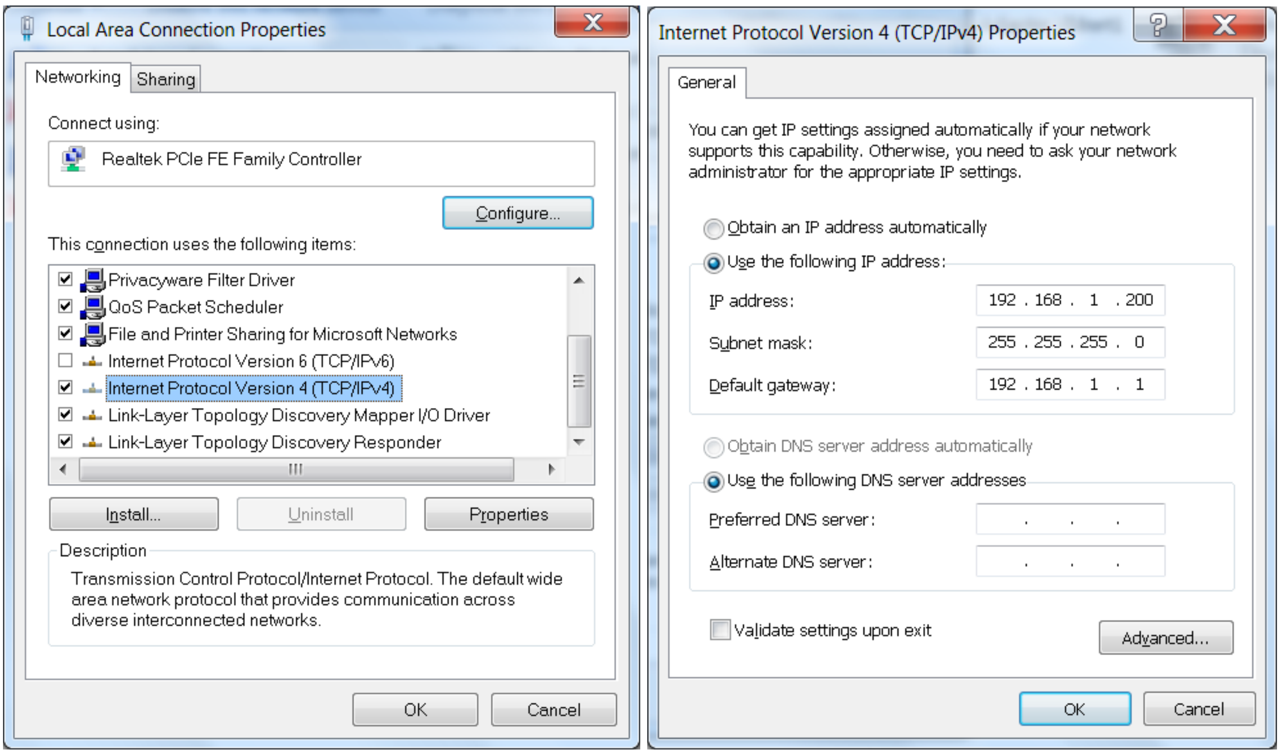


Figure 1.5 Setting up PC computer network parameters

2. In the list of available protocols (Figure 1.5 left) locate "**Internet Protocol Version 4 (TCP/IPv4)".** Select it and then click **Properties.**

3. In dialog box (Figure 1.5 right) specify:

- IP address: for example 192.168.1.200 (it is important that only last digit is **NOT** the same as the last digit of the IP address of the ETH-MC motion controller)
- Subnet mask: 255.255.255.0
- Default gateway: not relevant
- DNS servers are also not relevant.

4. Close all dialog boxes with OK

Presented settings correspond to default settings of ETH-MC motion controller because its factory set IP address is 192.168.1.222 so it is located on the same subdomain (192.168.1.*).

b) If the controller is connected to an existing network

This connection method is used when we want to keep existing network infrastructure that PC computer is connected to. IP address of the PC computer is then already defined (or is obtained from the router like other network parameters, wired or via WiFi) so we use existing settings and these parameters for the computer are not manually specified like mentioned above.

ETH-MC motion controller is connected to an available router port using UTP cable and thus connected to the network in that way.

In this connection method we must adjust network parameters of ETH-MC controller so that they correspond to the existing system. It is needed to use configuration software for ETH-MC controller (see below) and adjust controller IP address to the address on the same subdomain as computer IP address (usually 192.18.1.x or 192.168.0.x, also possible to be 10.0.0.x). Subnet mask: 255.255.255.0.

Also, instead of manually setting parameters, it is possible to turn on the option to obtain IP address and other network settings automatically from the router by using DHCP protocol (Figure 1.6).

For manual setup of parameters it is needed to know network subdomain of the computer. This we can find via IP address or/and subnet mask. What is current IP address of the computer in the local network and the other network parameters can be obtained in the following way:

- In Windows click **Start** button and in the field that appears enter **cmd** and then press enter. This will open command interpreter,
- Then in the command line, enter: **ipconfig/all,** press enter and all present network adapters in the system and their settings will be listed.

NOTE: For the best performance and secure connection, wired network connection of the computer is recommended. Wi-Fi connection along the convenience unfortunately also brings possible problems with speed and latency variations. Because in the field of machine control, continuous fast and timely communication between computer and controller is required, some more severe cases of communication delay can be recognized as break of connection, which will lead to detain in work of machine that is being controlled.

1.5 Software for configuring network parameters of ETH-MC motion controller

ETH-MC motion controller keeps network parameters in its EEPROM. Figure 1.6 presents factory set values of these parameters and if needed these parameters can be changed and stored to EEPROM of ETH-MC motion controller.

To begin work, ETH-MC motion controller must be powered and it is needed that ETH-MC controller and PC computer are both connected to the same network in any way.

Search network button is used to initiate search for all ETH-MC controllers on the network. More precisely, PC computer broadcasts requests to all present network connections (UDP multicast protocol) and all ETH-MC motion controllers that reply to identification request will be listed in the large field on the left side of dialog box. On the right side are shown current parameters for the selected device.

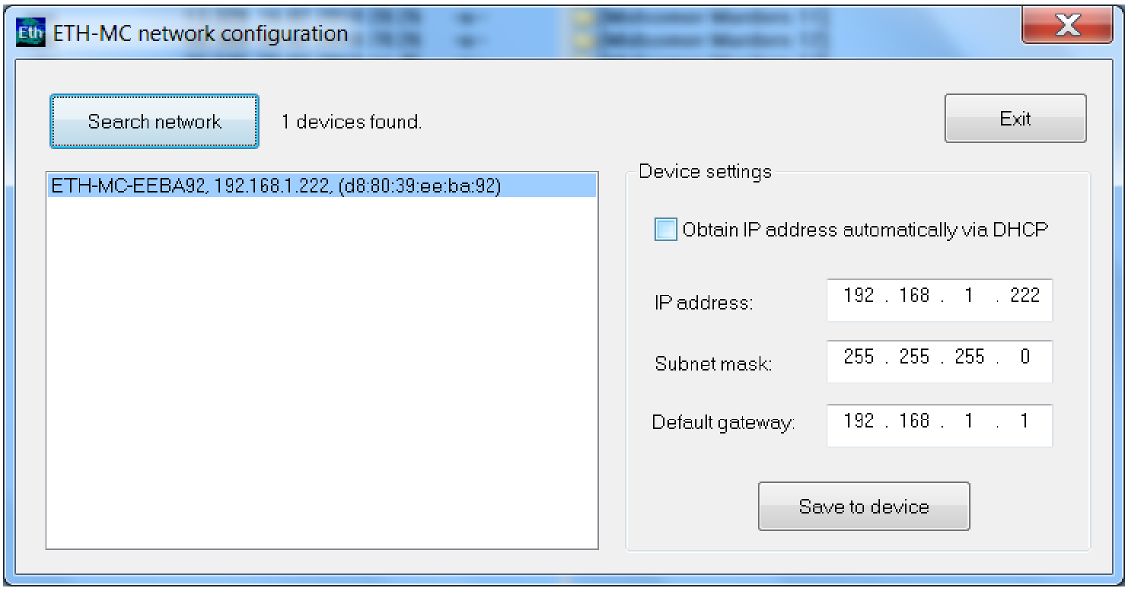


Figure 1.6 Software for configuring network parameters of the ETH-MC motion controller

WARNING: Software should always be able to find all devices connected to the network no matter what network parameters have been set up, i.e. whether set network parameters are correct or not. Nevertheless, in some cases depending on existing network infrastructure, after adjusting controller parameters it can happen that device detection is not possible any more. In that case it is needed to reset controller network settings to factory set defaults. This can be performed using reset button on ETH-MC motion controller.

Reset procedure for ETH-MC motion controller: Press and hold Reset button until green LED indicator lights up (few seconds). Release Reset button, then power off and power controller back on.

1.5.1 Possible connection problems

In case that occasional break of connection occurs, especially in periods of non-activity, it is possible that Power saving for network card is turned on. Also, it may help fixing connection speed to 10/100 Mb instead of using Auto speed option in network settings.

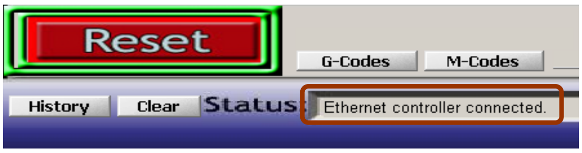


Figure 1.7

On power up, controller is in so called safe mode, i.e. all outputs are in high impedance state (disconnected). Red LED indicator on the controller blinks slowly.

After clicking **RESET** button, connection with controller is established and status **Ethernet controller connected** is displayed (Figure 1.7). Then the controller enters normal work mode and red LED indicator on the controller stops blinking and lights continuously.

If network connection is lost for any reason, controller instantly goes to safe mode. Then it is needed to investigate and eliminate cause of the error and then click **RESET** button to establish communication again. Also, controller enters safe mode on all configuration changes and also on exiting Mach3 application.

1.6 Automatic firmware update

ETH-MC plugin also contains needed firmware for the controller, thus upon establishing connection, if it is determined that firmware update is required, message like on Figure 1.8 will be shown. It is needed to click button **Yes** and wait for this process to be completed (Figure 1.9). Finally, result like on Figure 1.10 should be presented when firmware update procedure is finished successfully.

Current versions of the plugin and the firmware can be found on **About** window of the ETH-MC configuration dialog.

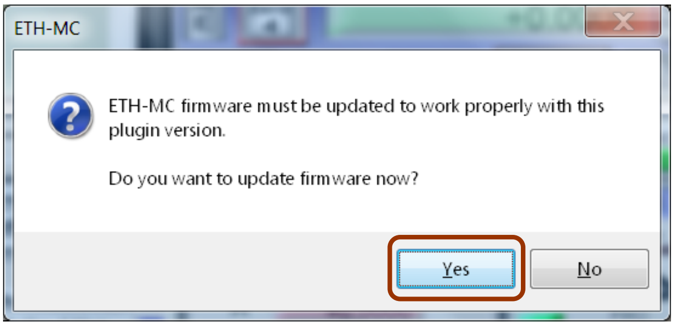


Figure 1.8

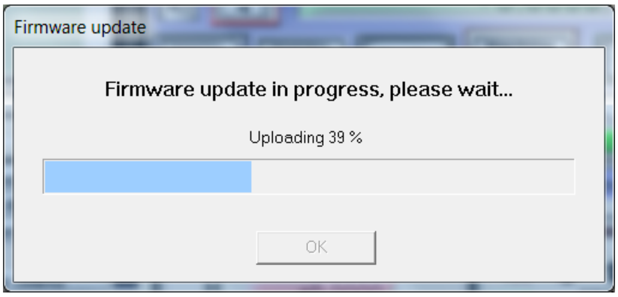


Figure 1.9

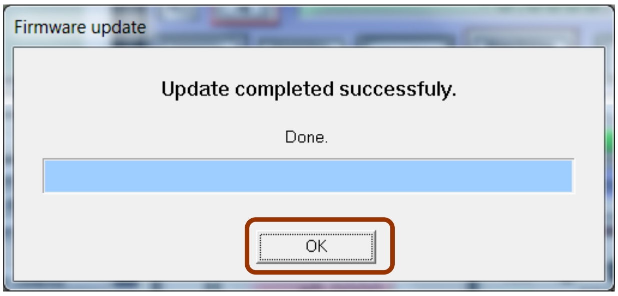


Figure 1.10

1.7 Mach3 software configuration

Most of configuration is done using existing dialogs for adjustments in Mach3 application, like **Ports and pins**, **General config** etc. just like when LPT driver is used. Some additional options, which are offered by ETH-MC controller, can be adjusted via dialog box that is opened using the menu option **Plugin Control/ETH-MC Config…**. Also, novelty is the status window that can be opened via **Plugin Control/ETH-MC Status…**

1.7.1 Adjusting ports and pins via Ports & pins window

ETH-MC motion controller provides one digital input port with 32 pins and one digital output port with 32 pins. These pins can be remapped as desired, that is, can be assigned different functions that are needed for the specific application.

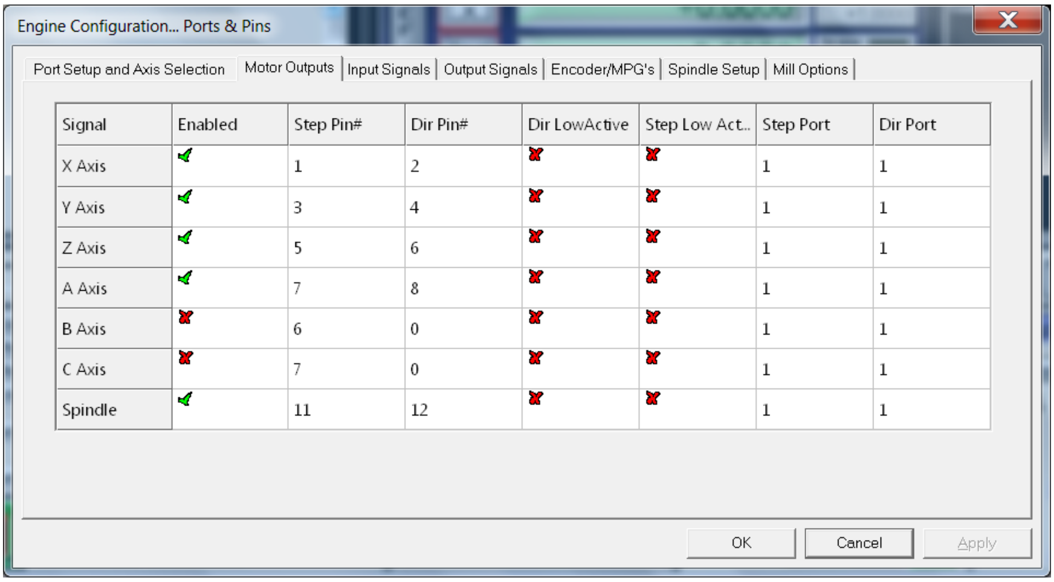


Figure 1.11 Ports and pins configuration

When using configuration dialogs like **Motor Outputs**, **Input Signals**, **Output Signals** (Figure 1.11) etc. number 1 is always used for port number. Available pins on the input port are numerated from 1 to 32. Similarly, output port pins are also numerated from 1 to 32. ETH-MC controller will ignore any port number different from 1 and any pin number that is out of available range.

When a breakout board (input/output card) is used, it is needed to refer to the card specifications for correct mapping of input and output pins.

1.8 ETH-MC configuration dialog

This dialog can be opened using the menu option **Plugin Control/ETH-MC Config…**

1.8.1 General setup tab

On the Figure 1.12 General setup tab is shown.

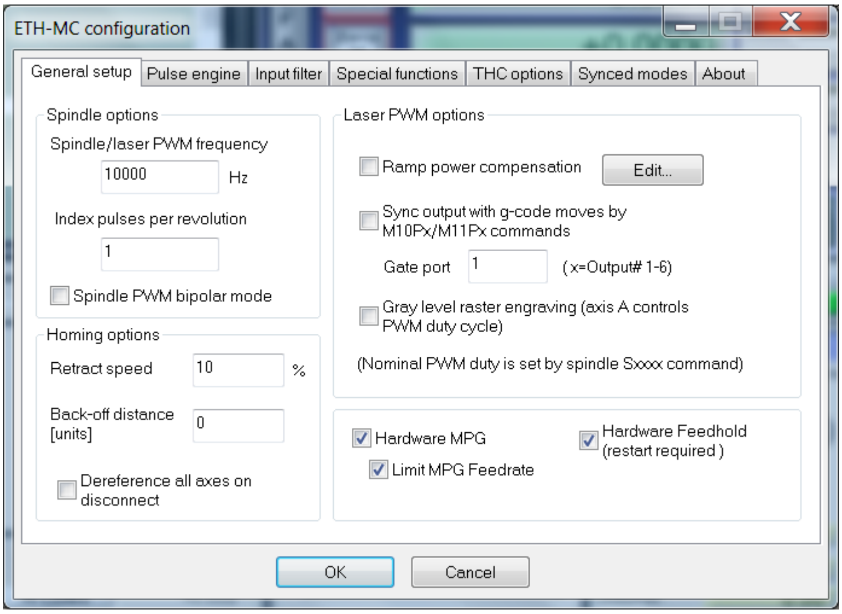


Figure 1.12 General setup tab

Spindle options

Spindle/laser PWM frequency

The frequency of PWM output signal that is used for spindle rpm control or for laser power control, can be adjusted in range of 10-200000 Hz. Output pin for this purpose is selected via axis line in Motor Outputs window (Figure 1.11). Only adjustments for **Step** signal are used (**pin/low act/port**), and **Dir** field is not used for PWM output.

Also, in **Ports&pins/Spindle setup** window, in **Motor control** group, options **Use spindle motor** and **PWM control** should be turned on**. PWMBase Freq** in the same group, is not used.

Index pulses per revolution

Index input is used for detection of spindle rotational speed. It is common to use one pulse per revolution, but more than one can also be used.

Spindle PWM bipolar mode

This options enables to control not only the rotation speed but also direction of the rotation. It is used when required by the controlled hardware. Namely, when this option is turned on, rotation speed of 0 RPM corresponds to 50% PWM duty cycle. Maximum rotation speed contra-clockwise is obtained by 0%, and clockwise by 100% PWM duty cycle. Rotation direction is controlled normally using M3 and M4 commands, and rotation speed via Sxxxx command from G-code.

Homing options

Home retract speed

This is speed of retraction from a home switch given as a percentage of homing speed. In first phase of homing (referencing) operation for an axis, movement toward home switch is performed until the switch is activated. Then, movement is performed in the opposite direction (retracting) until the switch deactivates and that position is used as a reference. Home retract speed should be low enough so that good referencing precision is achieved.

Back-off distance [units]

After an axis referencing is finished it is possible to back off from the home switch for the given distance.

Dereference all axes on disconnect

This option should be turned on when it is desired to dereference all axes in case of error or loss of communication with the controller.

Other options

Hardware MPG

If this option is **turned on** ETH-MC motion controller will use hardware MPG mode, that is, reading MPG inputs and generation of STEP/DIR output signals is done completely in hardware without need for communication with PC. This enables very fast response (low latency) and at the same time precise motor control. Configured motor parameters (maximum velocity, acceleration) are obeyed.

If this option is **turned off**, standard Mach3 modes are used for MPG operation. These options can be shown by pressing TAB key in Mach3. In this case ETH-MC motion controller reads MPG input, sends current position to Mach3, and Mach3 then, according to selected MPG mode (Velocity only, Multi-Step...), and generates appropriate commands for movements. These commands are then sent to ETH-MC controller and executed.

In hardware mode just like in standard modes, **CycleJogStep** is used for setting movement step, and also most of all settings (MPG axis, detent...) are common.

Limit MPG feedrate

If this option is turned on, speed limit given with parameter **MPG Feedrate** is obeyed in hardware MPG mode. This parameter is located on MPG/Jog window (Figure 1.17).

Hardware Feedhold

This option enables to choose whether the feedhold function should be performed by Mach3 or by the ETH-MC motion controller completely autonomously.

If Mach3 internal function is chosen (turned off option Hardware feedhold), then when Feedhold button is pressed during the work, Mach3 plans stopping and starts sending appropriate movement commands to the controller. Stopping is controlled but there is a delay of about 1s from the moment when Feedhold button is pressed to the actual execution of the function after all previously planned motion is consumed from the motion buffer.

Hardware feedhold enables instant, controlled (with slowdown) stopping. It works by gradually slowing down the whole feed (all axes) to a complete stop. To continue working it is needed to press Cycle start button and then feed is accelerated up to the normal speed. Nevertheless, during the pause it is not possible to perform other functions like Jog axis unless first the STOP button is pressed. **However, pressing the STOP button during the pause will lead to loss of all movement data currently present in the movement buffer.**

Nevertheless, work can be resumed from approximately the same position. Namely, ETH-MC motion controller will after the STOP button is pressed, present the line that was executing when break occurred as a current line of execution and set this line as next (SetNextLine). This means that when Cycle start button is pressed afterwards, execution of the G-code will resume from this program line and starting from the current axes positions.

Changing this options requires restarting Mach3 application so that new setting comes to be in effect.

Laser PWM options

Ramp power compensation

Laser power compensation is used to overcome typical problem during laser engraving, and that is that depth/intensity of engraving depends on movement speed of the laser head. This is particularly visible on start and at the end of one engraving segment, where laser head slows down and stops, so unwanted black dots appear. To eliminate this phenomenon, laser power can be controlled using PWM so that PWM duty cycle is directly dependent on velocity of laser head. Thus, for example, if velocity is zero, PWM duty cycle will also be zero. As velocity increases, also is increased duty cycle that controls laser power. It is possible to configure an arbitrary relation curve.

Sync output with g-code moves, M10px, M11px

This option enables that fast commands M10px and M11px, in addition to their primary function of setting state on output x (Output#1-6), at the same time can turn on/off PWM output. **Gate port** determines which output x controls PWM output in this way. So, for example, if command M11p3 is given and **gate port**=3, PWM output will be turned on.

Laser engraving requires much faster turn on/off of laser then it is possible to achieve using spindle commands (M3, M4, M5). By using M10/M11 commands, laser turn on/off is also ideally synchronized with g-code execution. This is done in following way: when, for example, command M11p1 (turn on output 1) is executed in g-code program, initially nothing happens, but this "turn on output x" command is remembered as armed for execution. When next command for positioning (like G01 probably at the very next program line) is executed, then at the same moment when commanded movement begins, also given output is activated. The same logic applies for M11px (turn of output) command.

Gray level raster engraving

This option is used for raster pictures engraving and 8-bit grayscale palette is supported, i.e. 256 shades of gray (from complete black to complete white). When this option is turned on, axis A is used to control laser power, namely commanded "movement" of A axis controls PWM output duty cycle.

G-code needs to be generated from the bitmap picture by using one of the software made for that purpose. More closely about this option and required Mach3 settings for laser raster picture engraving can be found in separate document (Laser raster engraving).

1.8.2 Pulse Engine tab

This dialog box (Figure 1.13) enables setting for every individual axis: output mode, maximum step signal frequency, and impulse width.

Axis output mode

It is possible to select one of the following modes of control pulses generation:

- **Step/Dir**, pulse on the first digital output (Step) executes one step and state on the second output (Dir) defines the direction of movement,
- **CW/CCW**, pulse on the first digital output (CW) causes movement in the clockwise direction, and pulse on the other output (CCW) causes movement in the opposite direction,
- **Quadrature**, encoder type output, A and B outputs feature phase shift of 90° like with incremental encoders.

Max step frequency [kHz]

Enables setting of the maximum frequency of the generated step output signals. This frequency should be set to the maximum value that is allowed by the controlled hardware (motor drivers etc.). It is possible to select the following maximum step signal values: 100 kHz, 200 kHz, 500 kHz, 1000 kHz, 2500 kHz and 5000 kHz.

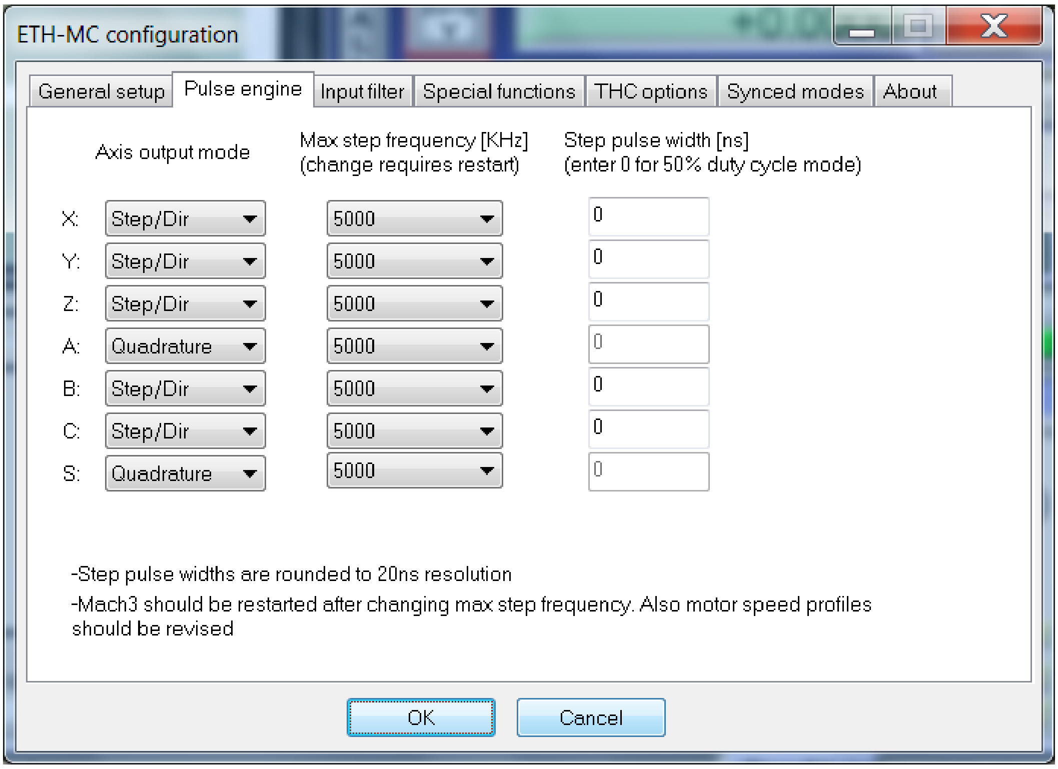


Figure 1.13 Pulse Engine tab

After changing this parameter it is required to restart Mach3 so that new settings comes into effect. Also it is needed after restart to check in MotorTuning if velocity for any axis is set to a higher value than that is possible by the new maximum frequency and correct the settings if needed.

Step pulse width [ns]

Enables adjusting pulse width for the output step signals. It is possible to enter:

- value in nanoseconds [ns] or
- value 0 which activates 50% duty cycle mode.

Pulse width adjustment is used for Step/Dir and CW/CCW output modes.

1.8.3 Input Filter tab

Digital filtering (debouncing) is possible for all inputs. **Input filter** window enables detailed setup of the filtering. Debounce time is given in microseconds (µs). For example, if value 3000 is specified, that means that 3ms of stable signal state is needed on input for signal state to be changed from active to inactive or vice versa. If time 0 is entered for an input, filtering is turned off for that input. This is recommended when maximum reading speed is desired and it is certain that signal is clean, free of noise (e.g. optical encoder).

Debounce time can be specified (Figure 1.14) for:

- the group of pins by function or
- for every pin individually.

Dialog box content can be scrolled by using the slider on the right side or by using mouse wheel.

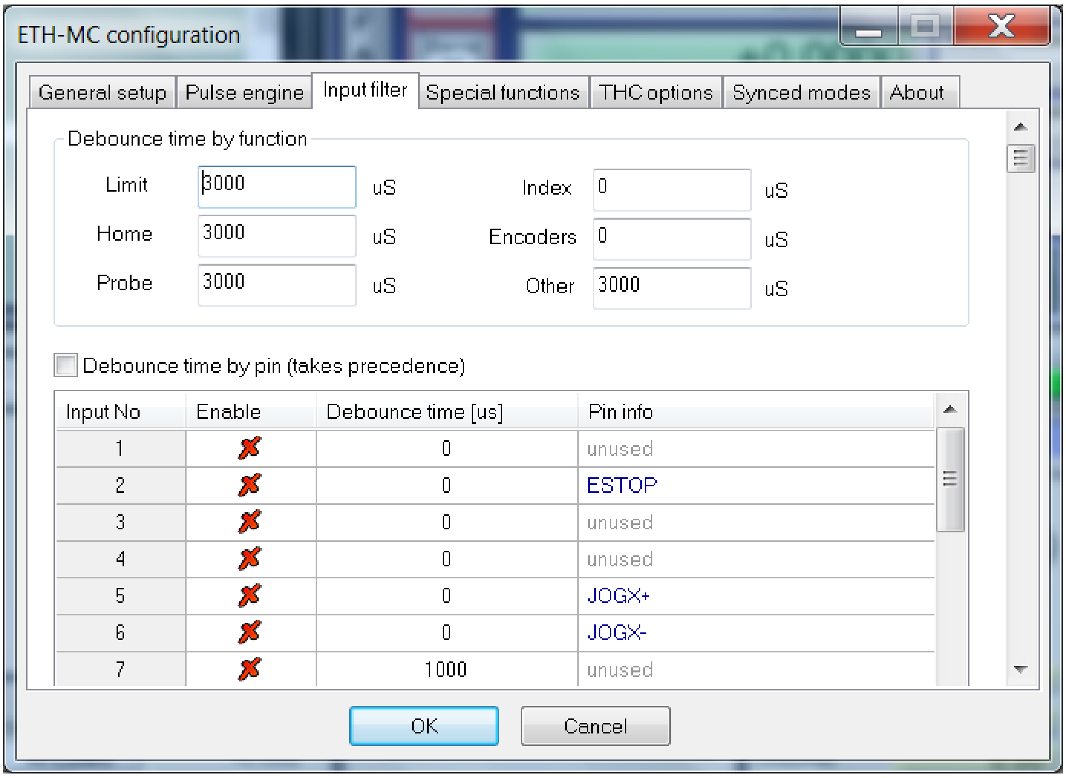


Figure 1.14 Input filter

In the bottom of the dialog box (Figure 1.15) is located group of fields for adjusting encoder digital filters. Filters can be adjusted to values in range from 1.04 to 6.25 MHz. If digital filter for encoder is turned on, debouncing for appropriate digital inputs that belong to that encoder will be disabled. In other words, encoder filter has priority over debouncing filters.

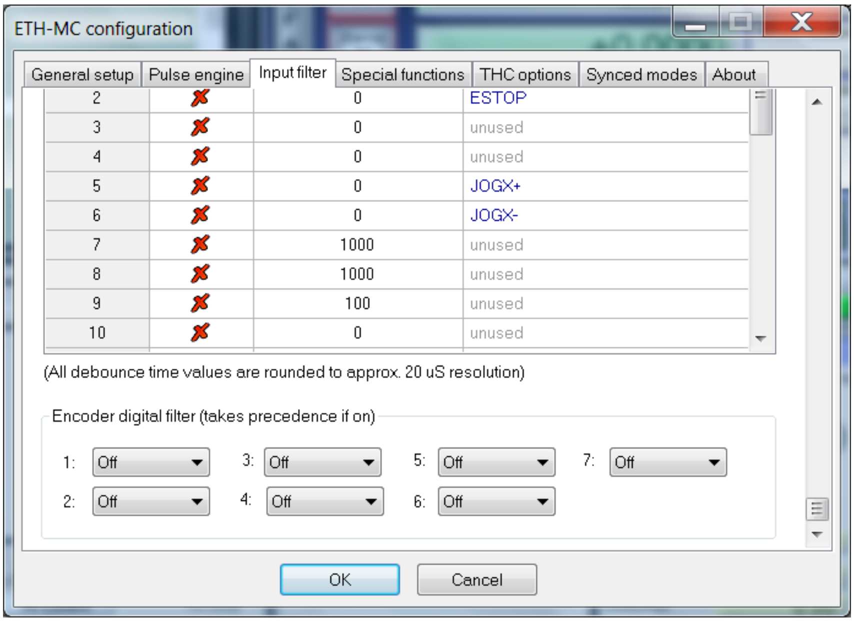


Figure 1.15 Encoder digital filters

1.8.4 Special functions tab

ETH-MC motion controller offers four analog inputs and also enables simultaneous reading of seven incremental encoders. Variety of functions can be assigned to these inputs and that can be configured using this dialog box (Figure 1.16).

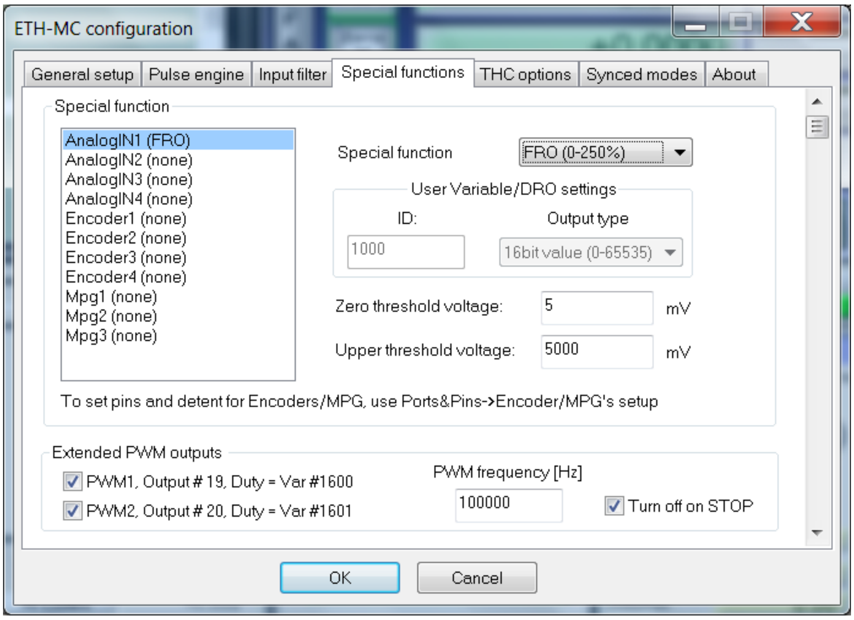


Figure 1.16 Analog input & encoders

Special function group

The area on the left side shows available signal sources and in parentheses assigned function (if there is any). For the selected input source, on the right sight are shown available parameters that can be set.

For **Special function**, available options are:

- **None** – signal is not used for special function.
- **FRO 0–250%** - feedrate override control.

- **SRO 0–250%** - spindle rate override control.
- **Set user variable** – read value is transferred to the specified inter Mach3 variable so that it can be used for example from a macro script or similar. **ID** represents identification (address) of the variable. It is possible to choose output type: 16-bit value (0-65535) or percentage (0-100%).
  Values of these variables can be monitored by using Mach3 function **Operator/GCode Var Monitor**.
- **Set user DRO** – similar to the previous option, but in this case **ID** represents identification of the DRO field.
- **Shuttle control** – control execution speed of G-code program.
- **THC Voltage (50-300V)** – control THC nominal voltage.
- **THC VOvr (80-120%)** – control THC voltage override.

This dialog box also enables adjusting the options for pendant operation and also for analog joystick control (more detail in section 3.2).

When encoder is used for a function, then the step for incrementing that function variable is adjusted by changing detent value for the encoder. Detent represents the number of pulses from encoder/MPG for one complete step.

Detent value can be set using Mach3 window **Config/Ports&Pins/Encoders/Mpg's** together with input pins and ports for encoders. Detent does not have to be a whole number and can also be negative if change of direction of rotation is desired. Usually MPG has detent value of 4 because for one step movement of the MPG, 4 pulses are generated.

Zero threshold voltage – Is used for adjusting voltage threshold in mV for analog inputs. Acquired value from the input that is equal or lower than threshold value is considered zero.

Upper threshold voltage – This field enables to specify the maximum voltage on analog input in mV (default value is 5000 mV). Acquired voltage value on the analog input higher or equal to this threshold corresponds to maximum value of the variable that is controlled.

Shuttle mode

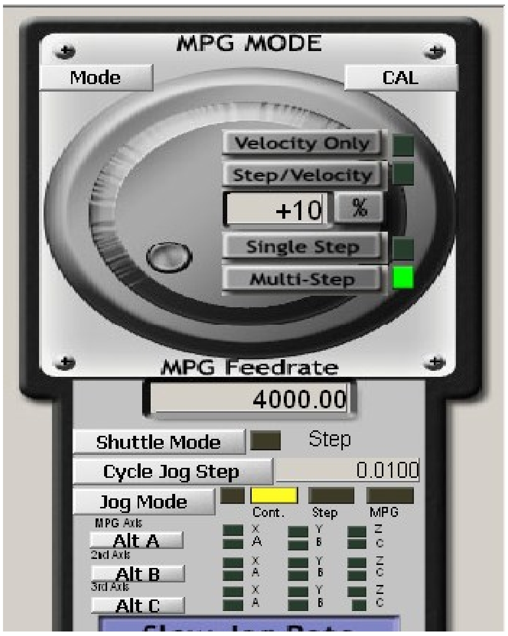


Figure 1.17

MPG or one of the analog inputs can be also used for Mach3 **shuttle mode**, (Figure 1.17) i.e. fine and real-time control of G-code program execution speed. This function is realized completely in hardware so that MPG rotation speed directly controls execution speed of the G-code program.

Shuttle mode button can also be used as fast FeedHold function even if there is no MPG in the system. In this case if Shuttle mode is activated during the execution of the g-code program, motion of all axes is gradually slowed down to complete stop.

When Shuttle mode is deactivated, motion of all axes is accelerated to resume to the original normal speed. This acceleration/deceleration can be adjusted by the field **Shuttle Accel.** which is located in the Mach3 **General Config** dialog.

Extended PWM outputs

Besides the standard PWM output that is used in Mach3 to control Spindle or laser, ETH-MC motion controller offers additional two PWM outputs that can be used for an arbitrary purpose.

PWM1 and PWM2 signals are generated on outputs Output#19 and Output#20 respectively. Port and pins for these pins should be set in **Config/Ports&pins/Output Signals** Mach3 window.

Pulse width for these PWM outputs can be set from G-code program by direct value assignment to the G-code variables #1600 and #1601. Value that is given in percent (0-100) does not have to be a whole number.

1.8.5 THC options tab

THC (torch height control) function is used for plasma cutting machines for continual regulation of the plasma torch height.

Beside the support for an external regulator, ETH-MC motion controller also has two integrated THC regulators (Figure 1.18) which can be utilized by connecting appropriate voltage sensor (THC Sensor) to one of the analog inputs of the ETH-MC controller (Figure 1.16).

ETH-MC motion controller supports the following regulation types:

- External THC regulator,
- Internal THC Up/Down regulator and
- Internal THC PID regulator.

ETH-MC motion controller offers a large number of options that enable a top quality control such as:

- servo regulation loop (PID regulator),
- voltage sampling for automatic voltage adjustment,
- kerf detect,
- anti-plunge options,
- THC lock from G-code etc.

In more detail about THC operation mode and Mach3 adjustments related to this mode can be found in section 3.3 (advanced controller options).

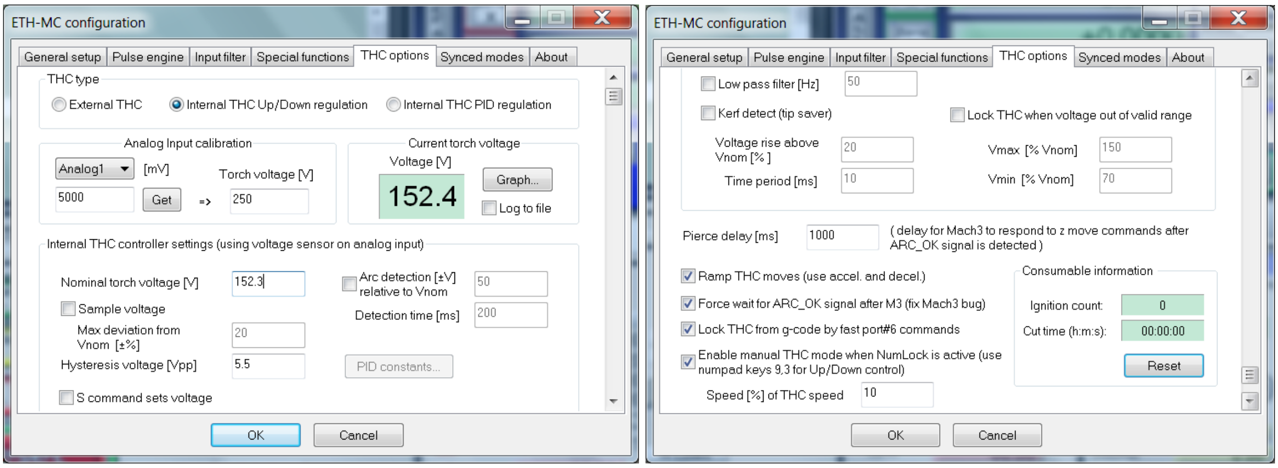


Figure 1.18 THC options

1.8.6 Synced modes tab

ETH-MC motion controller supports advanced real-time synchronized motion (Figure 1.19).

Namely, for some processing operation (such as threading on lathe or tapping into the holes) motion of some axes has to be precisely synchronized to a master axis, e.g. spindle axis that can freely rotate and during the work it can change rotation speed and even rotation direction. This master axis that is the reference for synchronization, must have installed incremental encoder that is used as a current position sensor.

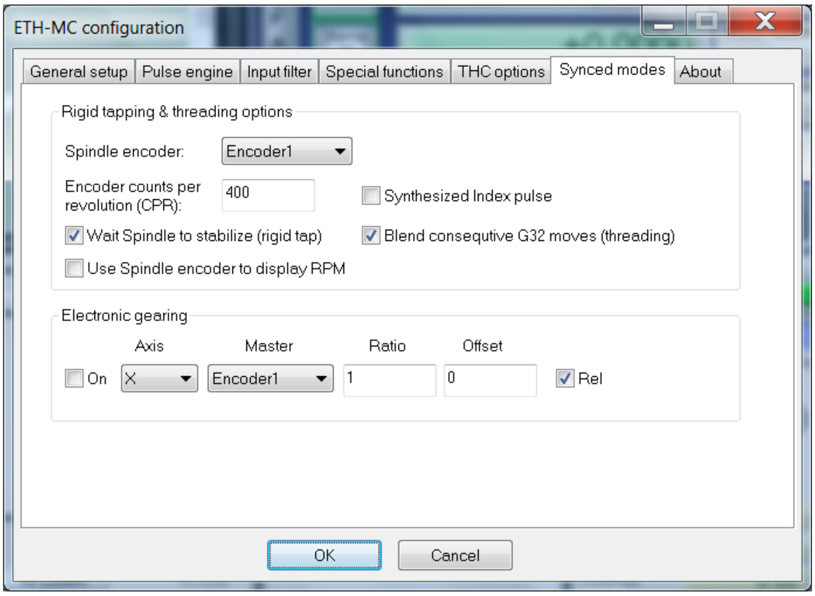


Figure 1.19

For **thread cutting** (functions G32, G76) ETH-MC motion controller has much improved algorithm in comparison to the standard Mach function. ETH-MC uses its own, autonomously generated linear motion that follows spindle rotation and as a feedback it uses an incremental encoder.

Rigid tapping is the function that Mach3 originally does not offer (does not support related G-code command). ETH-MC motion controller however enables also this advanced function and it is done by calling the appropriate macro.

Electronic gearing enables for one axis movement to be tied to another axis that has encoder as position feedback. Transfer ratio can be adjusted to an arbitrary number.

1.9 Status window

Status window (Figure 1.20) shows the current state of input and output pins of the ETH-MC motion controller. Also, on the left side position for all 6 axis is shown, in the middle area different controller statuses and on the right the current state of analog inputs and encoder positions are shown. Status window can "float" above other windows and does not prevent normal usage of Mach3 controls.

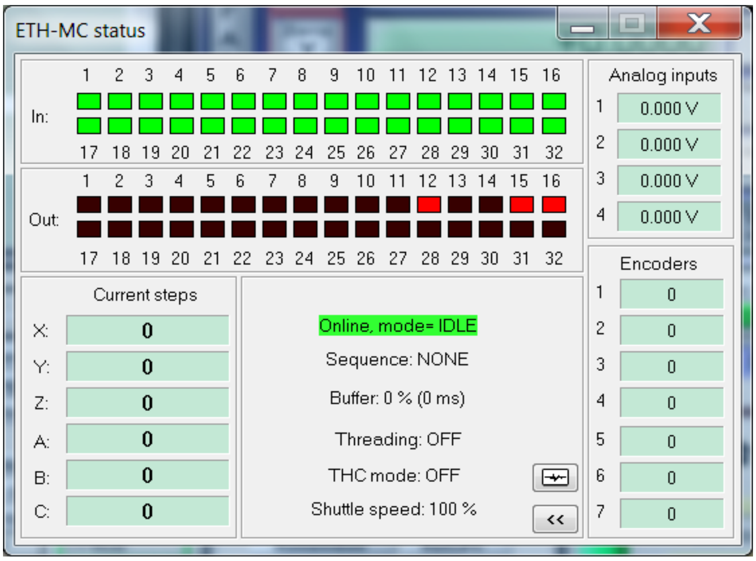


Figure 1.20 ETH-MC status window

1.10 ETH-MC controller wiring and input/output connectors pinout

For operation of ETH-MC motion controller it is needed to provide power supply with voltage in range from 8 to 25VDC (Figure 1.21). Current consumption of ETH-MC controller depends on supply voltage and also on the current draw of connected peripherals and can be up to 2A. Typically in most cases current draw will be less than 500mA.

For example, if power supply has voltage of 24 VDC, ETH-MC controller alone has current draw of about 100 mA.

Communication with PC computer is done via network (Ethernet) cable. More about the connection with computer can be found in section 1.4.2.

Peripherals can be connected to the ETH-MC controller using the connectors Con.3, Con.4, Con.5 and Con.6 (Figure 1.21).

Pinouts for connectors Con.3, Con.4, Con.5 and Con.6 (Figure 1.22) are given in tables 1.1, 1.2, 1.3 and 1.4.

General purpose digital inputs are marked with labels from IN1 to IN32 and are all of Schmitt trigger type, with voltage level of 5V. All inputs have 4k7 pull-up resistor.

General purpose digital outputs are marked with labels from O1 to O32. All digital outputs have TTL voltage levels.

Analog inputs are marked with labels from AN-IN1 to AN-IN4.

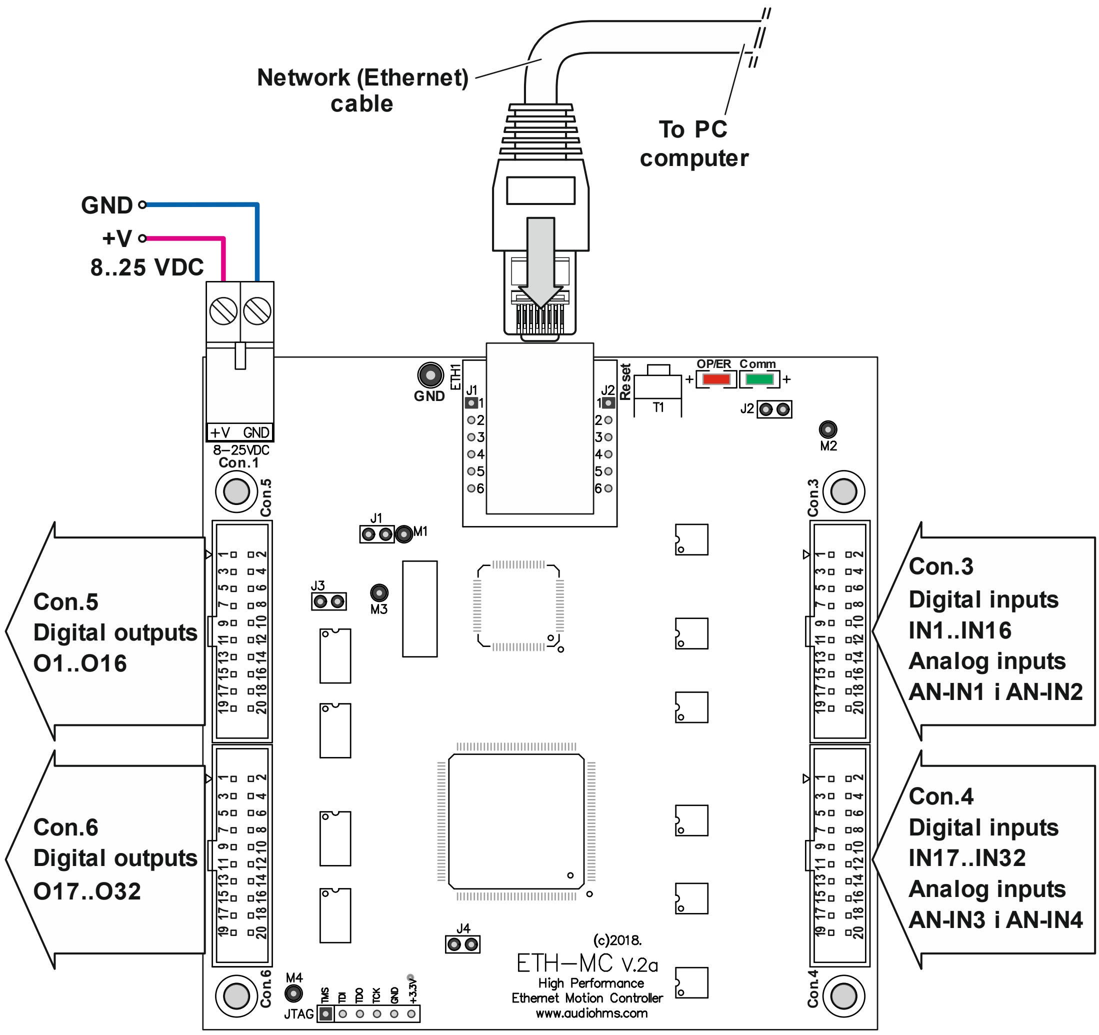
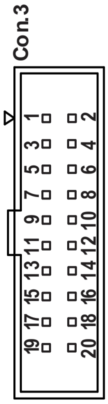


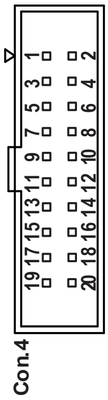
Figure 1.21 Connecting the ETH-MC motion controller

Table 1.1 Pinout of the connector Con.3



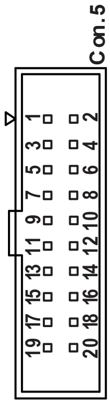
Pin	Name	Name	Pin
1	GND	+5 V	2
3	IN1	IN2	4
5	IN3	IN4	6
7	IN5	IN6	8
9	IN7	IN8	10
11	IN9	IN10	12
13	IN11	IN12	14
15	IN13	IN14	16
17	IN15	IN16	18
19	AN-IN1	AN-IN2	20

Table 1.2 Pinout of the connector Con.4



Pin	Name	Name	Pin
1	GND	+5 V	2
3	IN17	IN18	4
5	IN19	IN20	6
7	IN21	IN22	8
9	IN23	IN24	10
11	IN25	IN26	12
13	IN27	IN28	14
15	IN29	IN30	16
17	IN31	IN32	18
19	AN-IN3	AN-IN4	20

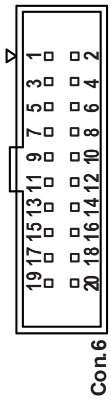
Table 1.3 Pinout of the connector Con.5



Pin	Name	Name	Pin
1	+V[1)]	+5 V	2
3	O1	O2	4
5	O3	O4	6
7	O5	O6	8
9	O7	O8	10
11	O9	O10	12
13	O11	O12	14
15	O13	O14	16
17	O15	O16	18
19	GND	+3,3 V	20

[1)] Supply voltage for ETH-MC motion controller

Table 1.4 Pinout of the connector Con.6



Pin	Name	Name	Pin
1	+V[1)]	+5 V	2
3	O17	O18	4
5	O19	O20	6
7	O21	O22	8
9	O23	O24	10
11	O25	O26	12
13	O27	O28	14
15	O29	O30	16
17	O31	O32	18
19	GND	+3,3 V	20

[1)] Supply voltage for ETH-MC motion controller

1.11 ETH-MC motion controller dimensions

Figure 1.22 shows outside dimensions and dimensions important for the installation of the ETH-MC motion controller.

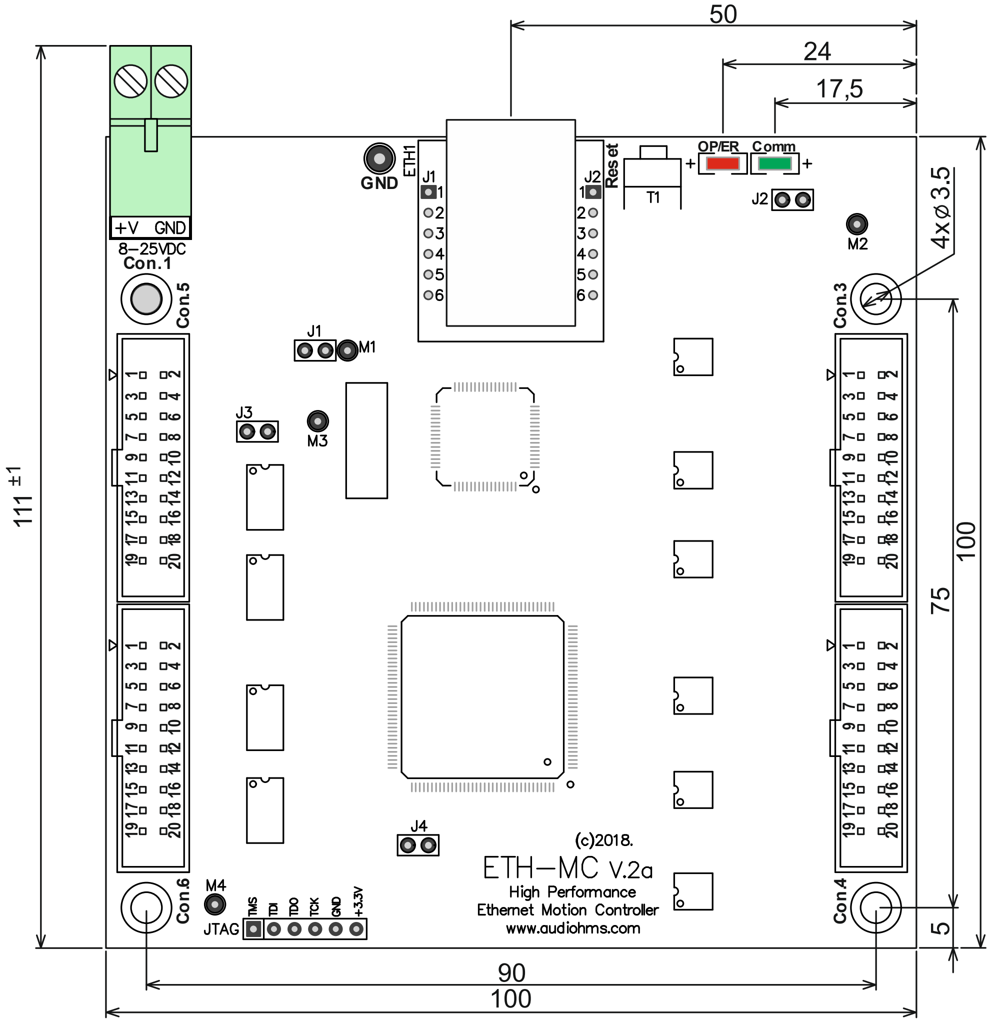


Figure 1.22 Outside dimensions of the ETH-MC motion controller

2 ETH-BOX motion controller based on Ethernet connection

ETH-BOX is designed with a goal of optimal utilization of ETH-MC motion controller features. ETH-BOX motion controller (Figure 2.1) is a complete solution that has a large number of detachable connectors for connecting different peripherals like servo and step motor drives, limit switches (inductive or electro mechanic), incremental encoders, potentiometers, THC sensor etc.

Figure 2.1 ETH-BOX version of ETH-MC motion controller

2.1 ETH-BOX motion controller dimensions

Figure 2.2 shows outside dimensions of the ETH-MC motion controller, and also dimensions important for installation, while Figure 2.3 shows the front view of the ETH-MC motion controller.

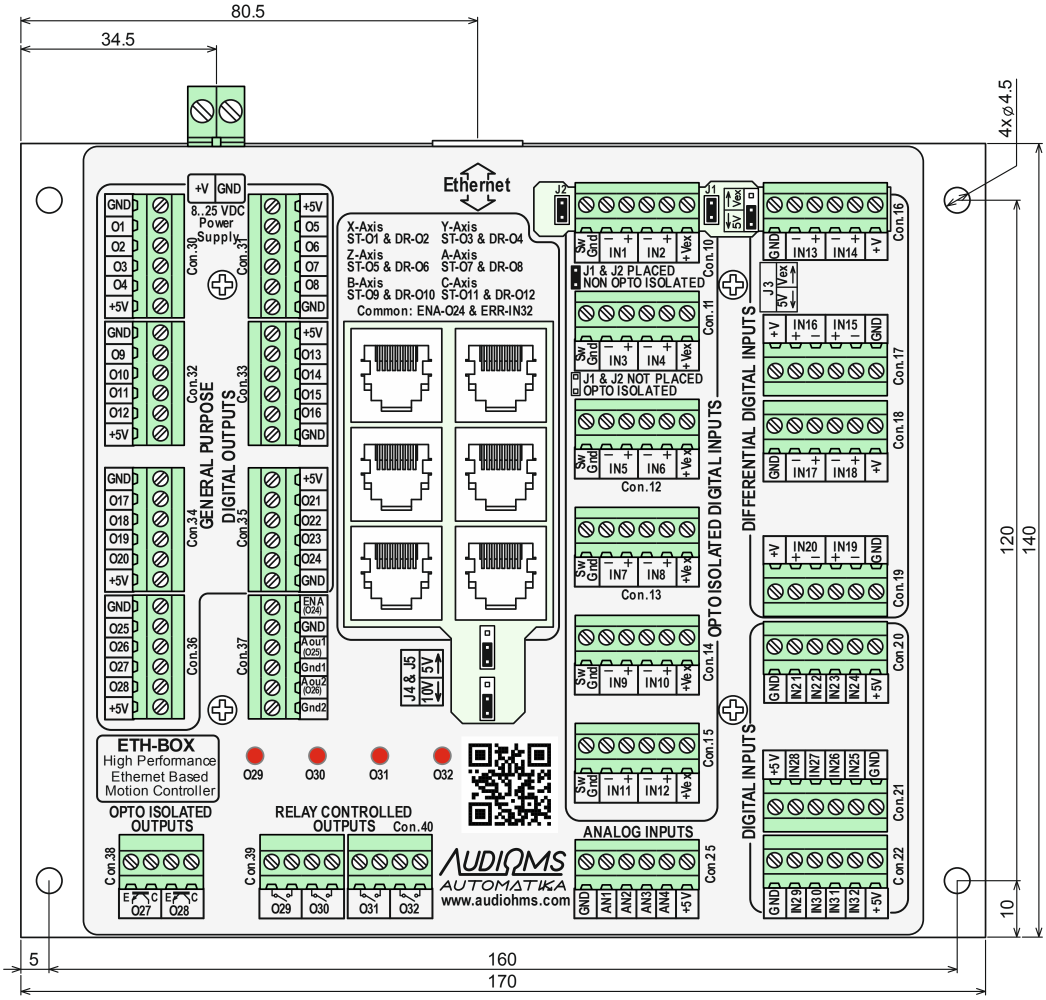


Figure 2.2 ETH-BOX motion controller dimensions

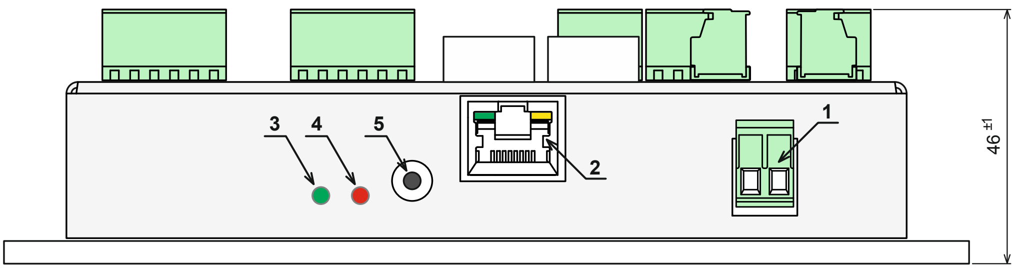


Figure 2.3 ETH-BOX motion controller (front view).
Marked positions: 1 – power supply connector, 2 – Ethernet connector, 3 – Comm indicator, 4 – ERR/OP indicator and 5 – RESET button

2.2 Connectors arrangement and recommended wiring schemes

On the top side of the ETH-BOX motion controller there is a large number of connectors that are divided into groups by intended usage purpose.

Bellow follows a detailed description of connector groups as well as recommended wiring schemes.

2.3 General purpose digital outputs

ETH-BOX motion controller has 24 general purpose digital outputs that are routed to the connectors Con.30 – Con.35 and marked with frames named "GENERAL PURPOSE DIGITAL OUTPUTS" (Figure 2.4).

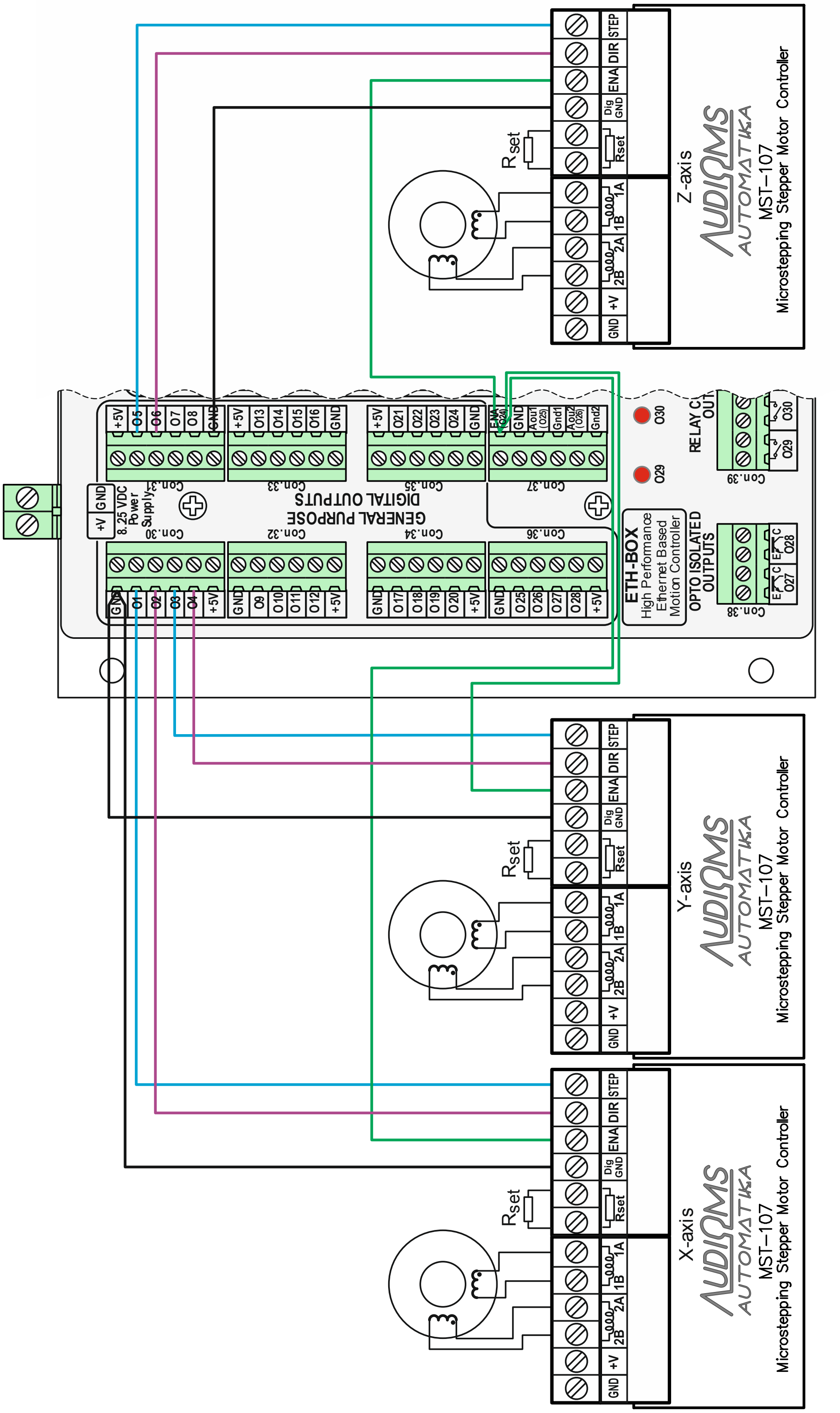


Figure 2.4 Connecting step motor drives MST-107 to the ETH-BOX motion controller

Common Enable output is located on the connector Con.37 and is labeled as ENA (O24). Enable output is realized using PNP transistor in open collector arrangement and is activated using digital output O24. Maximum current for Enable output is 150 mA.

Figure 2.4 shows recommended wiring scheme for four microstep drives MST-107 to the ETH-BOX motion controller. Optionally it is possible to connect up to 6 drives (independent axes).

ETH-BOX motion controlled can also accept connection of motor drives (step, DC or AC servo motors) of other manufacturers (Figure 2.5). Figure shows one way of wiring 4 drives from other manufacturers.

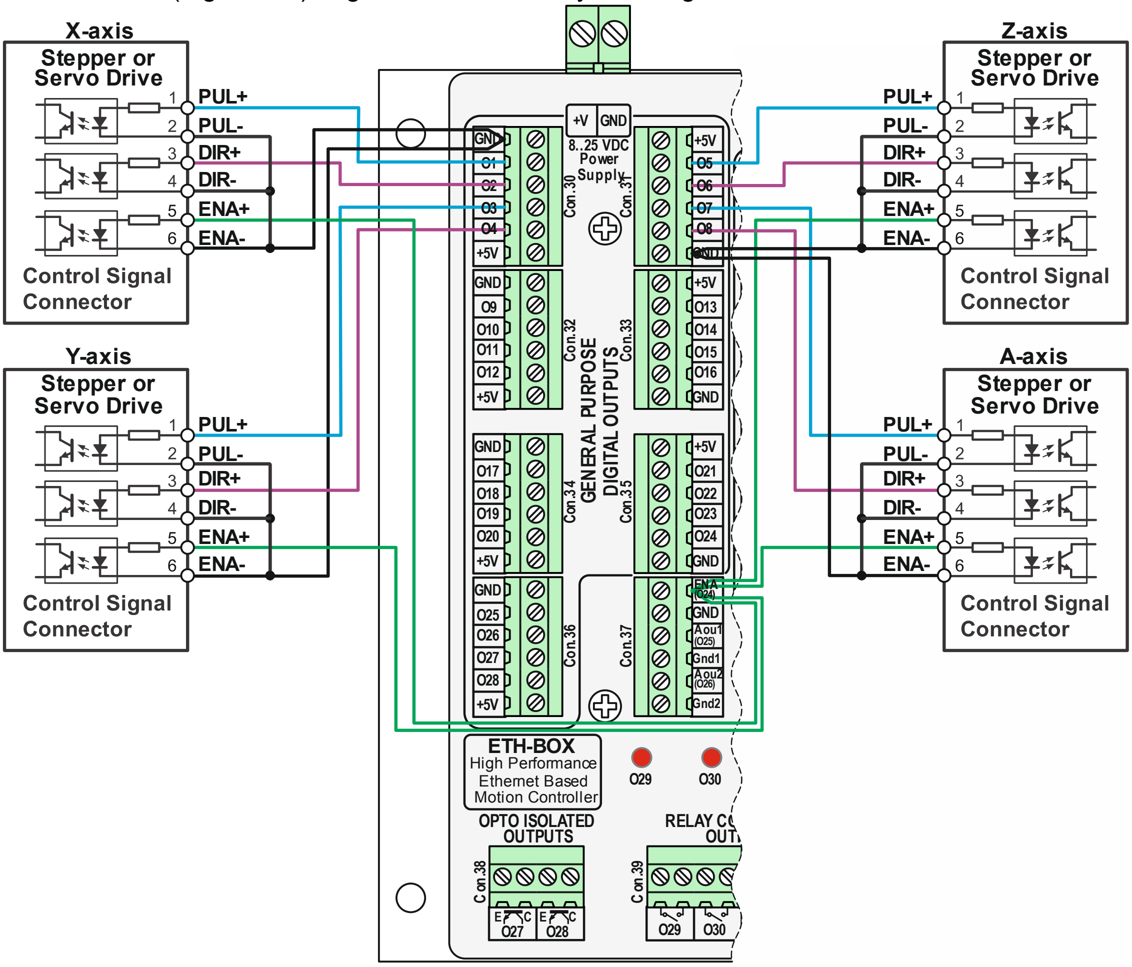


Figure 2.5 Connecting drives from other manufacturers to the ETH-BOX motion controller

On the top side of the ETH-BOX motion controller are located six 8-pin RJ-45 connectors that are used for controlling up to six DC servo drives DCS-3010(-HV) and/or DC servo drives with analog output DCS-100-A (Figure 2.6). For connection it is required to use a high quality network cables 1 on 1. Pins arrangement on RJ45 connectors on the ETH-BOX motion controller is pin-compatible with mentioned DC servo drives (control port for these drives). In this case it is not possible to change numeration of the pins for generation of control signals (Table 2.1).

Table 2.1 Reserved input/output lines when using control via RJ45 connectors

Axis	STEP (Out)	DIR (Out)	ENA (Out)	Error Offset (In)
X	O1	O2	O24	IN32
Y	O3	O4		
Z	O5	O6		
A	O7	O8		
B	O9	O10		
C	O11	O12		

More details about mentioned DC servo drives DCS-3010(-HV) and DCS-100-A can be found in their respective user manuals.

Figure 2.6 Connecting up to 6 DC servo drives DCS-3010(-HV) and/or DCS-100-A to the ETH-BOX motion controller

2.4 Opto-isolated inputs

ETH-BOX motion controller can accept connection of up to 12 digital inputs (IN1-IN12) of voltage level 24 VDC. These digital inputs are connected to connectors Con.10 – Con.15 (Figure 2.7). For level shifting the voltage levels from 24 VDC to 5 VDC optocouplers on-board are used. Figure 2.7 up-right shows the electric schematic of the input circuit for digital inputs IN1-IN12.

NOTE: For the activation of digital inputs, for safety reasons it is recommended to use NC type of switches (Normally Closed).

There are two modes for wiring limit switches:

- non-isolated mode and
- opto-isolated mode.

2.4.1 Non-isolated mode of wiring limit switches to the opto-isolated inputs

This mode implies usage of power supply for ETH-BOX motion controller for activation of digital inputs IN1-IN12. In that case it is necessary for supply voltage for ETH-BOX motion controller to be in range of 18-24VDC. Figure 2.8.a shows wiring of electro-mechanical switches, while Figure 2.8.b shows a possible connection of inductive switches to digital inputs IN1-IN12 in **non-isolated mode**.

IMPORTANT NOTE: When connecting limit switches in **non-isolated mode** (Figure 2.8.a and Figure 2.8.b) it is required to **set jumpers into positions J1 and J2**.

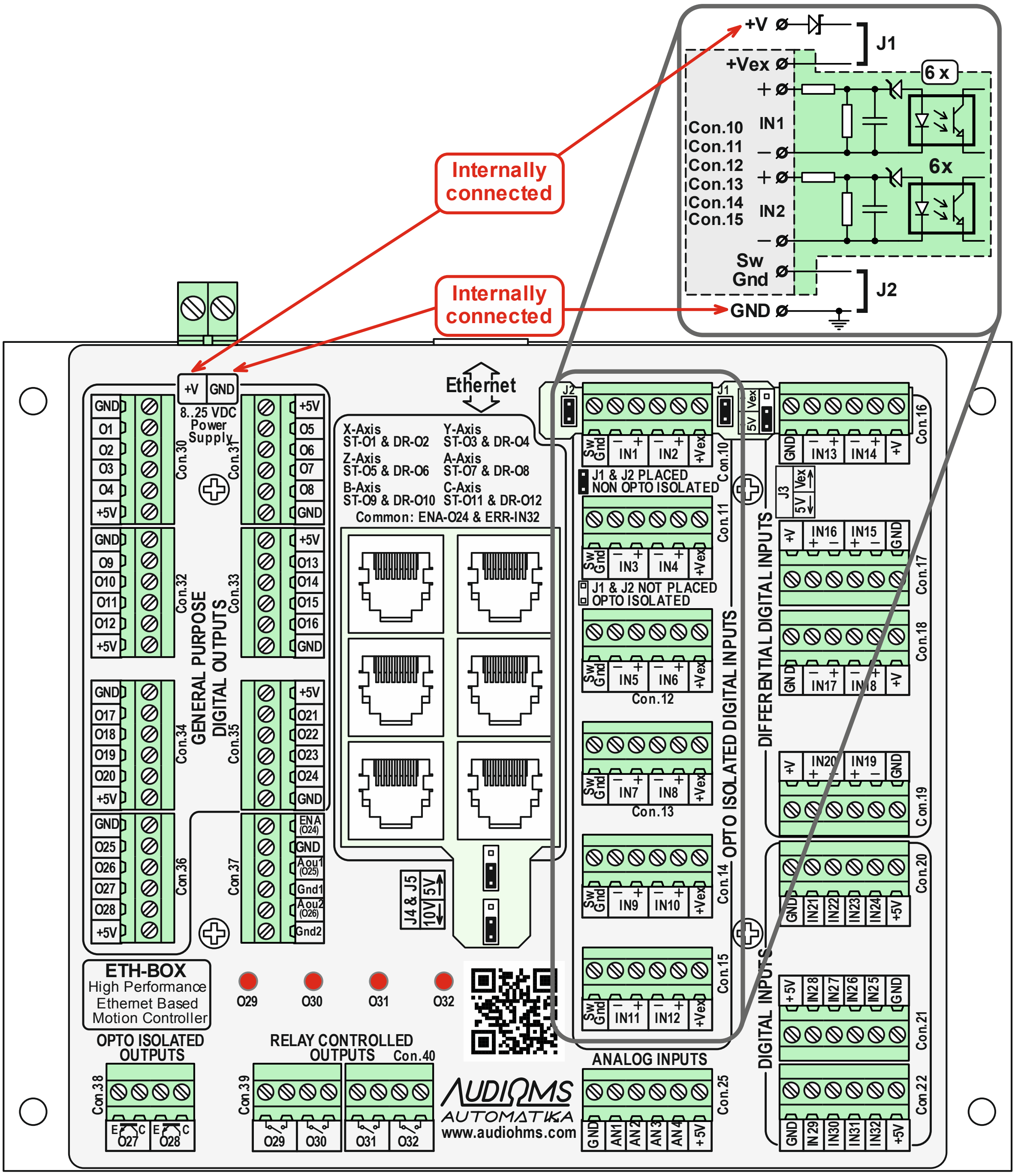


Figure 2.7 Location of opto-isolated digital inputs on the ETH-BOX motion controller

2.4.2 Isolated mode of wiring limit switches to the opto-isolated inputs

Isolated mode of wiring limit switches to digital inputs IN1-IN12 implies usage of **additional power supply** with voltage in range of 18-24 VDC. Figure 2.9.a shows connection of electro-mechanical switches, while Figure 2.9.b shows a possible way of connecting inductive switches to digital inputs IN1-IN12 in **isolated wiring mode**.

IMPORTANT NOTE: When connecting limit switches in **isolated mode** (Figure 2.9.a and Figure 2.9.b) it is required to **remove jumpers from locations J1 and J2**.

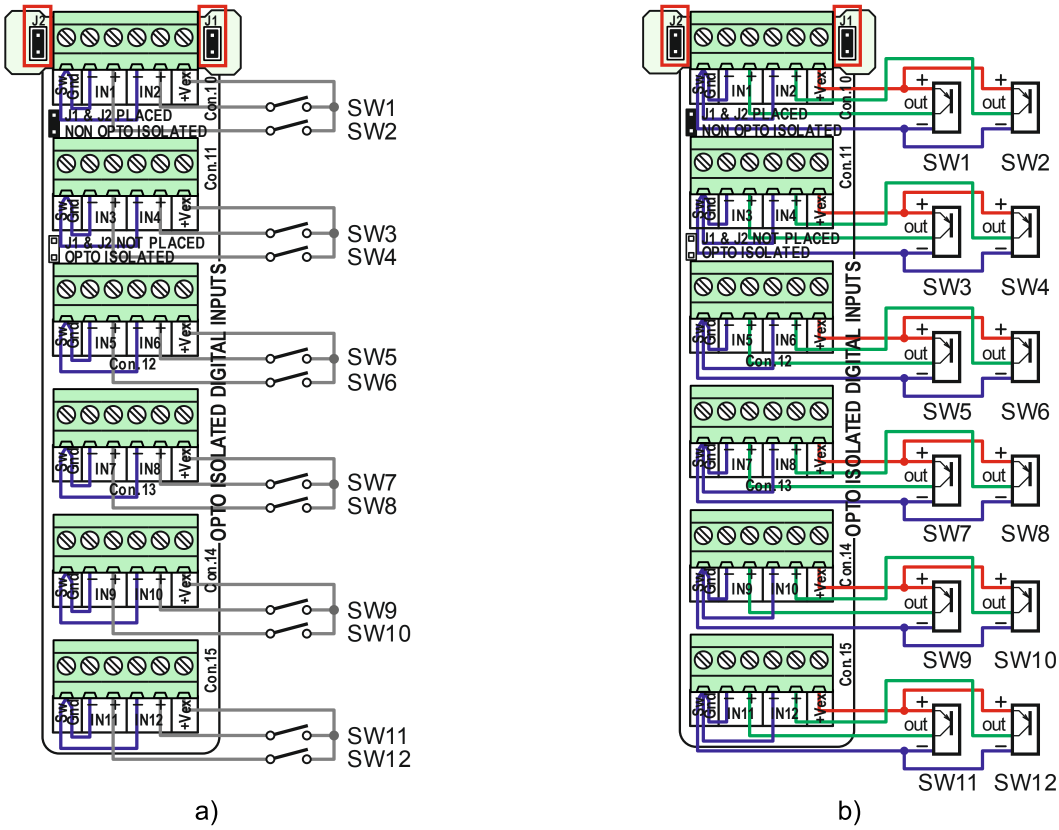


Figure 2.8 **Non-isolated mode** of wiring limit switches, a) electro-mechanical type and b) inductive type

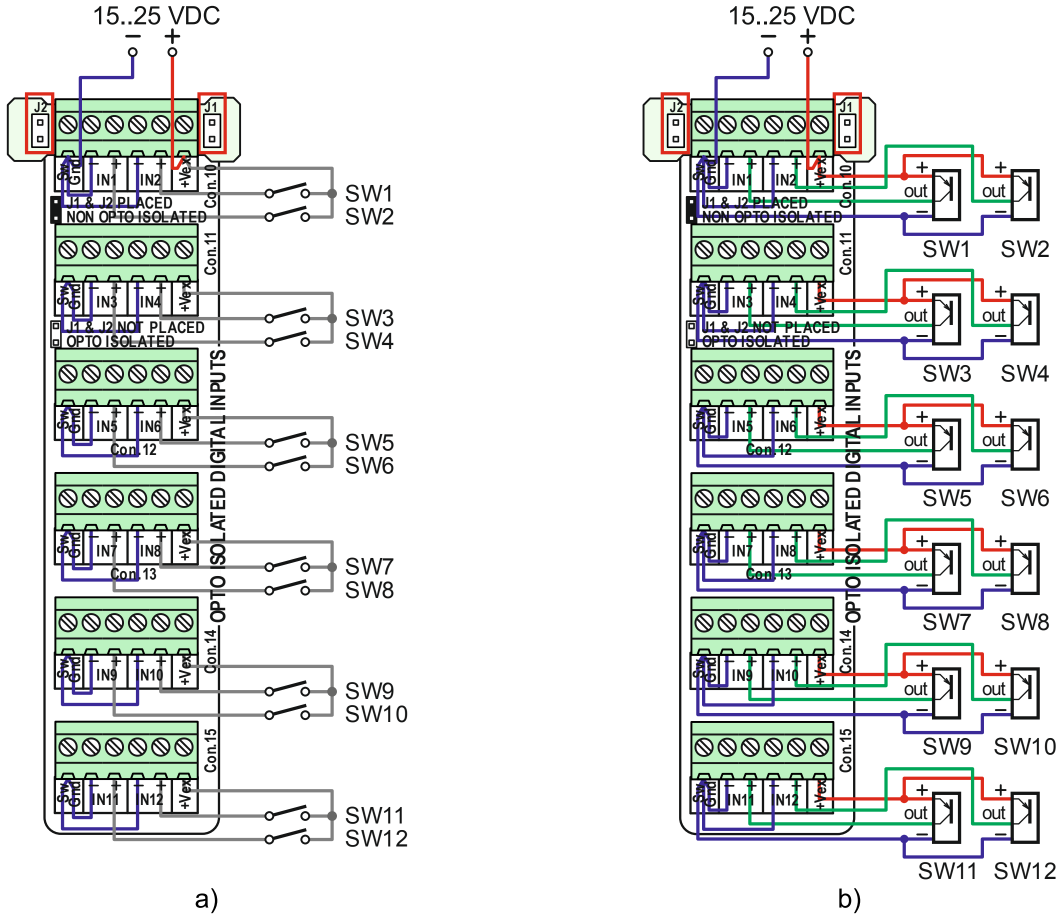


Figure 2.9 **Isolated mode** of wiring limit switches, a) electro-mechanical type and b) inductive type

2.5 Differential digital inputs

On the ETH-BOX motion controller, it is possible to connect 8 differential digital inputs (marked with IN13-IN20) via connectors from Con.16 to Con.19 (Figure 2.10). In the above picture, to the right, is the simplified diagram of the differential input circuit.

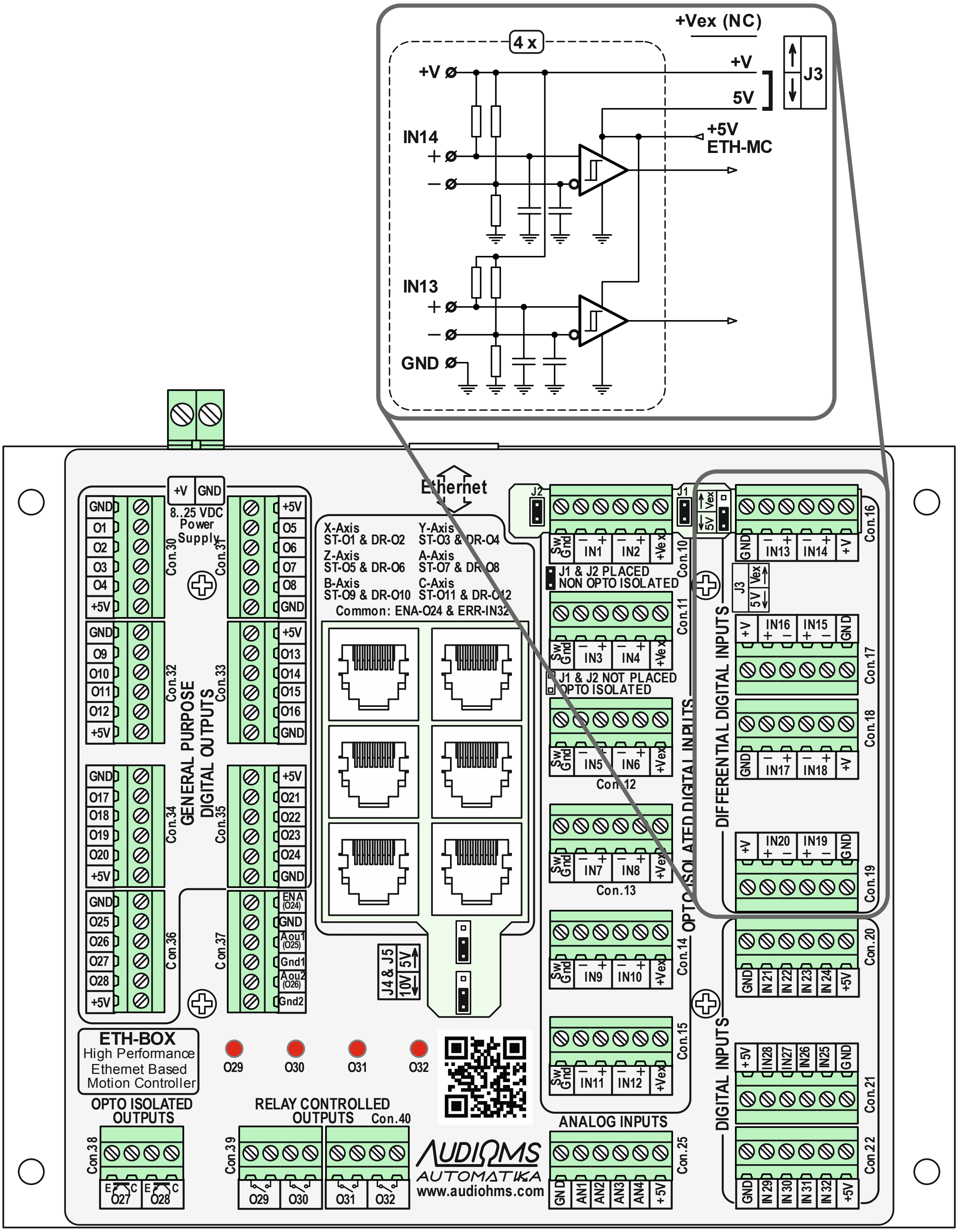


Figure 2.10 The position of the connector on the ETH-BOX motion controller for connecting differential digital inputs

Figure 2.11 provides some examples of peripheral binding to the differential inputs of the ETH-BOX motion controller. Differential digital inputs can connect sources with:

- Differential outputs (Figure 2.11, an example of a connection between a rotational incremental encoder and a linear encoder), and
- Single-ended outputs (Figure 2.11, an example of a MPG connection).

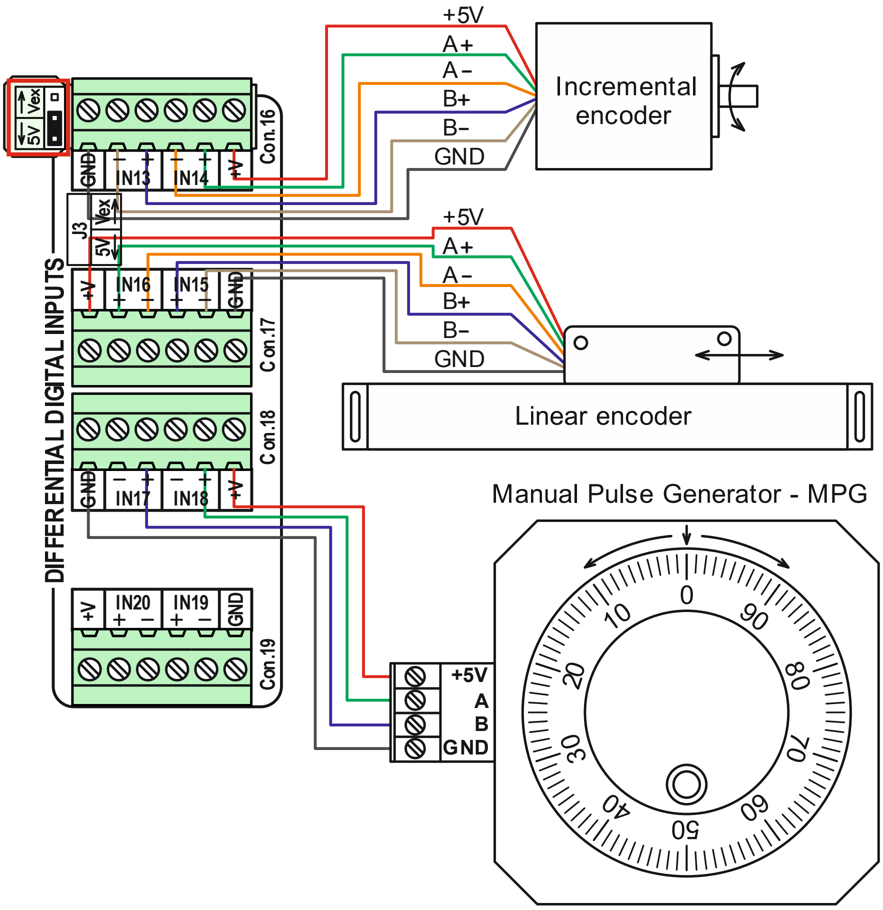


Figure 2.11 Examples of connecting peripherals to differential digital inputs

2.6 General purpose digital inputs

It is possible to connect 12 general purpose digital inputs on the ETH-BOX motion controller. They are framed under the name "DIGITAL INPUTS" and are marked with IN21-IN32. They are connected via connectors Con.20, Con. 21, and Con. 22 (Figure 2.2).

All general purpose digital inputs are of Schmitt trigger type, with a voltage level of 5V. All mentioned inputs have a 4k7 pull-up resistor.

2.7 Analog inputs

The ETX-BOX motion controller has four analog inputs (AN1-AN4) ranged from 0-5 V. Analog inputs (marked with "ANALOG INPUTS") are connected via the connector Con. 25 (Figure 2.2).

Analog inputs provide the possibility of connecting potentiometers, THC sensors and other sensors with analog outputs in order to realize some of the special functions (FRO, SRO, THC control, etc.).

Figure 2.12 provides the recommended method of linking the potentiometer to the analog input AN1, as well as the analog output from the THC Sensor to the analog input AN2. More details on THC Sensor binding are available in its user guide. A detailed description of the Torch Height Control (THC) is given in section 3.3.

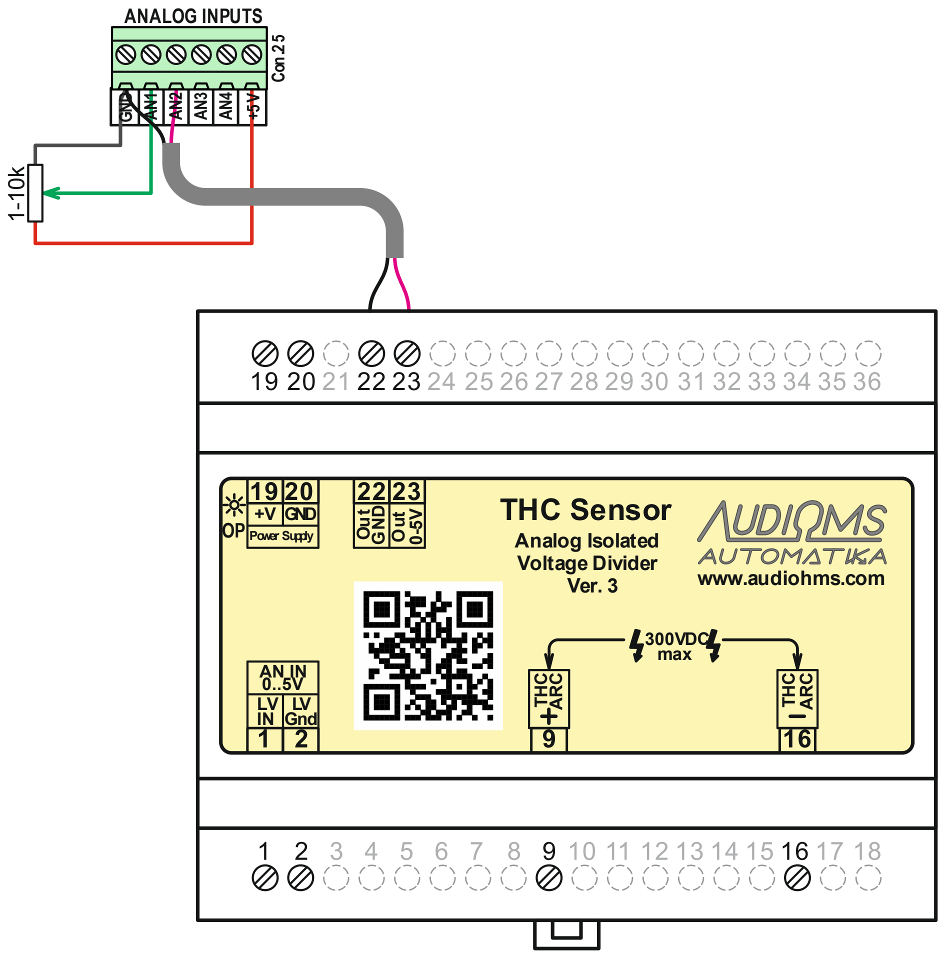


Figure 2.12 An example of connecting the source of analog signals to the analog inputs of the ETX-BOX motion controller

2.8 Isolated analog outputs

Mach3 has the ability to generate a PWM (Pulse-width modulation) signal. PWM or pulse width modulation is a method of control where the frequency of the control signal does not change. What is changing is the signal / pause ratio, i.e. the signal width changes.

If an appropriate filter is placed on the TTL output on which the PWM signal is received, then the analog signal will be output at this filter. The voltage level of the analog signal depends on the signal / pause ratio. For example, if the signal width is 10% and the pause width is 90%, the analog output voltage will be 10% of the maximum voltage. This analog signal can be used as a control signal for regulating the spindle speed or for controlling one of the other peripherals on the machine.

In addition to a single PWM output that is standardly supported by Mach3, the ETH-MC motion controller also supports 2 additional PWM outputs (described in more detail in section 1.8.4 in the section describing Extended PWM outputs) that can be used to generate analog outputs.

The ETH-BOX motion controller has two independent isolated analog outputs. Figure 2.12 provides a simplified scheme of isolating analog outputs, as well as the position of Con. 37 on which the said insulation outputs are located. The control of the analog output Aou1 is done by generating a PWM signal at the digital output O25, and for Aou2 generating a PWM signal at the digital output O26.

It is possible to select the voltage level at the isolation analog outputs, in the range 0-5 V or 0-10 V. The selection is made via the J4 and J5 positions of the jumper. Figure 2.12 provides the jumper J4 and J5 positions for the selected output range 0-10 V.

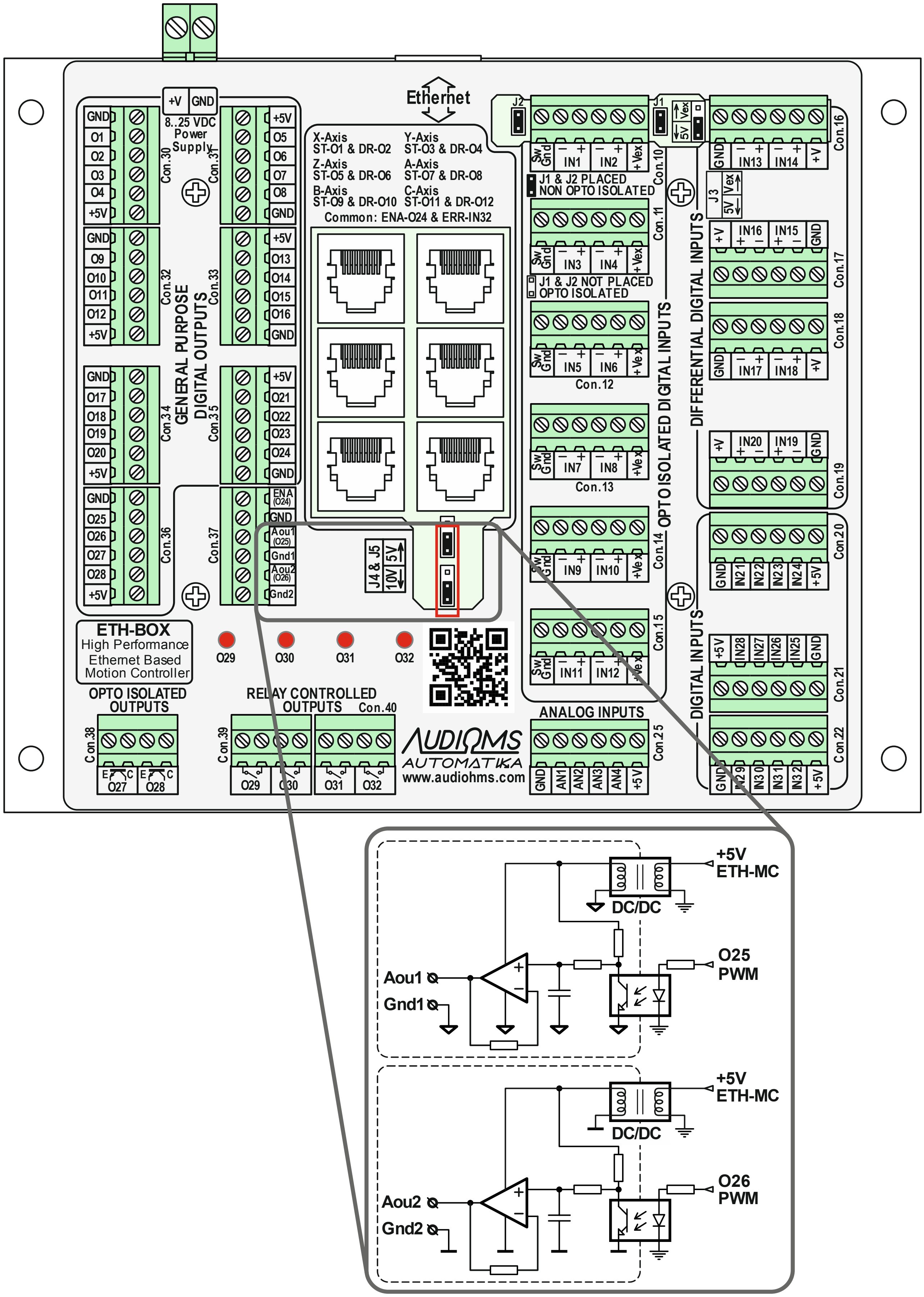


Figure 2.13 Simplified diagram of isolating analog outputs and position of the connector Con. 37 on the ETH-BOX motion controller

2.9 Opto-isolated digital outputs

At the connector Con. 38 two opto-isolated digital outputs are available (Figure 2.14 – labeled as "OPTO ISOLATED OUTPUT"). It should be noted that external resistors must be installed on opto-isolated outputs in order to limit the current through the output of the opto-cluster. Figure 2.14 provides one of the possible ways for binding opto-isolated digital outputs to an ETH-BOX motion controller.

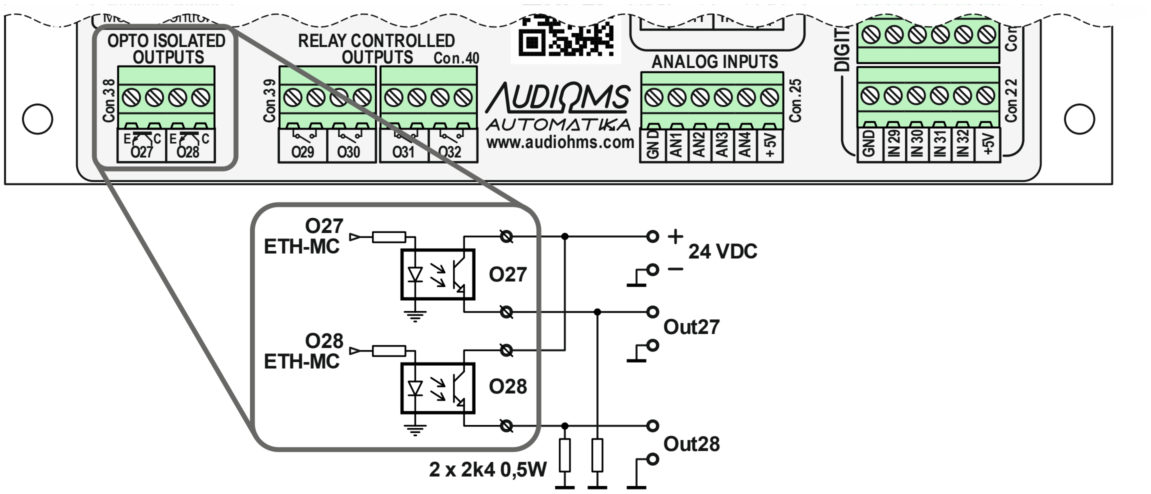


Figure 2.14 Position of opto-isolated digital outputs

2.10 Relay outputs

The ETH-BOX motion controller has four relay outputs on the connectors Con. 39 and Con. 40 (Figure 2.15). Relay outputs are marked with "RELAY CONTROLLED OUTPUTS".

All relay outputs are of NO type (Normally Open). The nominal current capacity of the relay contacts is 1 A at 30 VDC or 0.5 A at 125 VAC (resistive load). The maximum power that the relay can utilize is 62.5 VA / 30 W.

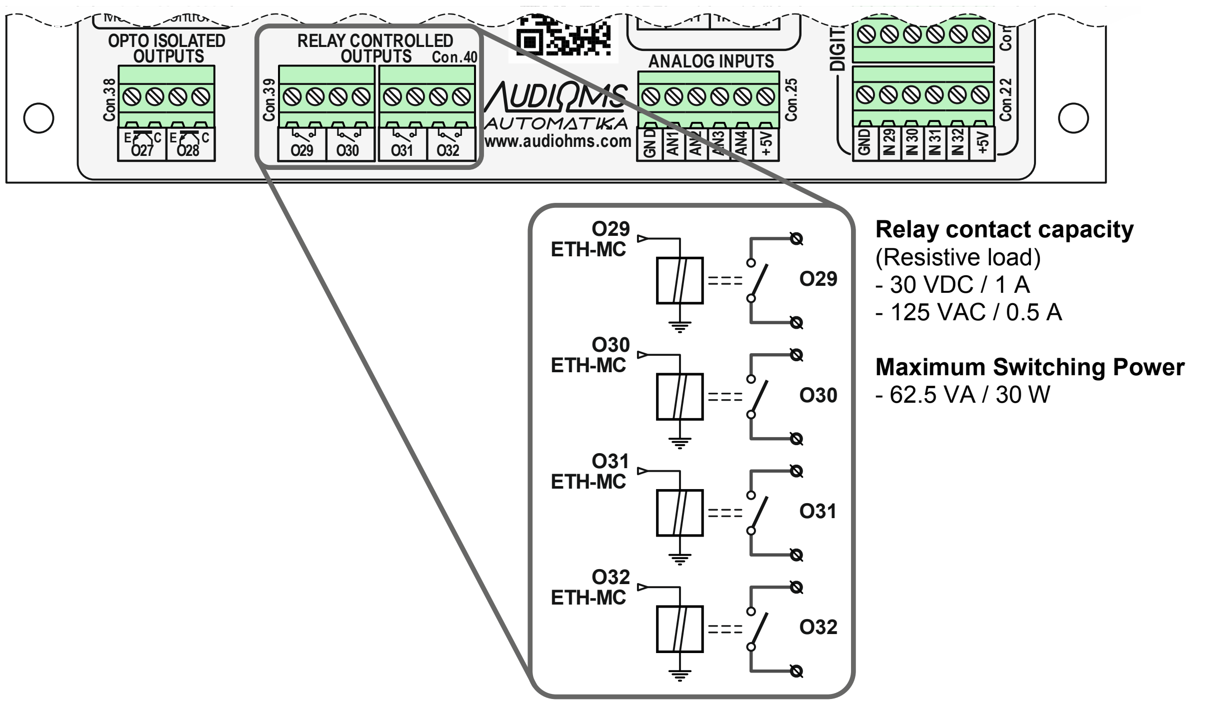


Figure 2.15 Position of the relay outputs on the ETH-BOX motion controller

3 Setting up advanced options

ETH-MC and ETH-BOX motion controllers offer a large number of advanced options that are not originally available from Mach3 control software.

This chapter describes some of the supported advanced options.

3.1 MPG (manual pulse generator) pendant operation

ETH-MC(-BOX) motion controller supports connecting MPG pendant (Figure 3.1) for controlling CNC machine, i.e. enables standard operations that these pendants offer.

It is supported:

- by pressing Enable button MPG operation is enabled, i.e. MPG mode is activated,
- selecting axis that should be controlled (maximum 6 axes),
- selecting step for MPG (maximum 4 positions),
- ESTOP button on pendant,
- LED indicator of activity,
- for axes 4, 5 and 6 it is possible to assign alternative functions (Shuttle, FRO, SRO, THCV).

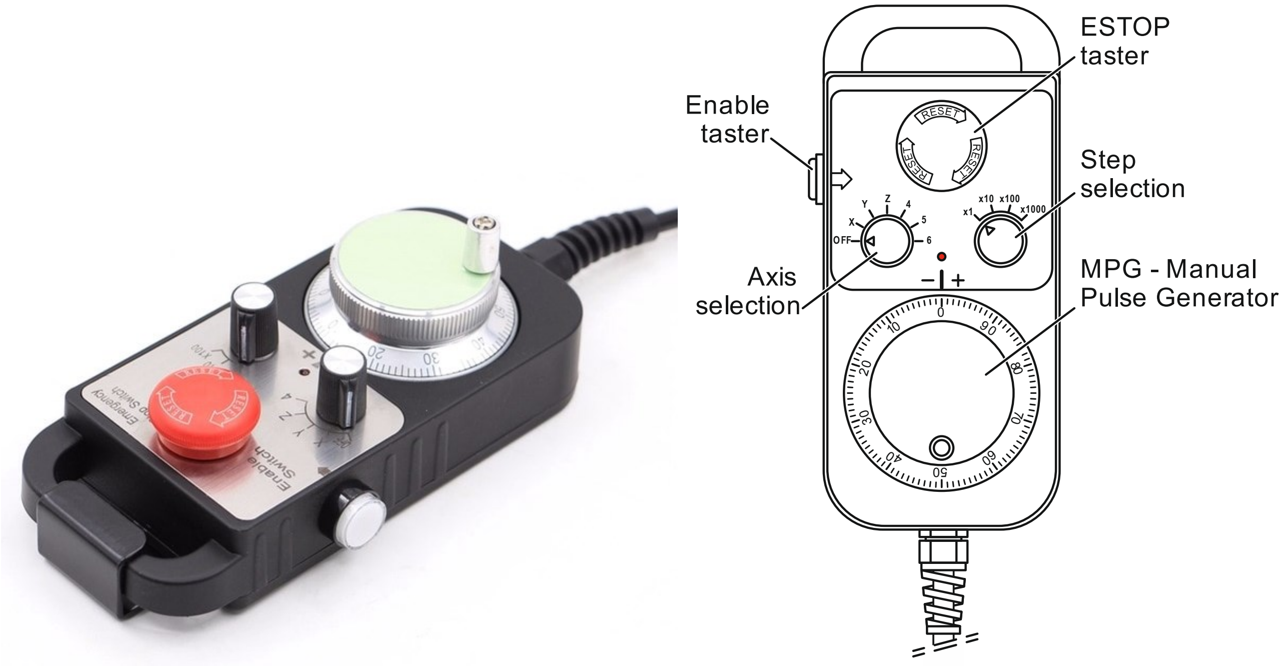


Figure 3.1 Pendant for CNC machine control

Mentioned pendants are usually realized in a way that it is required to press Enable taster (located on the right side Figure 3.1) for pendant operation to be enabled (this does not apply to ESTOP button which is always enabled).

By pressing Enable button MPG jog mode is automatically entered and by releasing this button MPG jog mode is deactivated. For axes 4, 5 and 6 if an alternative functions (Shuttle, FRO, SRO) is selected, pressing Enable button activates that selected function and releasing this button deactivates selected function mode.

Figure 3.2 shows one of possible ways for connecting pendant to ETH-BOX motion controller. This picture shows a general pendant case with:

- MPG that offers differential outputs,
- selector switch with 6 positions for axis selection,
- selector switch with 4 positions for step selection,
- ESTOP and ENABLE buttons and
- LED activity indicator.

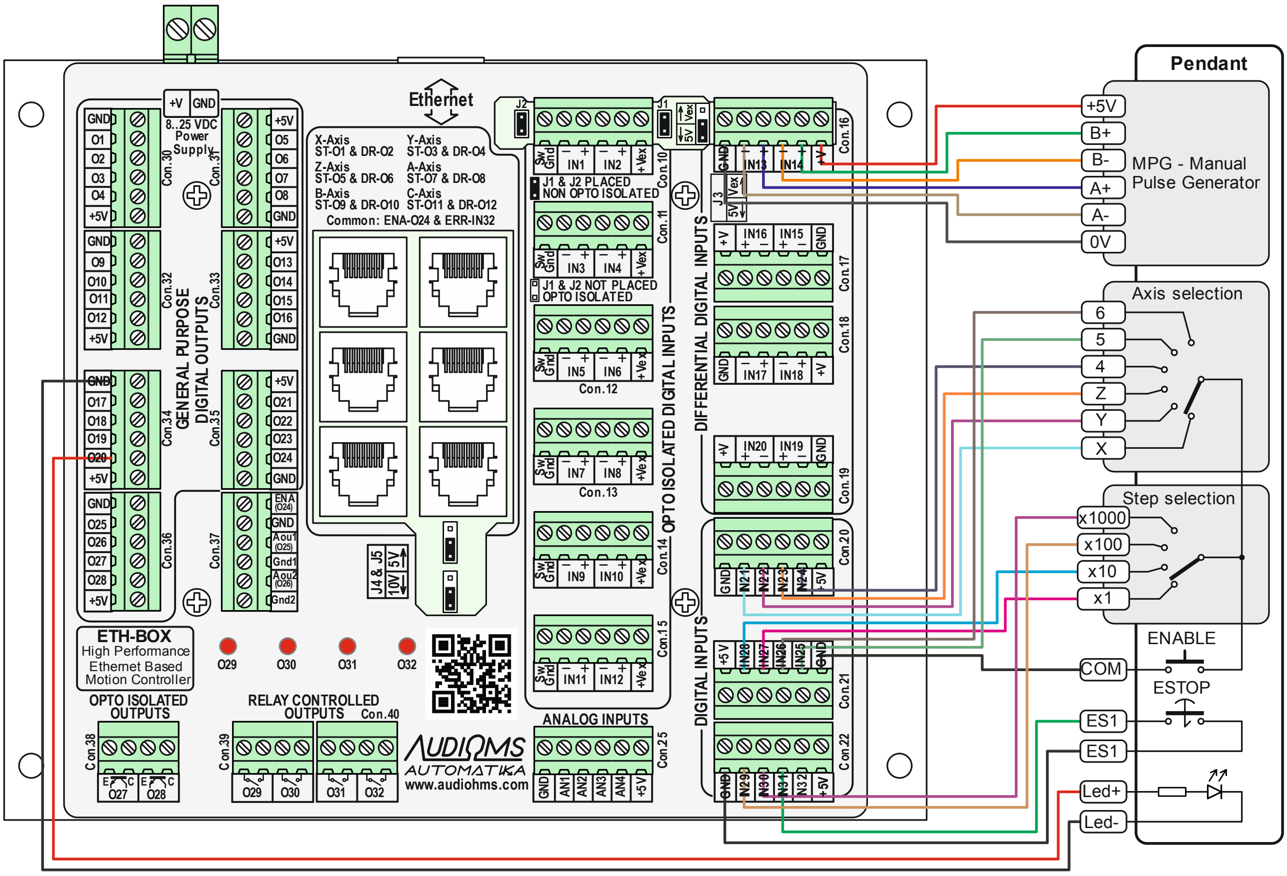


Figure 3.2 An example of pendant connection to the ETH-BOX motion controller

Options for pendant functions can be adjusted using ETH-MC configuration dialog box. Within Special Functions group there is a group of options for pendant (Figure 3.3).

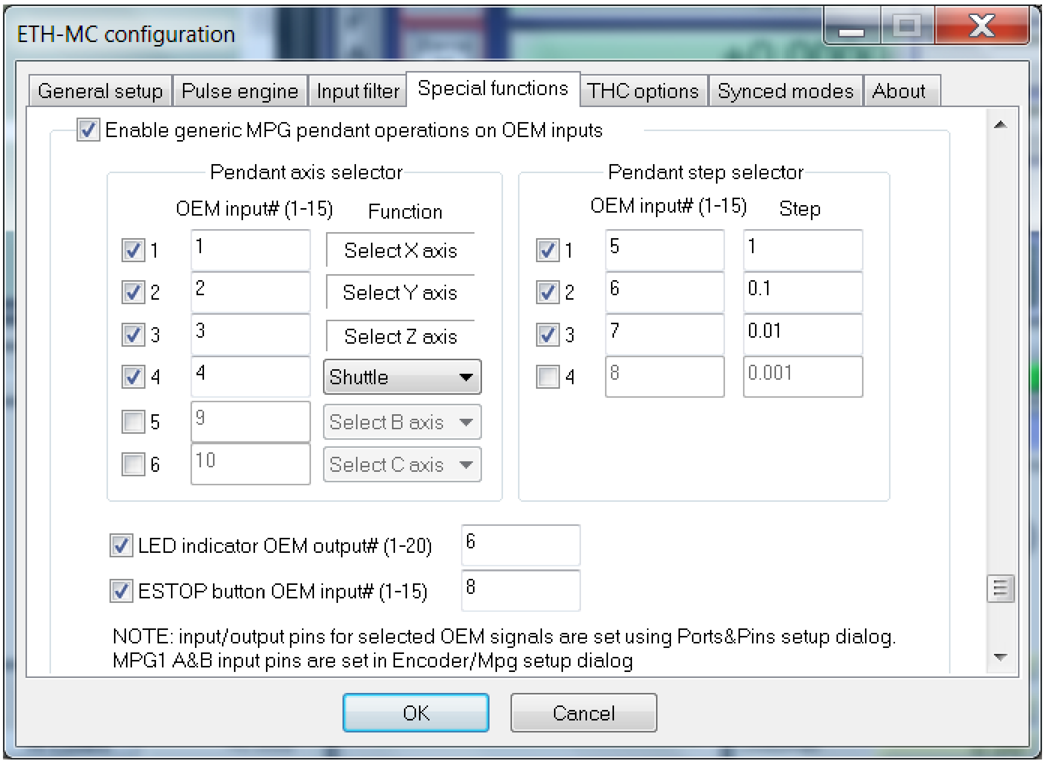


Figure 3.3 An example setup of functions for pendant with 4 positions for axis selector switch and 3 positions for step selector switch

Mach3 OEM input signals are used for reading current states of selector switches and the other pendant controls. More closely, state of mentioned signals is used regardless of the way they are activated (normally via digital inputs or alternatively set by some other plugin, script or similar).

Available options (Figure 3.3) are:

- Enable generic MPG pendant operations on OEM inputs – Activates/deactivates pendant operations.

- Pendant axis selector – enables setting up the functionality of the axis selector. Maximally a 6 switch positions are supported. Using OEM input# field it is possible (if needed) to change which OEM input signals are used for each switch position. Pin and port for digital inputs for these OEM signals can be set up using Mach3 Ports&Pins input configuration dialog (Figure 3.4).

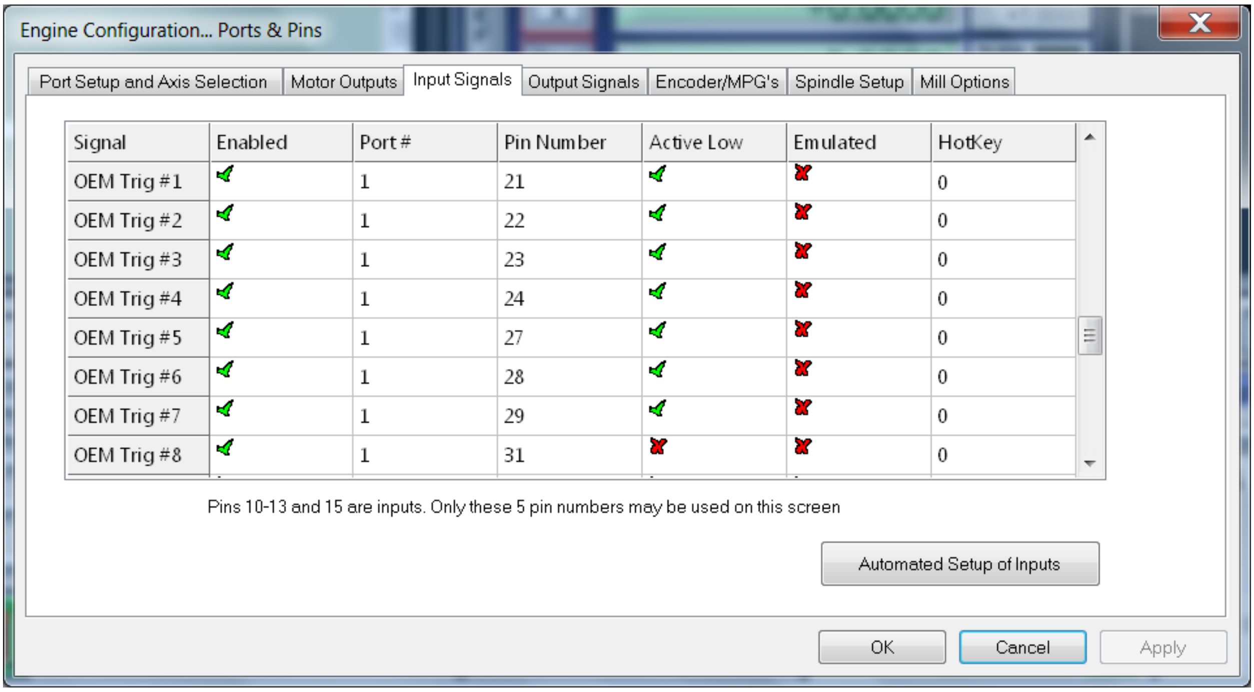


Figure 3.4 Example of setting up input pins for OEM input signals that are used for pendant functionality

As already mentioned, for positions 4, 5 and 6 it is possible to setup following functions:
- Shuttle mode activation (controlling the speed of G-code execution by turning MPG wheel),
- FRO (Feedrate override 0-250%),
- SRO (Spindle rate override 0-250%),
- THC Vnom (set nominal THC voltage, 50-300V), and
- THC VOvr (set THC voltage override, 80-120%).

- Pendant step selector – this option group enables setting up pendant step selector (Figure 3.3). Maximally 4 positions are supported for step selector. OEM input# and Step fields enable setting up OEM input and step value for each position.

- LED indicator OEM output# (1-20) – if pendant has LED indicator it is possible to use it by connecting it to a free digital output. LED indicator lights up when pendant is active.

- ESTOP button OEM input# (1-15) – if pendant has ESTOP button it is possible to use it by turning this option on

For setting up MPG (Manual Pulse Generator) Encoder/MPG's (Figure 3.5) dialog is used. It is needed to turn on MPG1 and set pin and port for A and B inputs as well as other required fields. For detent value (counts/unit) it is needed to enter a number of pulses that MPG generates when moved for one mark (usually 4 pulses).

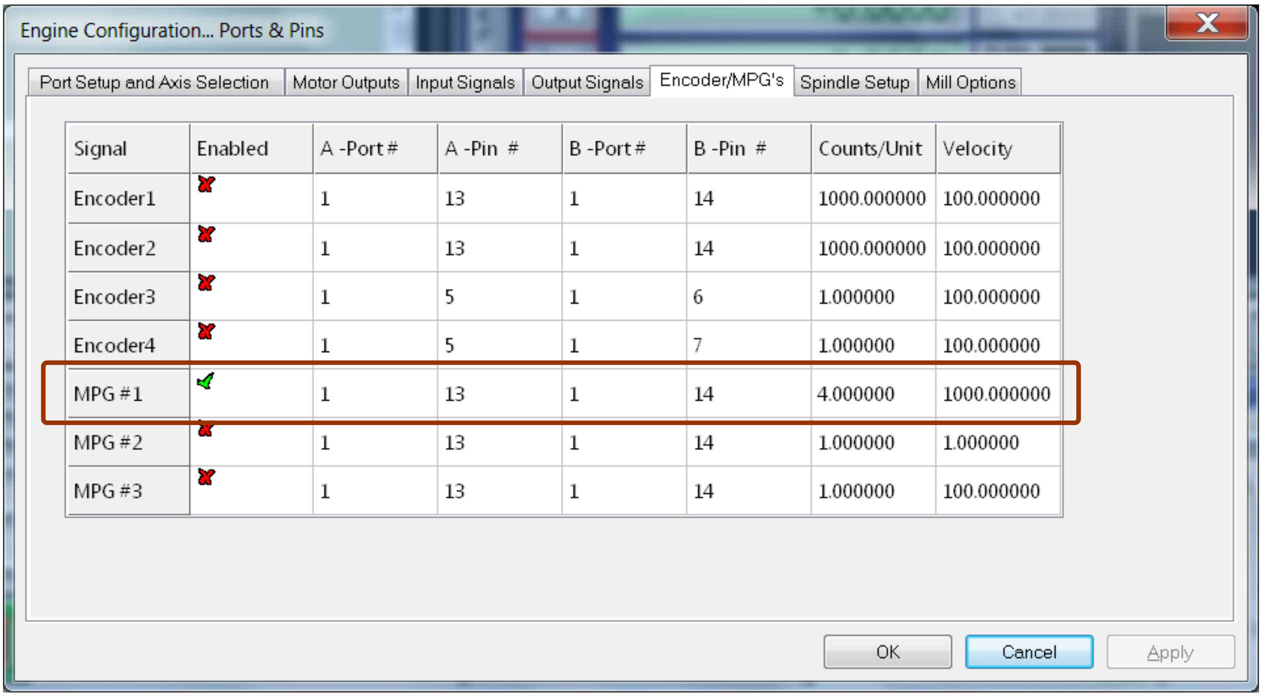


Figure 3.5 An example setting for case when A and B MPG lines are connected via digital inputs 13 and 14 (first pair of differential inputs on ETH-BOX motion controller)

NOTE: For the best performance it is recommended to enable option Hardware MPG in General Setup tab of ETH-MC controller configuration dialog. In that case controller autonomously reads MPG position and controls axis position without any need for communication with PC computer.

3.2 Joystick jog control

ETH-MC motion controller has implemented hardware support for analog joystick control. Joystick can be used to jog X, Y and Z axis and it should be connected to the ETH-MC controller via one or more analog inputs. Joysticks based on potentiometers, hall effect or other technology can be used as long as the output signal is in range of 0-5V.

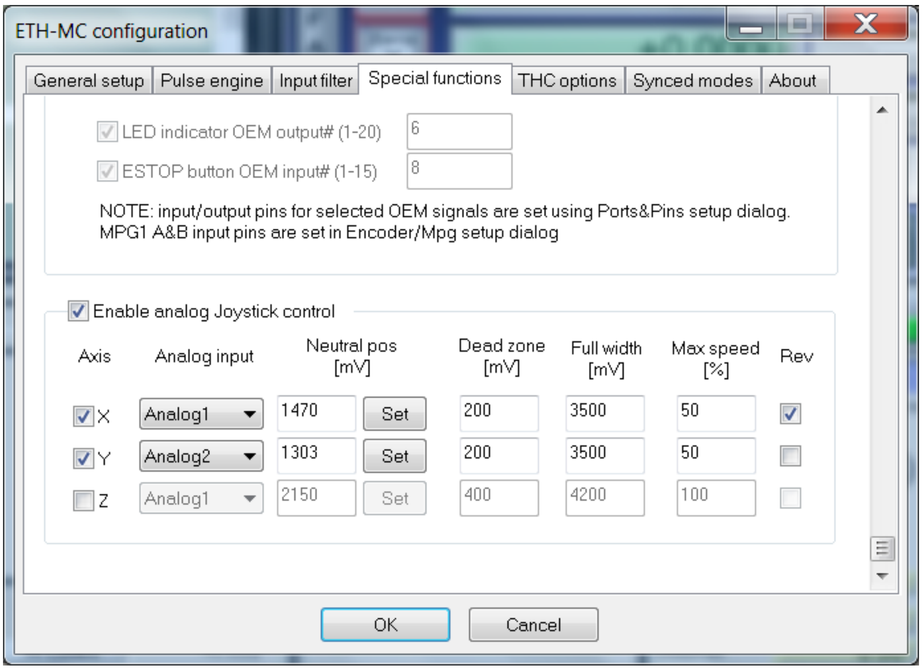


Figure 3.6 Analog joystick setup

Group of options for setting up Analog Joystick is shown in Figure 3.6.

Jog speed is variable, i.e. it is proportional to the joystick inclination angle. One 3-axis joystick can be used or any combination of 2-axis or single axis analog joysticks.

- **Enable analog joystick control** – must be turned on to enable analog joystick operation.
- **Axis (X, Y, Z)** – enable axis control using joystick.
- **Analog input** – combo box is used to select analog input that should be used for every axis.
- **Neutral pos [mV]** – this field is used to specify analog voltage that corresponds to neutral joystick position. Voltage value can be entered manually or the Set button can be used to read current value from the selected analog input.
- **Dead zone [mV]** – this field is used to specify dead zone width for corresponding joystick axis. Dead zone is centered on neutral joystick position and reading a voltage value that falls inside this zone will not cause movement. Dead zone should be set to be wide enough to ensure that there is no axis movement when the joystick is in idle state.
- **Full width [mV]** – this field is used to specify width of full work zone. This zone is centered on neutral position and corresponds to maximum joystick inclination angles from one side to the opposite side.
- **Max speed [%]** – this field is used to specify maximum jog speed and it relates to maximum joystick inclination angle. Maximum speed is given as a percent of maximum speed for the axis, and
- **Rev** – is used to reverse movement direction for the axis.

3.3 Plasma system torch height control – THC regulation

Torch height control (THC) for plasma system (Figure 3.7), is a function that is used with plasma cutting machines for continual regulation of the plasma torch height. It is important to maintain constant distance between plasma torch and work material. This function of ETH-MC motion controller is much improved in comparison to traditional Mach3 operation over LPT port.

NOTE: Full licensed version of Mach3 is required for THC function. Demo version does not support THC mode of operation.

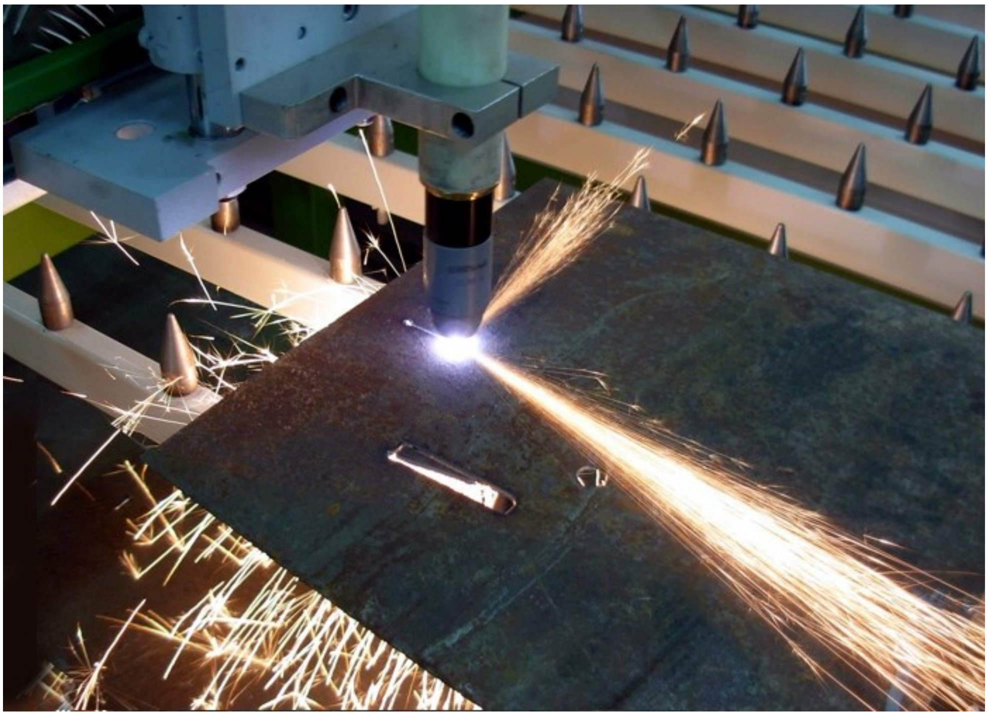


Figure 3.7 Plasma cutting

Main features that ETH-MC motion controller brings:

- **Three options for THC regulation:**
  - support for external THC regulators,
  - integrated advanced THC PID regulator (closed loop control 1 kHz),
  - integrated classic THC Up/Down regulator (1 ms response).
- **Advanced options for internal THC regulators:**
  - kerf detect - tip saver)
  - lock THC motion when arc voltage goes out of specified valid range,
  - voltage sampling (set nominal voltage by reading arc voltage at specified height),
  - set nominal voltage form G-code using S commands,
  - arc presence detection,
  - arc voltage sampling frequency of 1 kHz,
  - adjustable voltage low pass filter,
  - fine adjustment of THC nominal voltage during the cut,
  - graphical display of voltage change.
- **For both integrated and external regulator modes:**
  - THC enable/disable using G-code commands,
  - Consumable information (cut time and ignition count),
  - THC ramped motion (with acceleration and deceleration),
  - Anti-plunge option.
- **Customized Mach3 screen** with additional indicators and DRO fields.

The most common way for torch height regulation is by monitoring arc voltage as feedback information. This is because arc voltage is proportional to the arc length i.e. the height of plasma head above material that is being processed. THC regulator moves the torch up or down aiming to achieve and maintain specified nominal arc voltage.

Traditionally with Mach3, external THC regulator is used that measures arc voltage and via digital inputs it issues requests to Mach3 to move the plasma torch up or down.

Novelty that ETH-MC controller brings is that besides the support for external THC regulators it has integrated two types of internal THC regulators that can be utilized by connecting appropriate voltage sensor (THC Sensor) to one of the analog inputs of ETH-MC motion controller. Internal regulators also bring advanced options for THC regulation such as kerf detect, voltage sampling etc.

In both cases, regardless whether internal or external regulator is used, all important functions are performed autonomously in hardware of ETH-MC motion controller so that fast regulator reaction is guaranteed.

3.3.1 Mach3 THC controls on the main screen

In order to display THC specific controls on Mach3 main screen (Figure 3.8), it is required to either:

- chose any plasma profile when starting Mach3 (like supplied Plasma.xml) or
- load "plasma.set" screen or custom plasma screen (Figure 3.21) to any existing profile using menu option " View/Load screens...".

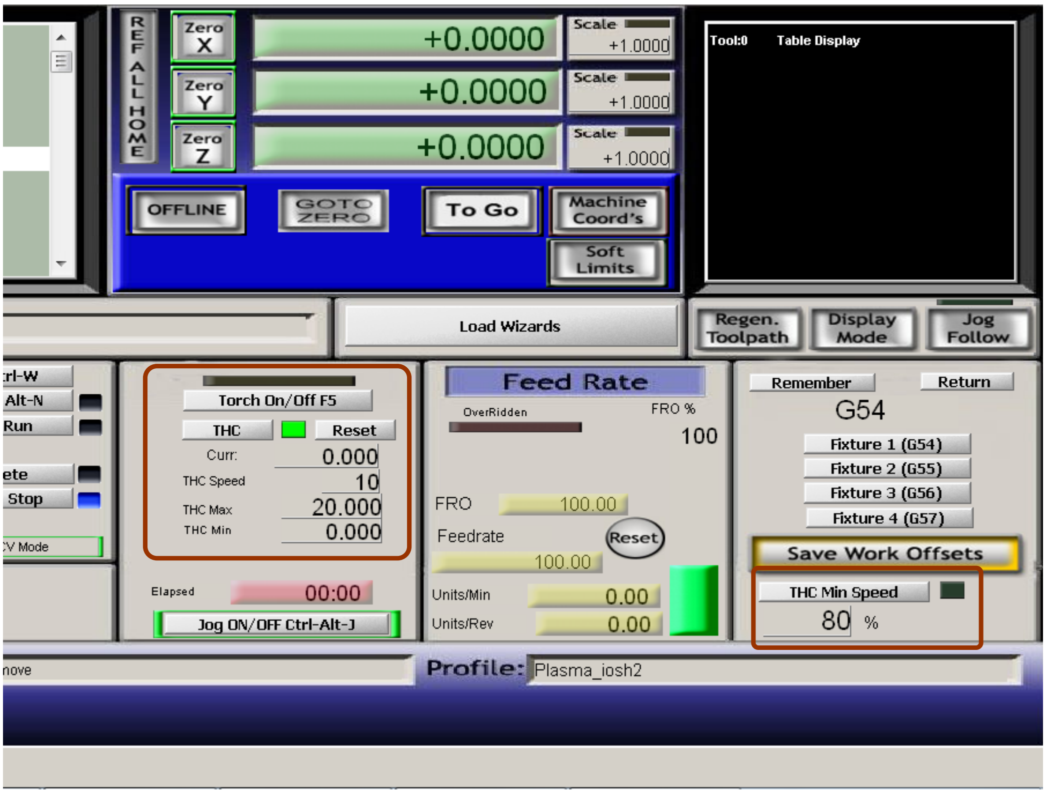


Figure 3.8 THC controls on Mach3 "Plasma.set" screen

Short description of THC controls:

- Torch On/Off – button can be used to manually turn torch on/off. Usually this button is not used except for testing purposes, and the torch is controlled programmatically by G-code commands, usually M3 is used to turn torch on and M5 to turn it off.
- THC – turns on/off THC mode of operation. **THC mode must be turned on manually before the beginning of work so that ETH-MC motion controller could correctly execute THC functions**. LED indicator near the button shows whether this mode is active (green rectangle).
- Reset button – resets to zero internal variable (Curr: field) that represents correction of vertical position (z axis) of the plasma torch. Current Z position of the torch then becomes reference point for defined minimum and maximum of Z correction.
- Curr field – displays current value of z position correction. At the moment of torch ignition, current z position is remembered as a reference, so THC Max and THC Min are defined in relation to this reference.
- THC Speed – maximum vertical movement speed of plasma torch when performing regulation from Up/Down or PID regulator. It is given as a percentage of the maximum speed of Z axis that is defined in motor tuning adjustments. **ETH-MC motion controller offers option for THC motion without acceleration and deceleration (similar to operation via LPT port/driver). In that case it is necessary to carefully set THC speed to a lower value that will not cause step motor to stall. On the other hand, even if option for ramped motion is used, too high THC speed can lead to regulator oscillation. This can happen with Up/Down regulator if hysteresis zone is too narrow or with PID regulator if aggressive PID constants are used.**
- THC Min / THC Max – fields define minimum and maximum correction for Z position of plasma torch in relation to the reference position.
- THC min speed – button enables **anti-plunge** option, that prevents plasma torch from falling too low. This can happen if during cutting motion velocity in X-Y plane drops significantly, for example at sharp corners of cutting contours, i.e. on abrupt changes of moving direction. This slowdown leads to creation of wider kerf path which causes arc to spread and as a consequence arc voltage rises. THC regulator then reacts by moving the torch down so even contact with work material is possible. THC min speed is specified as a percentage of maximum motion speed (maximum feedrate) that is achievable on the system used. If speed in X-Y plane drops below specified THC min speed, Up/Down THC commands are ignored until speed rises again.

WARNING: **It is recommended to avoid simultaneous Z axis control by G-code and by THC Up/Down regulator, internal or external (when ARC_OK signal is active)**. ETH-MC motion controller will in that case perform complex motion (THC motion superpositioned to G-code motion in Z axis direction). In some cases, due to sudden changes of motion mode also change in speed/direction, it is possible for step motor that controls Z axis to stall.

Therefore it is advisable to correctly define a time period ETH-MC THC options/ Pierce delay (Figure 3.13) so that all G-code controlled movement of Z axis is finished before enabling regulation performed by internal or external THC regulator.

Alternatively it is possible to specify appropriate pause time in external controller if it supports such an option. THC controllers usually offer the option to specify pause time from the torch ignition to the activation of Up/Down commands in order to prevent sudden drop of plasma torch head toward the material just after torch ignition. Namely, it is necessary to wait for arc voltage to fall to a normal value and stabilize.

Figure 3.9 shows one possible procedure for initial positioning of the plasma torch and the arc ignition. It can be seen that in the beginning period a G-code movement along z axis is performed, first to position for the arc ignition, and then after the pierce, for the actual cutting. When this later positioning is finished, and after pierce_delay time delay has elapsed, Up/Down movements from THC regulator are enabled..

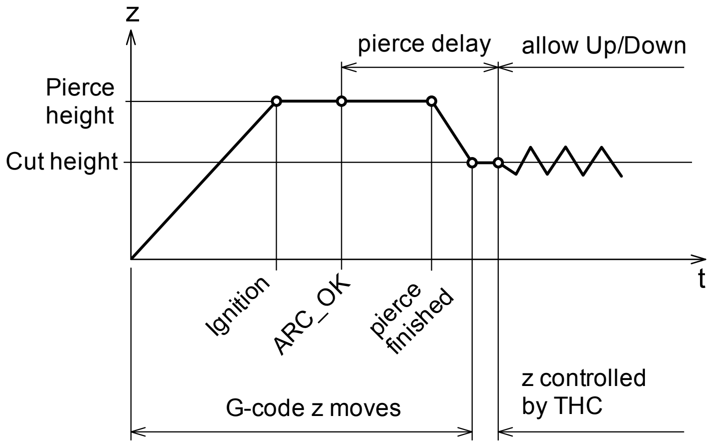


Figure 3.9 Example of plasma cutter operation

Ignition of the arc is initiated usually using M3 command which, for example, activates Output #1 signal that is connected to the plasma inverter.

ARC_OK (THC on) signal is sourced from the plasma inverter (or from external/internal THC controller) and indicates presence of the arc. Mach3 waits for this signal to continue program execution after arc ignition is commanded. If arc is lost at some time, then all movement is suspended until arc presence is detected again.

Figure 3.9 does not show initial search for the material i.e. zero z position. That function can be realized using PROBE or HOME G-code commands and for this it is required that machine supports some means to detect contact between the plasma torch and the material (floating head or ohmic sensor).

3.3.2 Configuration for operation with external THC regulator

For operation with external THC regulator it is required to setup port and pins for digital inputs THC On (ARC_OK), THC Up, THC Down (Figure 3.10).

THC On – signal name may be confusingly formulated and really means ARC_OK i.e. working arc is detected. This signal can be sourced from plasma inverter, external THC controller or a special current sensor installed for the purpose of arc detection.

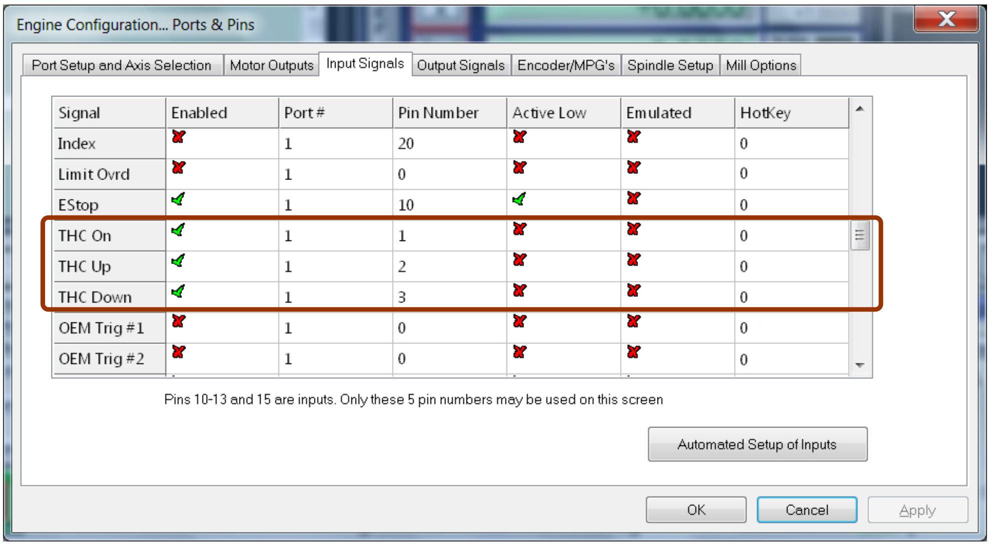


Figure 3.10 Configuration of THC input pins

NOTE: This example shows pin setup when using ETH-BOX and opto-isolated inputs 1-3. For other cases of input-output hardware it is necessary to adjust pin numbers.

Alternatively, it is possible to completely avoid usage of this ARC_OK signal and in that case it is required to open Mach3 dialog box Config/Ports and Pins/Mill Options and in THC options group to turn on the option Allow THC UP/DOWN Control even if not in THC mode. **In that way Mach3 is instructed not to wait for the ARC_OK signal when executing G-code, so after M3 command for the arc ignition, execution does not pause but instead it is continued immediately.**

In other words, **if internal/external detection of ARC_OK signal is used then this option should be turned off** (Allow THC UP/DOWN Control even if not in THC mode).

THC Up – command to move plasma torch up.

THC Down – command to move plasma torch down.

In addition, it is necessary to set up digital output that is used for the arc ignition that is controlled by command M3/M4. In example that is shown (Figure 3.11), Output#1 has been chosen and for that signal, port and pin number has been set (Figure 3.12).

Optionally it is possible to set delay times that are introduced upon the torch turn on/off, shown in General parameters group (Figure 3.11). **This settings apply also to the internal regulator**.

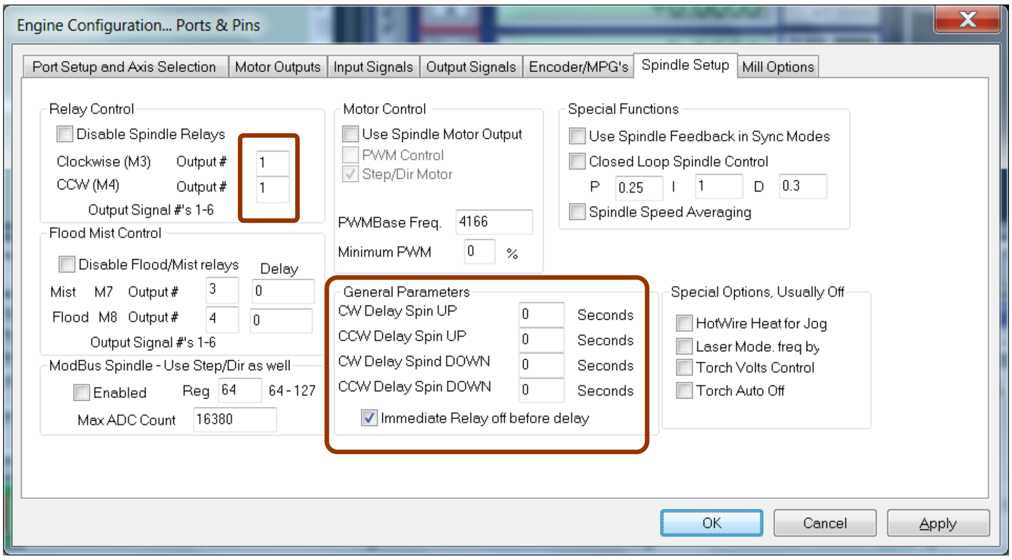


Figure 3.11 Setting up digital output signal for ignition of the plasma torch

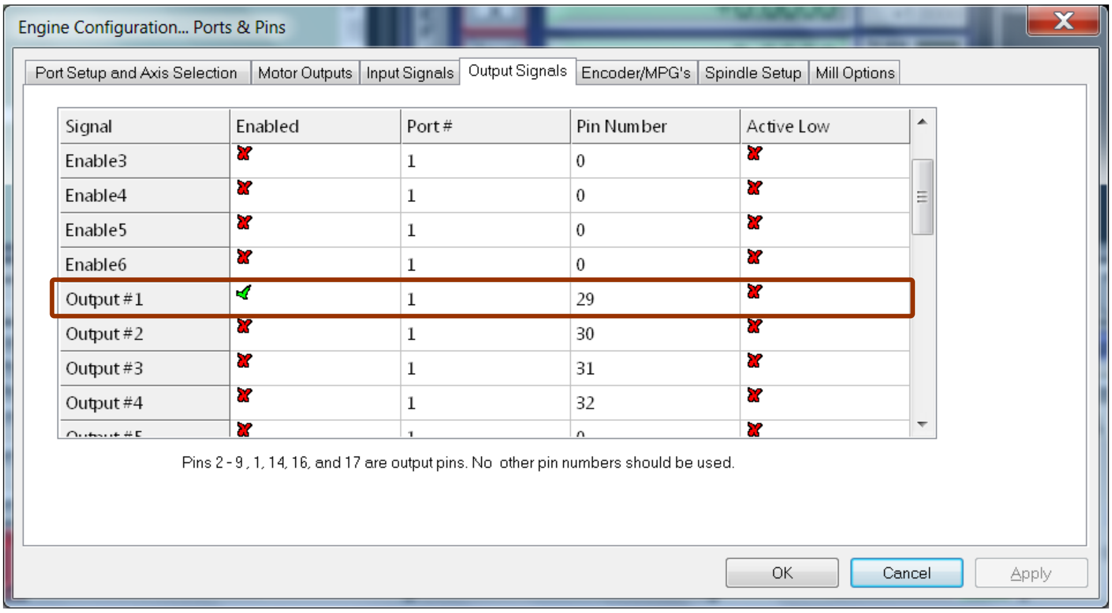


Figure 3.12 Setting up output pin for plasma torch ignition signal

NOTE: This example shows pin setup when using ETH-BOX controller and relay 1 (pin 29).
For other cases of input-output hardware it is necessary to adjust pin number.

In ETH-MC configuration dialog that can be opened using menu option Plugin Control/ETH-MC Config.../THC options (Figure 3.13) for THC type it is needed to select option External THC.

For both regulator types (internal and external) the following options are available to setup:

Pierce delay – As already mentioned, this field defines the time delay from the moment when ARC_OK signal is detected to the moment of enabling Up/Down motion requested from THC regulator.

Usually M3 command for arc ignition is followed by G04 command that is used to wait for the pierce to be completed. After that, torch is positioned to cut height and cutting operation (moving in *X-Y* plane) begins. Pierce delay parameter should be set so that THC motion is enabled only when all this mentioned steps are completed (Figure 3.9).

Ramp THC moves (use accel. and decel.) – when this option is turned on THC motion by *Z* axis is performed with acceleration when starting motion and deceleration when stopping. In other words, given acceleration parameters for *Z* axis are obeyed. If this option is turned off THC motion starts instantly with full speed and stop is also instant.

Force wait for THC_ON after M3 (fix Mach3 bug) – Mach3 has a bug (or at least illogical feature) regarding the order of operations after execution of M3 command for the arc ignition. Namely, as already mentioned, often after M3 command for the arc ignition then follows G04 command for waiting material pierce to be completed before continuing further code execution.

So, correct order of steps should be:

- execute M3 command,
- wait for ARC_OK signal,
- wait for G04 dwell time and
- continue execution.

How Mach3 really works:

- execute M3 command,
- immediately execute G04 dwell pause,
- wait for ARC_OK and
- continue execution.

The difference often goes unnoticed if after M3 is executed torch gets ignited very fast while dwell pause time is still in progress. But, if torch ignition takes longer so that ARC_OK signal appears later after the dwell pause, Mach3 then continues operation without any delay. Also, time needed for torch to ignite can vary (especially is longer for the first ignition), thus it is desirable for pierce pause (given via G04) to be measured from the moment of ARC_OK signal appearance.

To get over this problem an option is introduced to force waiting for ARC_OK signal first after M3 command issuance and only then continue further operation. This way the correct order of steps is achieved and also more precise timing for torch ignition sequence is achieved.

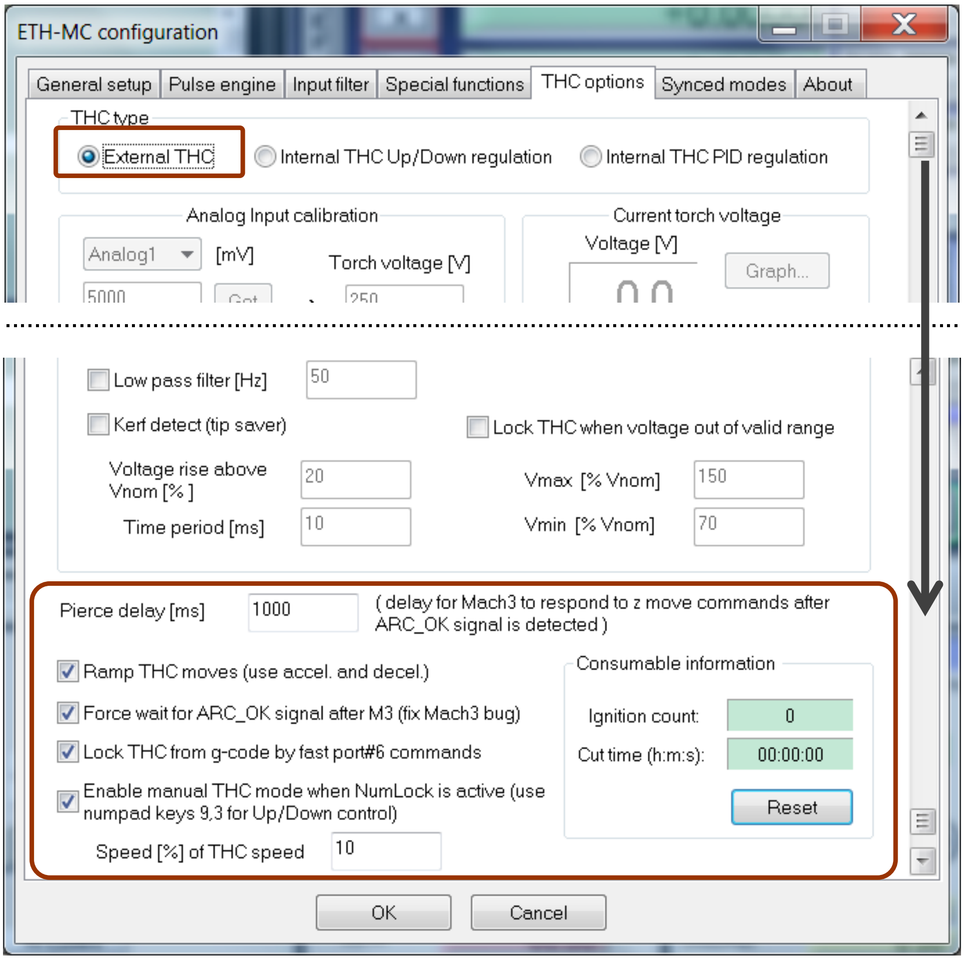


Figure 3.13 ETH-MC dialog for configuring options when working with external THC regulator

Lock THC from g-code by fast port#6 commands – it is often desirable to temporarily disable THC movements by commands from G-code. Examples for this are for instance when cutting small holes, when during the cutting, pieces of the material drop down and leave a void, also when cutting traces with sharp corners where movement in X-Y plane is slowed down and that leads to lowering of the plasma torch etc.

For this purpose are chosen fast port output commands (originally intended and implemented for laser control). This control type has a few good properties: commands are fast i.e. there is no delay in execution, does not disrupt CV (Constant Velocity) continuity for G-code moves thus they can be invoked in the middle of some path and their execution is ideally time synchronized with G-code moves along the axes.

When this option is enabled, fast commands for port 6 control are interpreted as THC movement lock or unlock commands. Signal Output#6, namely corresponding port and pin in Mach3 settings (Ports & Pins) **does not need to be setup** for these commands to work properly.

Specifically, commands are:

```
E6p1 (disable THC motion)
E6p0 (enable THC motion)
```

Popular CAM programs that are used for plasma cutting support generating THC enable/disable commands in G-code according to previously defined criteria.

NOTICE:

It should be reminded about the feature of these fast port commands that, strictly speaking, **they are executed at the start of next G-code motion in the program**. For example, if G-code similar to this everything is clear:

```
G1X100
E6P1
G1X200
```

But in the following G-code program THC motion will be disabled only at fourth program line which is not obvious at first glance:

```
G1X100
E6P1
G04 P1
G1X200
```

Nevertheless, when this kind of behavior is not desirable it can easily be overcame by inserting any kind of motion of any axis just after command E6P1 in this case.

Enable manual THC mode when NumLock is active – this option enables manual THC mode that is used for manual control of the plasma torch height. Namely, regardless of selected THC regulator, sometimes it is useful to temporarily take manual control. This may be the case for example for experimental determination of optimal height of the plasma torch during the cutting process. Manual mode can be activated at any time by pressing the NumLock key on numeric pad part of the keyboard. During the time while manual mode is active, THC automatic control is suspended and torch head can be moved up or down by pressing keys 9 and 3 on numeric part of the keyboard.

By pressing NumLock key again, manual THC mode is deactivated and automatic regulation takes over control over the torch height.

In manual mode, motion control is enabled even if there is currently active THC lock by some of the lock related THC options, and also the presence of the arc does not have to be detected.

Speed [%] of THC speed – this field enables specifying the speed of movement in manual THC mode. Speed is given as a percent of the specified THC speed (field THC Speed on Mach3 main screen)

Consumable information – information about electrode wear:

- Ignition count – number of plasma torch ignitions,
- Cut time (h:m:s) – total work time (hours : minutes : seconds). Cut time is running while plasma arc is present, i.e. while ARC_OK input signal is activated,
- Reset – button is used to reset to zero above mentioned fields.

3.3.3 Configuring the internal THC regulator

Internal THC regulator integrated in ETH-MC motion controller replaces the function of external THC regulator and is realized completely in hardware. Torch height regulation is performed by monitoring the arc voltage as feedback. For this function it is necessary to connect voltage signal from the plasma inverter via special isolated interface (THC Sensor, Figure 3.17) to one of the analog inputs of ETH-MC motion controller. Figure 3.14 gives one possible wiring scheme for THC regulator based on THC Sensor when input option ratio 1:50 is used and ETH-BOX motion controller. There are plasma inverters on the market that have low voltage analog output that can be used for torch height control. In that case THC Sensor can be wired as shown on Figure 3.15.

NOTICE: **More about THC sensor can be found on site www.audiohms.com**

ETH-MC motion controller offers two types of regulation:

- classic hysteretic regulator with up-down motion where voltage hysteresis (dead zone) is specified, and
- PID regulator with closed loop of 1 kHz. PID regulator is more advanced and offers precise regulation, but it requires careful parameters adjustment.

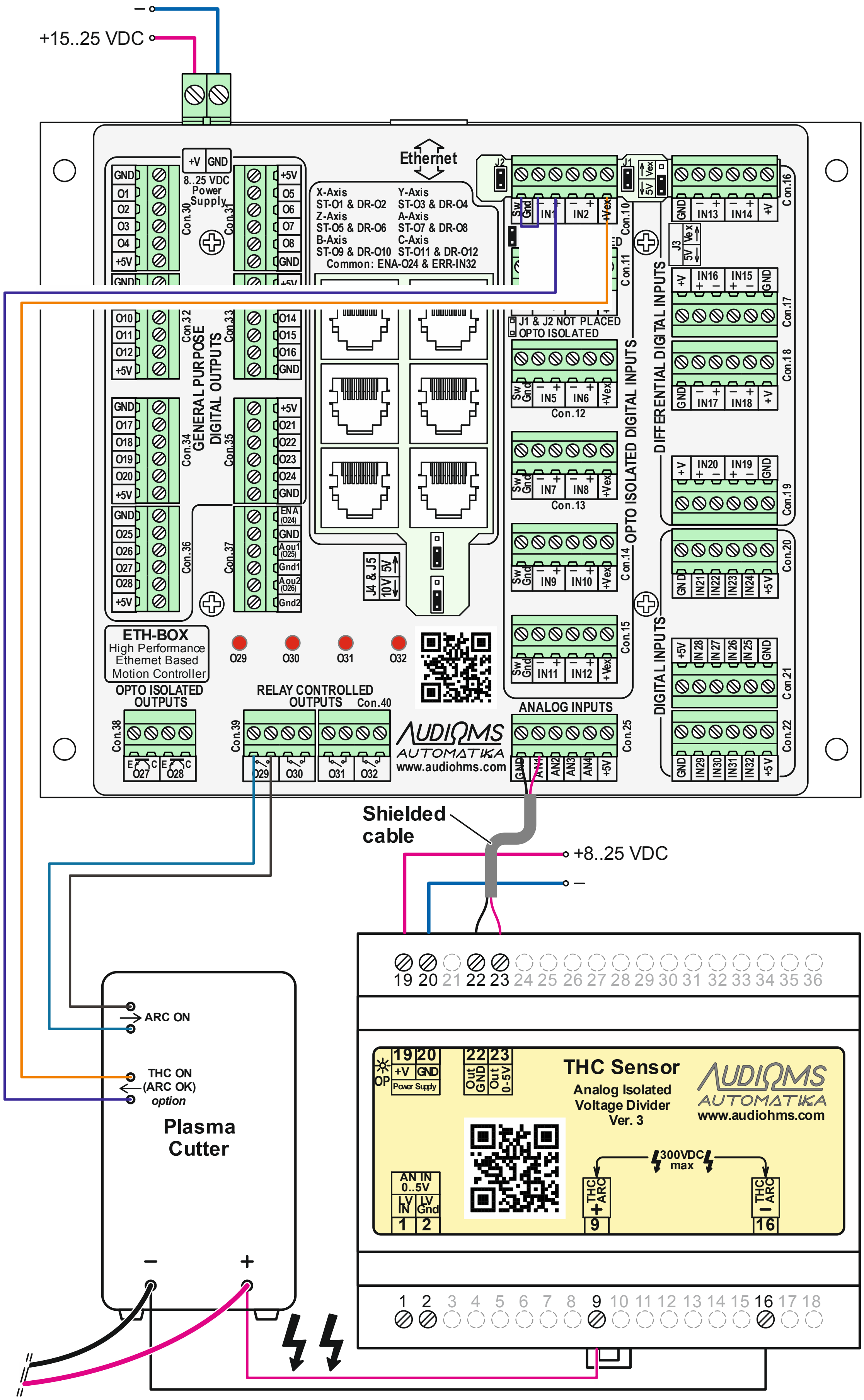


Figure 3.14 ETH-BOX motion controller and THC Sensor wiring in case of high voltage input up to 250 V (300 V max), i.e. transfer ratio 1:50

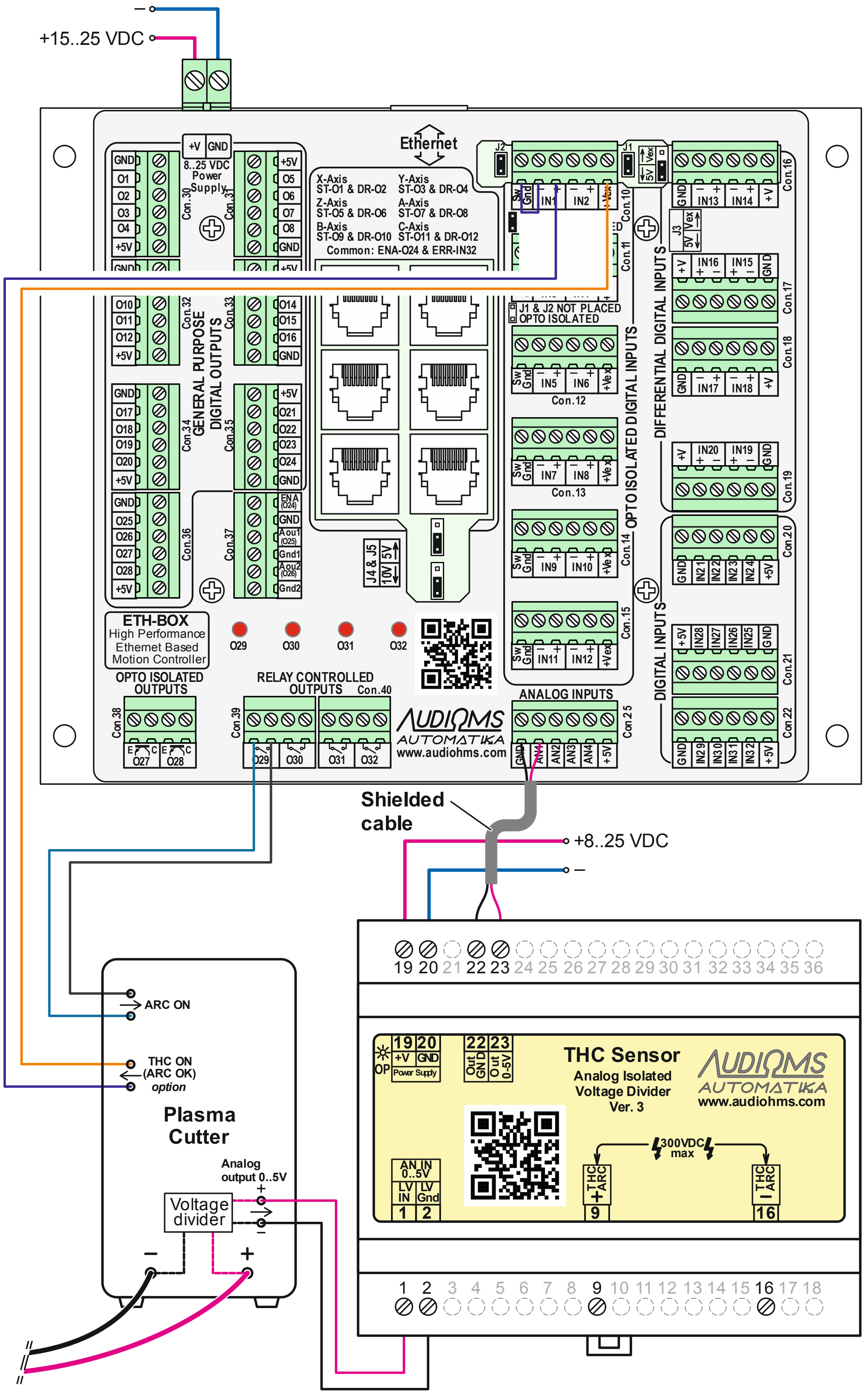


Figure 3.15 Connecting of ETH-BOX motion controller and THC Sensor in case of using low voltage input up to 5 V (10 V max), i.e. transfer ratio 1:1

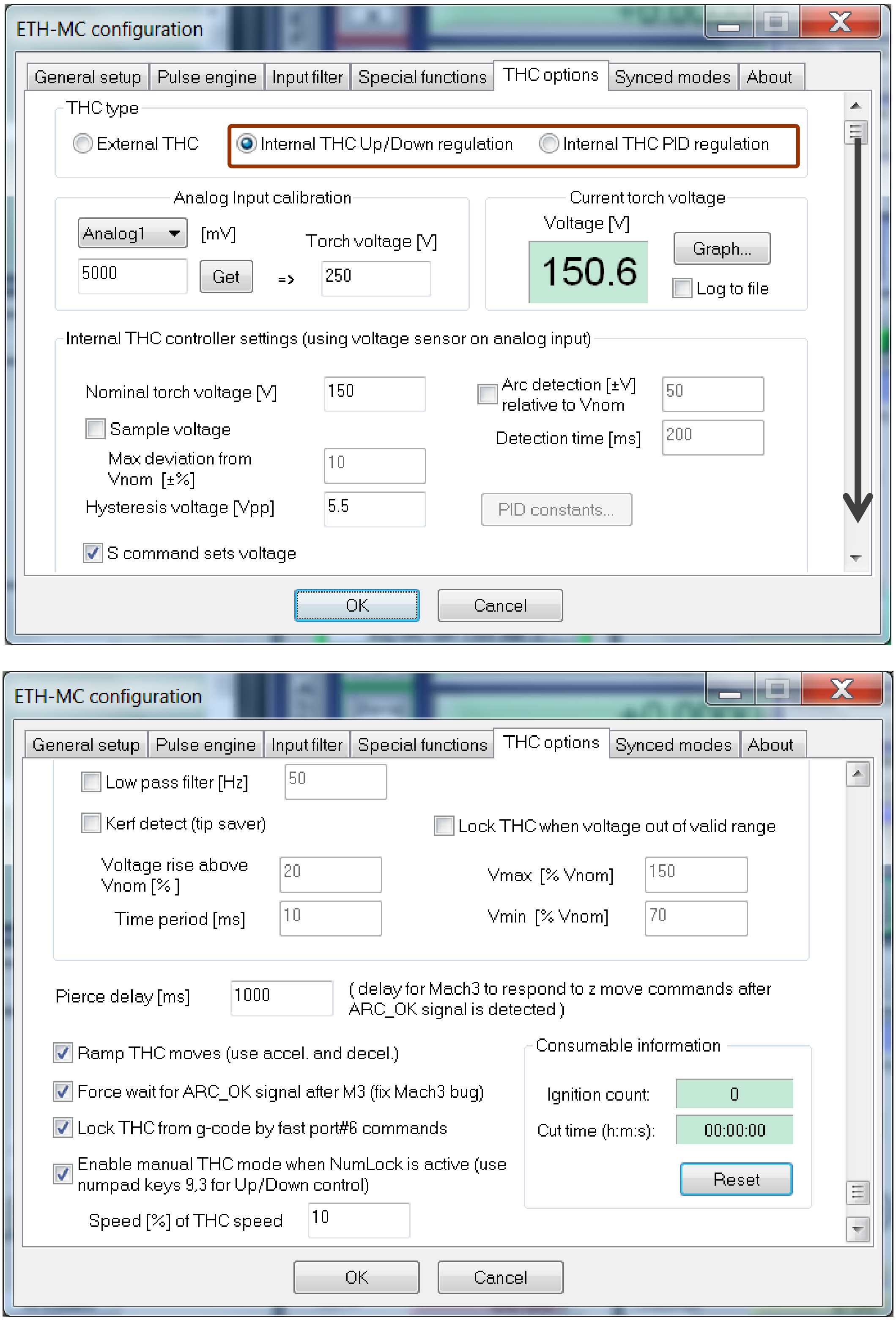


Figure 3.16 ETH-MC dialog for adjusting THC options when working with internal THC regulator

THC type – it is required to turn on the option Internal THC Up/Down regulation or Internal THC PID regulation (Figure 3.16).

3.3.4 Input calibration

Interface that is used to connect plasma system to ETH-MC motion controller has a certain voltage transfer ratio, i.e. high voltage that is present on plasma system side is downscaled to a voltage level that is appropriate for reading by ETH-MC motion controller. This transfer ratio (voltage divider) is 50:1 on Audiohms plasma interface (optionally 1:1). THC sensor appearance is shown on Figure 3.17.

Figure 3.17 THC Sensor

So, to ensure correct calculation of arc voltage from a voltage reading on the analog input, it is necessary to perform a calibration. That can be done by providing one pair of values input-output. Transfer ratio 50:1 is related to default setting: 5000mV–250V.

Some plasma inverters have integrated voltage divider feature so that they offer lower voltage output signal (usually 0-5V) that is proportional to the plasma arc voltage. In that case it is possible to utilize voltage input 1:1 that is located on THC sensor (Figure 3.17).

Field Voltage [V] (Figure 3.16) on the right side should, after the calibration, show the correct value of current arc voltage.

Analog input (Figure 3.16) combo box enables selection of analog input (1-4) to which THC Sensor output is connected.

In the field below it is needed to enter voltage value that is read from the analog input [mV]. Maximum is 5000 mV. This field can be populated manually or by pressing Get button in which case a current voltage value read from the analog input is taken.

Torch voltage [V] (Figure 3.16) plasma arc voltage that corresponds to previously specified voltage on the analog input.

Log to file – option is useful for diagnostics because it enables continual voltage logging to the file thc_voltage.log that is created in Mach3 folder. Logging is performed when THC mode is active.

Graph... – button opens a window that shows arc voltage graph in real-time (Figure 3.18). This window can float above other windows and does not prevent usage of other Mach3 controls.

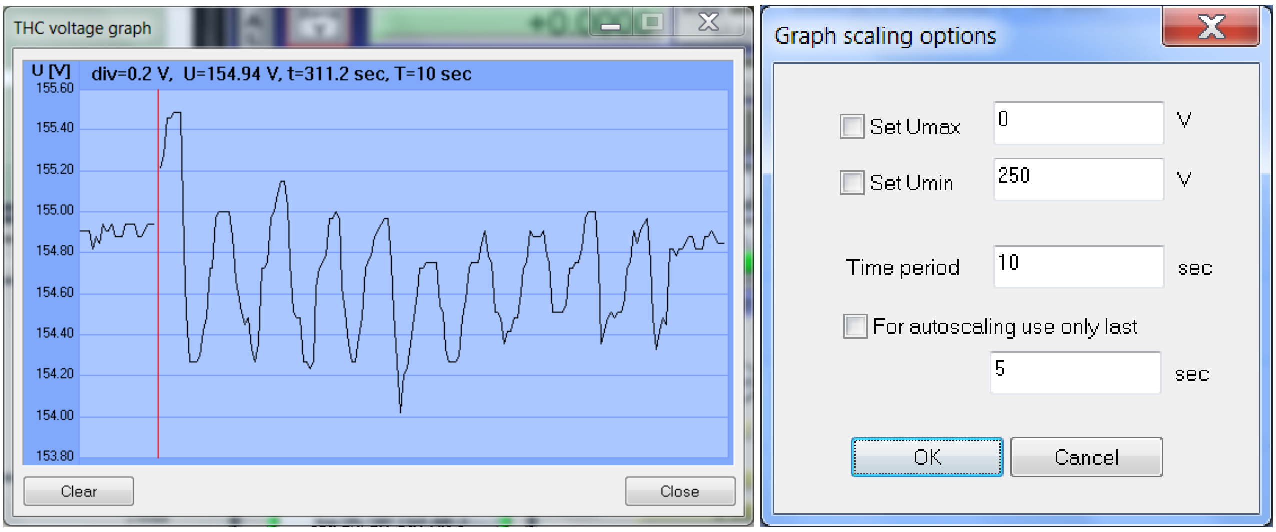


Figure 3.18 Arc voltage graph window and display options dialog

Right mouse click on the graph area opens dialog box for adjusting display options.

Available options are:

- Set Umax – If this option is turned on it enables manual adjustment of the maximum graph value. Otherwise, maximum graph value is determined automatically.
- Set Umin – If this option is turned on it enables manual adjustment of minimal graph value. Otherwise, minimum graph value is determined automatically.
- Time period – Time period that is show on graph (X axis).
- For auto scaling use only last x sec – if turned on this option enables that for autos calling only last x seconds are used.

3.3.5 Internal THC regulator options

Nominal torch voltage [V] – desired arc voltage i.e. nominal voltage value (V_{nom}). Nominal voltage can be also specified by entering a value in the field on the Mach3 main screen in the THC group (if custom THC screen is used). In addition, nominal voltage can also be specified by using S command from G-code (see option below).

Nominal torch voltage can also be adjusted manually by using potentiometer or encoder via special functions or via pendant functions. THC voltage override option also enables changing effective THC voltage temporarily. THC voltage override options are shown on custom Plasma screen (see section 3.3.6, Figure 3.21).

Sample voltage [V] – instead of manual nominal voltage specification, sometimes it is more practical to specify voltage via torch height i.e. distance from the material that should be preserved during the cut. Namely, the optimal arc voltage value can vary in relation to electrode wear and also depends on condition of processed material thus it is desirable to determine target voltage in specific conditions.

Voltage value is read while torch head is at the desired cut height just after torch is ignited and at the moment when pause pierce delay elapses.

So in more detail, after the initial search for material is performed (for instance, by using G31 probe function) and the arc ignition by M3 command, plasma torch should be positioned from G-code to the desired cut height (Figure 3.9) and cutting is started. At the moment when pierce delay pause elapses, and just before THC up-down motion is enabled, current arc voltage is sampled and that value is then used as target voltage for regulation.

In the field Max deviation from Vnom [±%] it is needed to enter maximum allowed deviation of sampled voltage from the specified nominal voltage value.

Hysteresis voltage [Vpp] – voltage hysteresis, peak-to-peak. is specified for Up/Down regulator and represents allowed voltage variation around nominal value, i.e. difference between maximum and minimum voltage value (Figure 3.16).

PID constants – in case of PID regulator it is required to adjust P, I and D regulator constants. Clicking this field opens PID settings dialog box (Figure 3.19). Proportional, integral and differential constant can be set manually (option Custom) or by selecting one of predefined presets (option Preset).

Fast (far right) slider position leads to more aggressive parameters for fast regulator reaction. Slow (far left) position implicates slower regulator response but also less chance for regulator instability and oscillation.

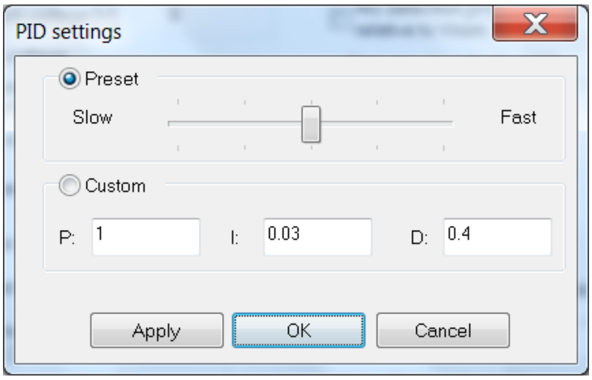


Figure 3.19 Adjusting regulator PID constants

While dialog box is shown it is possible to activate current settings by clicking Apply button and without need to close dialog with OK.

S command sets Voltage – When this option is turned on S command from G-code (which is otherwise used for setting the spindle speed) adjusts nominal arc voltage value.

Arc detection [±V] relative to V_{nom} – option for torch arc presence detection (ARC_OK) that works by monitoring the arc voltage. The first parameter that should be specified is voltage margin in positive and negative directions in relation to the nominal value (V_d Figure 3.20), and second parameter Detection time (Td), is time interval for the detection. Namely, it is required for the arc voltage to stay during this defined time period inside given voltage range to consider that arc is established and ARC_OK signal is then activated.

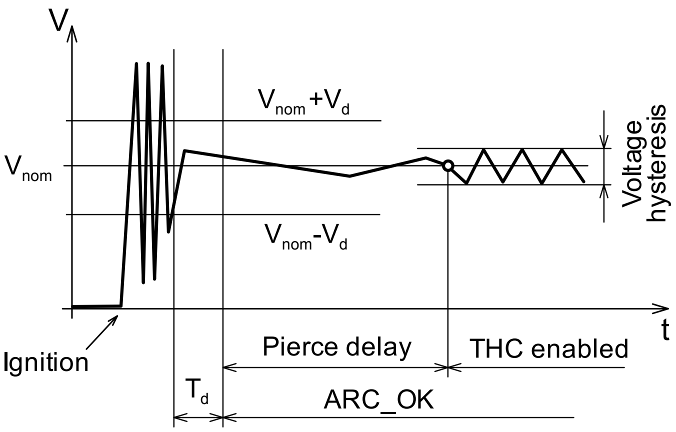


Figure 3.20 Plasma torch arc detection procedure

This option is useful if there is no possibility of bringing in an external ARC_OK signal and **in that case it is needed to turn off THC_ON signal in Ports&Pins settings** (Figure 3.10) **because ARC_OK signal is internally generated.**

On the other hand, if that possibility exists, it is required to setup digital input for **THC_ON** signal in the same way like when using external THC regulator (Figure 3.10).

NOTE: As already mentioned in external regulator section, it is possible to completely avoid usage of this ARC_OK signal and in that case it is required to open Mach3 dialog box Config/Ports and Pins/Mill Options and in THC options group to turn on the option Allow THC UP/DOWN Control even if not in THC mode. **In that way Mach3 is instructed not to wait for the ARC_OK signal when executing G-code, so after M3 command for the arc ignition, execution does not pause but instead it is continued immediately**. In other words, **if internal/external detection of ARC_OK signal is used then this option should be turned off** (Allow THC UP/DOWN Control even if not in THC mode).

Low pass filter [Hz] – Arc voltage signal that is monitored by THC controller can have a considerable noise present. Analog THC Sensor (Figure 3.17) has embedded filter for noise suppression, but further filtering may be needed.

Low pass filter is used to suppress frequencies above specified frequency. Lower this filter frequency is specified, better will be noise suppression, but at the same time reaction of the regulator to the real signal changes becomes slower.

Kerf detect (tip saver) – When torch head crosses already cut path (kerf) or any other void in material, while crossing the void arc is lengthened, sparsed and is closed via near-by material edges. That leads to arc voltage rise, so THC controller reacts by lowering the torch and in worst case torch head can crash in the material.

To prevent this problem an option is introduced to detect kerf crossing and to disable THC movements during the crossing time. THC movement is allowed again only when torch voltage drops to a normal value.

Parameters to specify:

- Voltage rise above Vnom [%] – Arc voltage rise above specified nominal value (in percent). If lower value is given (like few %) detection sensitivity is higher, but false detection can happen because of the present noise or other normal voltage variations. On the other hand, if too high value is specified, kerf may not be detected or may not be detected fast enough.

- Time period [ms] – detection time period. Voltage rise must be fast enough to happen inside this time period to be detected as kerf crossing. In other words, if lower value is specified for time period (for example 5 ms), and voltage change (rise) is slow, then in this case this will not be recognized as kerf crossing.

  It should be noted that Low pass filter if enabled (previous option described) suppresses fast voltage changes when filter frequency is set lower. In that case for kerf detection to work properly it is needed to enlarge detection time or to specify higher filter frequency.

Lock THC when voltage out of valid range – this option is used to disable THC movements if arc voltage is out of range. That can happen as mentioned when crossing kerf or other void in work material or for example when torch is moved out of the material bounds.

Parameters to specify:

- Vmax [%Vnom] – upper arc voltage limit as a percent of the nominal voltage,
- Vmin [%Vnom] – lower arc voltage limit as a percent of the nominal voltage.

Regarding the Ports & Pins dialog settings (Figure 3.10), digital inputs THC Up and THC Down signals must be turned off as these signals are generated internally. Also, if option for internal detection of plasma arc is enabled, the input signal THC On should be turned off as well.

Digital output that initiates plasma torch ignition is setup the same way like it is done when using external controller (Figure 3.11 and Figure 3.12).

Also, as already mentioned, options Pierce Delay, Ramp THC moves, Force wait for THC_ON after M3 (fix Mach3 bug) and Lock THC from g-code by fast port#6 commands also apply to the internal regulator (these options are explained in external regulator section of this setup guide).

NOTE: For proper wiring of plasma system to ETH-MC motion controller via plasma isolation interface please consult documentation for this interface.

3.3.6 Custom plasma screen set

For a more comprehensive display of options and status indicators that are used in THC mode with ETH-MC motion controller, it is possible to load a custom made screen set. This screen is a modified version of the original Mach3 Plasma.set screen.

Five new LED indicators (ArcOK, Up, Down, Lock, Manual) have been added to the main plasma control group, and they show current state of corresponding signals and modes of operation (Figure 3.21). Lock indicator is active when THC motion is disabled (during pierce delay pause, during anti-dive or by advanced options kerf detect, voltage out of valid range, or from G-code by appropriate commands).

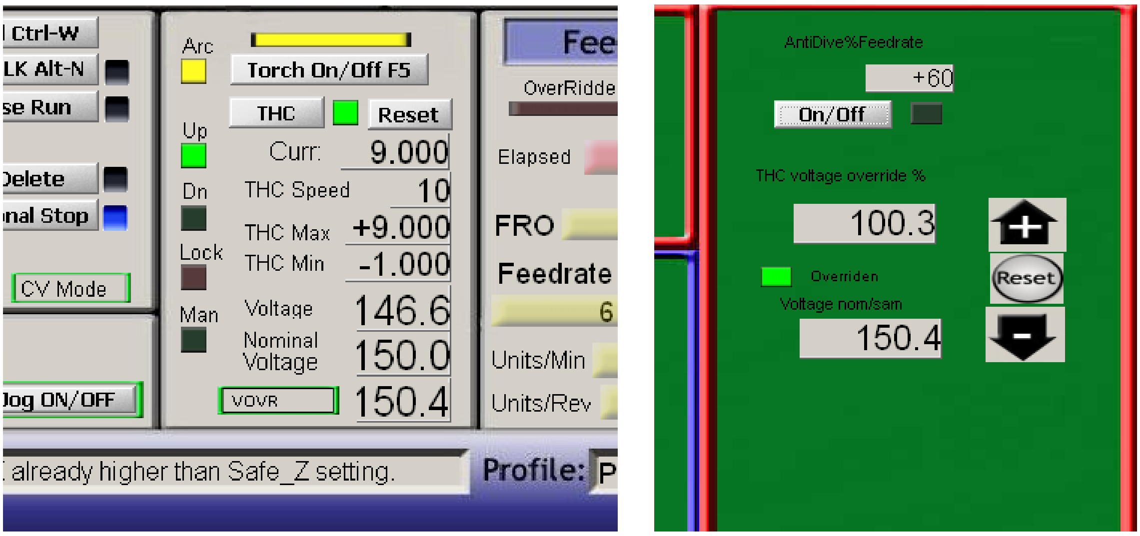


Figure 3.21 Mach3 screen set customized for THC mode when using ETH-MC motion controller
Left: Mach3 main screen, right: settings screen

Manual THC mode indicator flashes when this mode is active.

Also added are the fields that display current and nominal value of the torch voltage as well as overridden voltage value. These three fields are specific for the internal THC regulator of ETH-MC motion controller. Nominal voltage can be specified by directly editing this field (in addition to using THC dialog of ETH-MC motion controller shown on Figure 3.16).

If voltage override is active VOVR DRO field shows overridden THC voltage value (effective and final nominal voltage value that THC controller uses). Otherwise this field shows the same value as shown in nominal voltage field.

THC Voltage override percent can be set by using controls on Mach3 settings screen (Figure 3.21, right), or by means of an external potentiometer or encoder (by using special functions or pendant operation).

Sometimes it is necessary to enter a negative value in the field THC Min, and that is not possible when using the original plasma.set screen. In this modified version that also has been enabled.

Custom screen set is available for download from www.audiohms.com site on the page that describes ETH-MC motion controller.

3.3.7 Practical considerations and examples of THC cutting

Searching for material

This procedure is not specific to ETH-MC motion controller, i.e. it is the same as when working with parallel port, but it is given here for completeness of the manual.

Searching for material, i.e. adjusting initial z position before the arc ignition, can be performed in two ways:

- using probe function (G31)
- using home (G28.1) function of Mach3

If G31 method is used, it is needed to setup floating head as Probe input signal in Ports&Pins settings of Mach3, and then CAM postprocessor should generate a G-code like this:

```
G31 Z-100 F50    (probing downwards with speed 50 mm/min)
G92 Z-0.1        (set current position as Z=-0.1)
G00 Z5.0         (continue work, go to arc ignition height)
```

In case that G28.1 method is used, it is needed to setup z axis homing to be performed downwards and floating head should be setup to generate home signal for z axis (acting as a home switch).

In that case CAM postprocessor should generate G-code like this:

```
G28.1 Z0.50      (homing Z axis via point Z=0.5)
G92 Z-0.1        (set Z=-0.1)
G00 Z5.0         (continue work)
```

Example G-code for plasma cutting using THC

```
G0 X0Y50         (go to appropriate X,Y position)
G31 Z-100 F50    (probing downwards with speed 50 mm/min)
G92 Z-0.1        (adjust Z offset so that current position becomes Z=-0.1)
G0 Z5.0          (go to Z height for the arc ignition)
M3               (command for the arc ignition, Mach3 waits for ARC_OK to
                 continue execution)
G4 P0.5          (dwell time 0.5s, wait for material pierce to complete)
G0 Z2.0          (go to cut height)
F1000            (feedrate = 1000 mm/min)
G2 X100 Y50 R50  (cutting the first part of the circle; when elapses pierce_delay
                 time that is measured from the moment of ARC_OK signal
                 appearance, then THC Up/Down regulation is enabled)
G2 X0 Y50 R50    (cutting second part of the circle)
M5               (turn off the arc)
M30              (end of program)
```

In the first part of the code searching for material is performed using G31 method, then torch is moved to ignition height. After M3 command for arc ignition, appearance of ARC_OK signal is waited (it is recommended to turn on option Force wait for THC_ON after M3 (fix Mach3 bug) in THC options of ETH-MC motion controller).

When ARC_OK signal is recognized Mach3 continues execution of G-code and next command is G4 i.e. pause for 0.5s until material pierce is completed. At the same time, from the moment when ARC_OK signal is recognized, pierce delay time elapses (time delay to enable THC up/down regulation). This time period should be adjusted so that THC regulation is enabled only after pierce of material is completed and cutting of the material has been stared.

Manual control of plasma torch height by using emulated inputs

Sometimes it is useful to manually (using keyboard keys) control up/down motion of the plasma torch. Besides the manual THC mode offered by ETH-MC controller, this is also possible to realize by using emulated inputs.

Mach3 offers a possibility for input signals (including also THC Up and THC Down) to be emulated by keyboard. These signals should be selected as Emulated and assigned a keys (HotKey) for manual control (Figure 3.10).

For this simulated control to work, THC function requires that:

- in ETH-MC configuration (Figure 3.13) for THC type it is selected External THC mode because otherwise (if internal THC regulator is active) signals Up/Down are generated internally,

- THC mode is turned on (using THC button on the main screen),
- arc ignition is initiated either manually clicking the button Torch On/Off F5 or by M3 command from G-code,
- ARC_OK (THC_ON) input signal is detected. After this signal is activated, defined time period (pierce delay) is waited and then Up/Down motion is enabled.

  Alternatively, if this signal is not used, it is necessary to turn on option Menu/Config/PortsAndPins/MillOptions/Allow THC UP/DOWN Control even... In that case, right after the arc ignition is initiated, it is considered that arc is present and no further waiting for the arc is performed.
- To enable THC Up/Down motion even in still state it is required to turn off the option THC Min Speed on the main Mach3 screen in the lower right corner (Figure 3.8). This option (so called anti-dive) is used to disable THC regulation when feedrate in *X-Y* plane drops below certain specified speed (set as a percent of maximum speed).

3.3.8 THC control – frequently asked questions

- ***THC regulation works, but constant up-down motion in regular rhythm is present, why is this happening?***

  This is regulator oscillation that can happen if too high speed of THC motion is specified (THC Speed) or (when using internal regulator) too small voltage hysteresis (difference between maximum and minimum voltage) is specified. Especially when option for ramped THC motion is turned on it is required to carefully adjust these parameters. Namely, acceleration and deceleration require some time so it is not possible to start and stop instantly therefore it is possible to jump over hysteresis zone from one side to the other and wise versa.

  More aggressive or inadequate settings of PID regulator can also lead to oscillation.
- ***ARC_OK signal is activated right after M3 command for the arc ignition is executed, instead of waiting for the real recognition of this input signal..***

  Option Menu/Config/PortsAndPins/MillOptions/Allow THC UP/DOWN Control even not in THC mode... is turned on. This option, as the matter of fact, is indeed used to avoid usage of ARC_OK signal.
- ***THC regulator does not react on occurrence of some of the input signals (Up, Down, THC On/ARC_OK).***

  It should be verified that inputs in Ports&Pins settings are properly setup, also that option Emulated is not selected for one of the signals.
- ***Mach3 during the G-code execution after the arc ignition by M3 command, does not correctly wait specified G04 dwell pause time.***

  It is needed to turn on the option Force wait for THC_ON after M3 (fix Mach3 bug) on ETH-MC THC configuration dialog.
  Also check if time is given in seconds or milliseconds, i.e. according to the setting in Mach3 (Menu/GeneralConfig/G04 Dwell in ms).
- ***Z axis motion range is limited and is insufficient for proper THC regulation.***

  It is needed to correctly setup fields THC Min and THC Max on Mach3 main screen. Also check if specified SoftLimts for Z axis are limiting the movement range. Furthermore, it is possible that Z axis is not properly calibrated, so check in Menu/Config/MotorTuning dialog whether field steps per unit is set to a correct value.

3.4 Rigid Tapping

ETH-MC(-BOX) motion controller supports real-time synchronization of an axis motion in relation to the master axis that can freely rotate, change speed and even direction of rotation. This feature enables realization of rigid tapping function in which the straight line motion, most often in Z axis, must be precisely synchronized to the spindle axis rotation.

The name "Rigid Tapping" originates from the fact that for tool holder it is not used floating tapholder. Floating tapholder offers elastic pretension and enables significant tension-compression float in Z axis under the influence of resistance forces and in order to compensate position.

With rigid tapping, tapping tool is rigidly mounted in tool holder so a precise synchronization of Z axis movement with Spindle rotation is needed to achieve a quality result of the operation.

Mach3 originally does not offer Rigid Tapping operation i.e. it does not support appropriate G-code (usually G84). However, this is achieved with ETH-MC(-BOX) motion controller by using user macro (M841). Below is given an example G-code (listing 1) as well as contents of M841.m1s macro for Rigid Tapping (listing 2).

In G-code (listing 1) first is performed positioning to the location for tapping. Then, parameters for the operation are specified by assigning values to variables from #1500 to #1503. After that, macro M841 is called and this macro performs the rigid tapping operation. When the operation finishes G-code continues execution.

It should be noted that tapping depth is negative which indicates motion downward and as well that separate spindle rotation speeds are given for tool motion downwards and for retraction back up.

Example G code for Rigid Tapping operation:

```
;optional: use g17,g18 or g19 to select work plane
G0x10y10z10      ;goto start position
#1500 = -20      ;z depth [units]
#1501 = 1        ;thread pitch [units/rev], <0 for CCW thread
#1502 = 1000     ;spindle rpm forward
#1503 = 2000     ;spindle rpm reverse
M841             ;call rigid tapping macro
G1f1000x0y0
```

Listing 1

M841.m1s (this macro file should be created in the folder Mach3\macros\xml_profile_name):

```
'Rigid tapping macro for ETH-MC controller
'parameters are taken from user variables
'#1500 = z depth (negative for downward tap)
'#1501 = thread pitch [units/rev], negative for ccw tap
'#1502 = forward spindle rpm
'#1503 = reverse spindle rpm

SetVar(1510, 0)         'reset return value

NotifyPlugins(18000)    'Exec canned cycle

While(GetVar(1510) = 0)       'Wait for rigid tapping sequence to finish
     Sleep(50)
Wend
```

Listing 2

For Rigid Tapping operation to be possible it is necessary that Spindle axis has mounted incremental encoder which will give feedback information about current Spindle position. Figure 3.22 shows dialog that is used for setting up the options for Rigid Tapping operation.

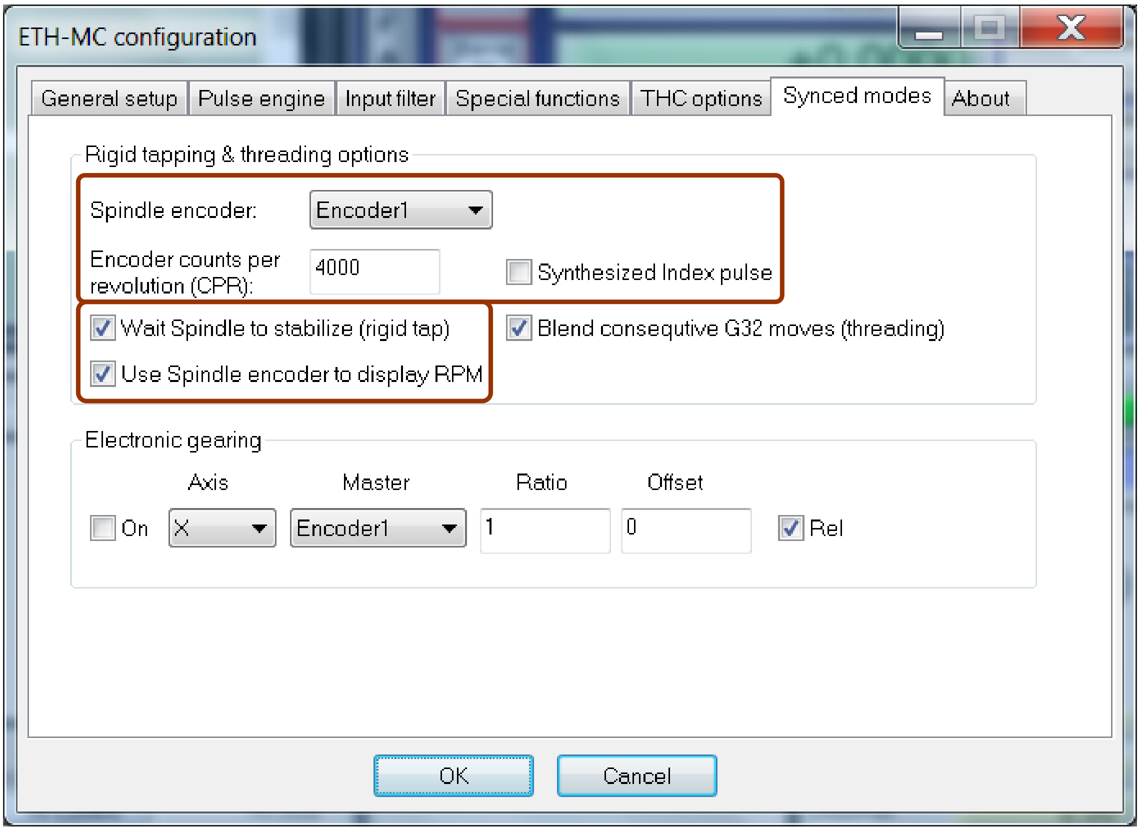


Figure 3.22 Dialog box for setting up the options related to Rigid Tapping operation

Spindle encoder – enables selecting the encoder (1-4) that is used for this operation. Input pins can be set using Mach3 dialog Ports&Pins\Encoders/Mpg's.

Encoder counts per revolution (CPR) – in this field it should be entered the number of counts per revolution for the encoder that is used. It is recommended to use an encoder with a higher resolution but lower values like 400 CPR (counts per revolution) should also give good results. CPR number is 4 times larger than number of pulses per revolution (PPR) of the individual A and B lines. ETH-MC(-BOX) motion controller performs position interpolation between encoder steps by using position prediction based on current rotation speed thus a smoother motion trajectory is achieved even if encoder with lower resolution is used. However, in that case a certain position prediction error is possible if sudden changes of Spindle rotation speed occur.

Synthesized Index pulse – besides A and B phase shifted signal outputs, encoders usually also offer Index output on which one pulse per revolution is generated. This pulse is always generated on the same revolution position so it can be used for synchronization purposes.

If Index signal is not offered by the encoder or it is not connected to the ETH-MC motion controller then this option can be used to emulate Index signal. Otherwise, if Index signal from encoder is connected and set up in Mach3 Ports&Pins\InputSignals then this option can be turned off.

Wait Spindle to stabilize – If this option is enabled, when starting Rigid Tapping operation controller first waits for Spindle rotation speed to stabilize (monitored via encoder) and only then continues with further operation. This is recommended mode of operation.

Use Spindle encoder to display RPM – this option is not exclusive for Rigid Tapping. It makes possible to use Spindle encoder (if it is present) for monitoring and displaying real current Spindle rotation speed on the Mach3 main screen. Otherwise for this purpose is used Index input that provides one pulse per revolution.

Figure 3.23 shows Rigid Tapping sequence in more detail. First, by using command from G-code the tool is positioned to the location for tapping, i.e. above drilled hole (Figure 3.23 – position 2). Then macro **M841** is called that takes over the control and performs Rigid Tapping operation.

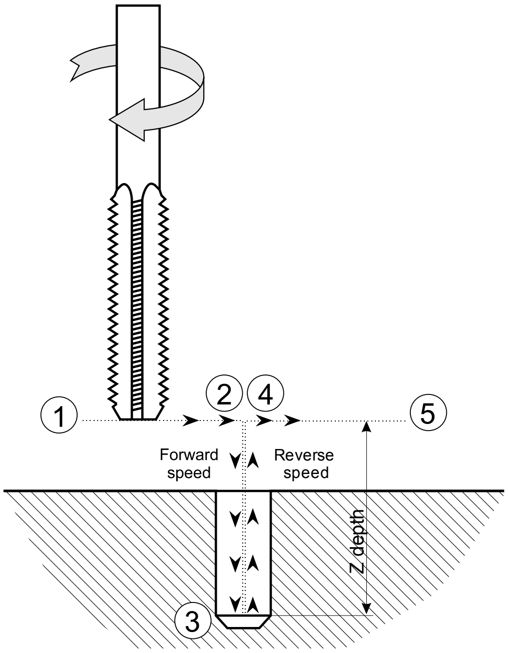


Figure 3.23 Rigid Tapping sequence

Spindle rotation (tapping tool) is started and then waiting for Spindle speed to stabilize is performed (if the appropriate option is turned on). Then, when Index signal appears Z axis motion downward begins, simultaneously entering synchronization with Spindle axis rotation. Because Z axis acceleration is limited (required speed is not achieved instantly) entering synchronization requires some short time period.

After that Z axis (tapping tool) moves downward in synchronism with Spindle axis until specified Z depth is reached. Then Spindle stop is commanded and since stopping is not instant but gradual, Z axis which is still in sync, continues to move downward little longer until Spindle rotation is stopped. Therefore it is needed to ensure that hole depth is big enough (or specified Z depth small enough) to avoid crashing the tool to the bottom of the hole.

When controller detects that Spindle axis is stopped (Figure 3.23 – position 3) it commands Spindle rotation in reverse direction. Z axis is still synchronized and now it performs motion upwards to the position 4 (Figure 3.23) i.e. tool is returned to the starting position.

That concludes Rigid Tapping operation and Z axis synchronization to Spindle axis is dropped. G-code execution is continued.

3.5 Lathe threading operation – Mach3Turn

For lathe threading operation (functions G32, G76) ETH-MC(-BOX) motion controller has greatly improved algorithm in comparison with the standard function offered by Mach3 control software. ETH-MC(-BOX) motion controller uses its own autonomously generated linear motion that is synchronized with Spindle rotation and for Spindle position feedback an incremental encoder is used.

Algorithm implemented in ETH-MC(-BOX) motion controller eliminates delay before tool retraction after every cutting pass which is otherwise characteristic for Mach3. Also, since incremental encoder is used for feedback, much more precise motion synchronization is achieved in comparison with using just one (Index) pulse per revolution which is characteristic for Mach3.

In addition, it is enabled seamless joining of multiple successive G32 moves which makes possible for thread to be laid over joined conical surfaces with different slope angles.

Important guidelines for threading:

- Licensed version of Mach3 software is required,
- Threading should be done in G95 (unit/rev) feedrate mode,
- Adjusted options for lathe threading (Figure 3.24),
- Index input should be configured (or use synthesized Index signal, as shown below),
- Index prescaller (index pulses per revolution) should be set in ETH-MC(-BOX) configuration dialog if Index input is used,
- in Mach3 Spindle setup (Ports&Pins/Spindle setup) turn on options:
    - Use Spindle feedback in Sync Modes and
    - Spindle speed averaging.

3.5.1 Threading sequence

Thread cutting is performed in multiple passes of the tool by using commands G32 or G76. On the start of every pass, Mach3 will, by monitoring Index signal frequency (or by feedback information from incremental encoder), recognize current Spindle revolution speed and plan feedrate so that specified tool speed [units/rev] is achieved during the pass that follows.

Controller then waits the Index pulse as synchronization signal to start cutting pass. In that moment motion specified by command G32/G76 gets fully synchronized i.e. slaved to the Spindle revolution. If during this thread cutting pass Spindle revolution speed drops, e.g. because of load increase, then linear movement speed of the tool will also slowdown so that the tool remains on the correct helicoids path. And vice versa, when Spindle revolution speed is increased it will be compensated by faster tool motion along the specified path.

3.5.2 ETH-MC(-BOX) motion controller threading options

Figure 3.24 shows the options of ETH-MC(-BOX) motion controller that are related to threading.

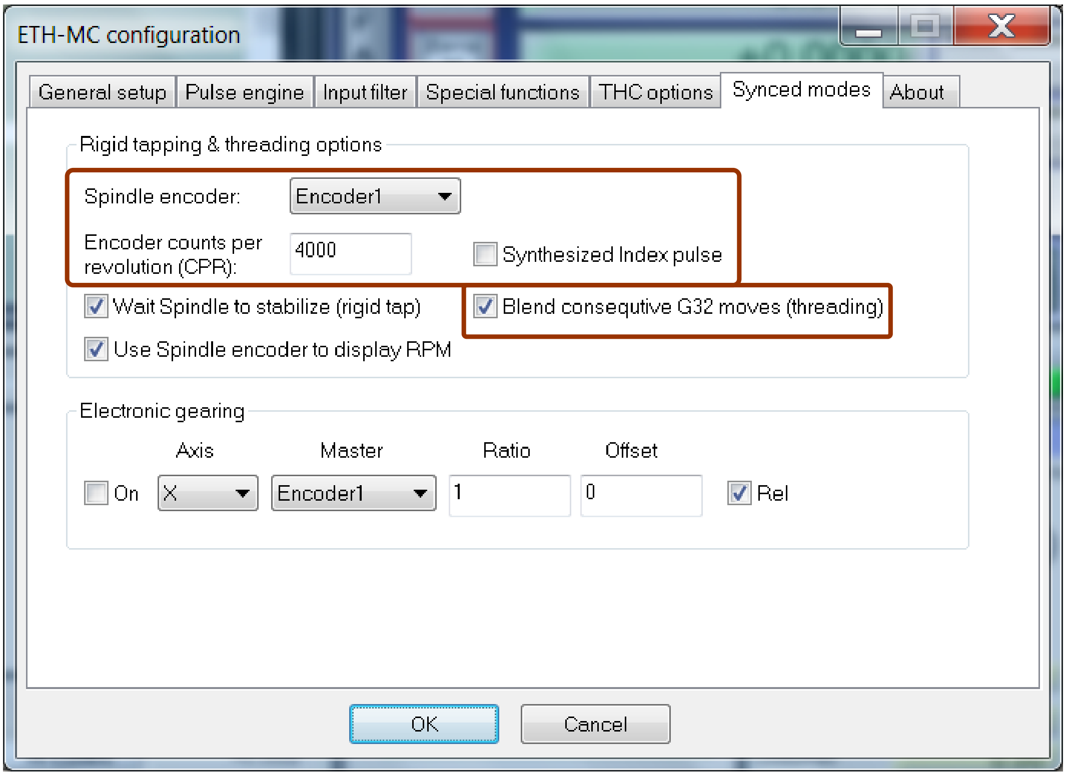


Figure 3.24 Lathe threading options

Spindle encoder – enables selecting encoder (1-4) that is used for this operation. Input pins for the incremental encoder can be set using Mach3 dialog Ports&Pins/Encoders/Mpg's.

Encoder counts per revolution (CPR) – in this field it should be entered the number of counts per revolution for the encoder that is used. It is recommended to use an encoder with a higher resolution but lower values like 400 CPR (counts per revolution) should also give good results. CPR number is 4 times larger than number of pulses per revolution (PPR) of the individual A and B lines. ETH-MC(-BOX) motion controller performs position interpolation between encoder steps by using position prediction based on current rotation speed thus a smoother motion trajectory is achieved even if encoder with lower resolution is used. However, in that case a certain position prediction error is possible if sudden changes of Spindle rotation speed occur.

Synthesized Index pulse – besides A and B phase shifted signal outputs, encoders usually also offer Index output on which one pulse per revolution is generated. This pulse is always generated on the same revolution position so it can be used for synchronization purposes.

If Index signal is not offered by the encoder or it is not connected to the ETH-MC(-BOX) motion controller then this option can be used to emulate Index signal. Otherwise, if Index signal from encoder is connected and set up in Mach3 Ports&Pins\InputSignals then this option can be turned off.

Blend consecutive G32 moves – Mach3 normally does not enable joining multiple G32 moves to one continual thread, but instead on the start of every G32 move tool stops and there is a procedure for re-synchronization to Index signal for new threading cut. If mentioned behavior is not wanted, then it is required for this option to be turned on. In that case synchronization with Index signal is done only at the beginning of the first G32 move. Synchronization to Spindle revolution is maintained until the last G32 move in series is finished.

Use Spindle encoder to display RPM – this option is not exclusive for threading. It makes possible to use Spindle encoder (if it is present) for monitoring and displaying real current Spindle rotation speed on the Mach3 main screen. Otherwise for this purpose is used Index input that provides one pulse per revolution.

NOTE: Lathe threading is complex operation that requires certain level of knowledge and experience. As a guide, the good manual from this link can be used:
http://www.machsupport.com/wp-content/uploads/2013/02/Mach3_Threading.pdf

DOCUMENT REVISION:

- Ver. 1.0, March 2019, Initial preliminary version
- Ver. 1.1, June 2019, Updated part for ETH-MC motion controller
- Ver. 1.11, September 2019, Added Chapter 3 Setting up advanced options
- Ver. 1.2, November 2019, Added Chapter 3.2 Joystick jog control
- Ver. 1.21, November 2020, Minor revision
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