SMCU4

Four axis stepper motor control unit

User's manual

AUDIOMS AUTOMATIKA

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CONTENT

1 Description

Microstep bipolar stepper motor control unit SMCU4 is used to control small and medium sized CNC machines (for wood and light metal alloys machining, engraving, coordinate drilling, gas cutting, water jet cutting, etc.).

SMCU4 is control unit for control of up to 4 stepper motors. Control unit contains of main breakout board which have slots for inserting of up to 4 microstep drivers MST-109 which are designed to be used for maximum current of 9A. Optionally microstep stepper motor drives MST-107 could be used.

The front panel contains 4 five-pin GX-16 connectors for connecting stepper motors. On the main breakout board there are connectors for connecting 5 digital inputs (usually limit switches, tool height measurement systems, etc.) as well as a connector for analog output for controlling the revolution speed of the Spindle motor.

A single DC voltage source in the range of 20-48VDC is used to power the SMCU4 control unit. Two isolation DC-DC converters are used to power the control electronics on the main breakout board, as well as for the isolation power supply of the digital inputs.

To control the SMCU4 control unit, an IDC26 connector is used with a pinout that is compatible with the LPT (parallel) port on the PC as well as with an Audioms Automatika doo motion controllers or with large number of motion controllers available on the market.

Control of a stepper motor is carried out over three lines, STEP, DIR and ENA (enable). This means that for a multi-axial control can be used already developed popular software such as: mikroCNC, Mach3, Mach4, LinuxCNC (free), and similar.

2 Specifications

Type	Control unit with microstep drives for bipolar stepper motor
Number of axis	1–4
Stepper motors current	9 A max (set up by using of one external resistor per axis)
Connection with PC	Via parallel (LPT) port or via motion controllers
Inputs	5 digital opto-insulated inputs for limit switch connection
Outputs	- 2 relay outputs 120-220VAC / 8A max - analog output 0–5 V or 0–10V selectable
Power supply	20 – 48VDC / 200-400W depending on used stepper motors
Dimensions (wide x high x deep)	315mm x 97mm x 125mm
NET weight	1.6 kg

NOTE: specifications are subject to change without notice

3 Layout of the SMCU4 control unit

Figure 3.1 and Figure 3.2 give an outside view of the SMCU4 control unit and a side view of the main printed circuit board.

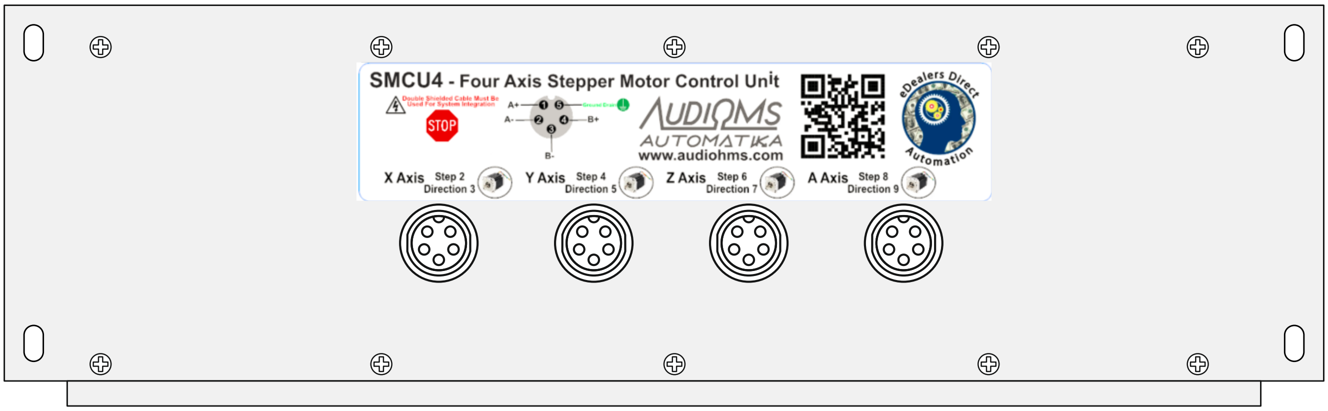


Figure 3.1 SMCU4 control unit – Frond panel view

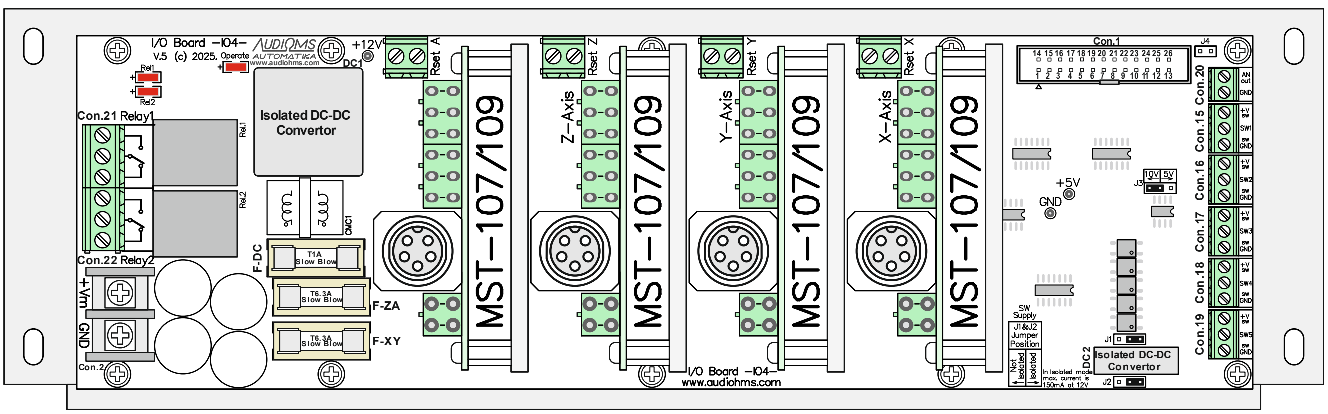
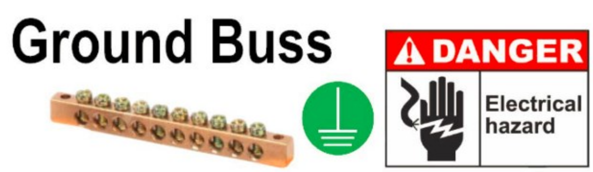


Figure 3.2 SMCU4 control unit – Main circuit board view

NOTE: The drive's ground bus is to be used to allocate all double-shielded cable accessory shield drains for proper EMI dissipation.



4 Connecting the SMCU4 control unit

The following is a detailed description of the connection of the SMCU4 control unit.

4.1 Connecting the control connector

The SMCU4 control unit is controlled via the 26 pin IDC connector marked Con.1. Pinout on this connector matches the pinout on a standard LPT port and also matches the pinout on commercially available motion controllers.

Figure 4.1 and Table 4.1 provide a layout and description of pin functions on the Con.1 connector.

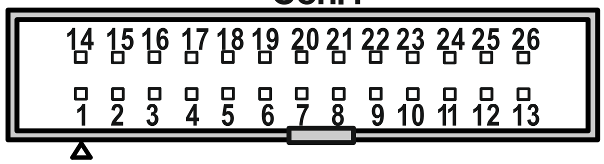


Figure 4.1 Pinout on the IDC-26 connector

Table 4.1 Description of IDC-26 connector pin functions

IDC-26 Connector Pin No.	BD25 LPT Pin Number	SMCU4 Function	IDC-26 Connector Pin No.	BD25 LPT Pin Number	SMCU4 Function
1	Out 1	Relay 1	14	Out 14	Relay 2
2	Out 2	Step X	15	Input 15	SW 5
3	Out 3	Dir X	16	Out 16	PWM Analog Output
4	Out 4	Step Y	17	Out 17	Enable
5	Out 5	Dir Y	18	GND	GND
6	Out 6	Step Z	19	GND	GND
7	Out 7	Dir Z	20	GND	GND
8	Out 8	Step A	21	GND	GND
9	Out 9	Dir A	22	GND	GND
10	Input 10	SW 1	23	GND	GND
11	Input 11	SW 2	24	GND	GND
12	Input 12	SW 3	25	GND	GND
13	Input 13	SW 4	26	-	NC

4.2 Connecting the power supply to the SMCU4 control unit

A single direct current 20-48 VDC power source is used to power the control unit. The power supply is from 200 VA to 400 VA depending on the number of axes used and the size of the stepper motors connected to the control unit. The power connection is via the Con.2 connector, as shown in Figure 4.2. Figure 4.2 also shows the location of the fuses and their rating.

There are two isolation DC-DC converters on the main printed circuit board of the SMCU4 control unit. One DC-DC converter is used as an isolation power supply for the logic circuit on the SMCU4 control unit, and the other provides an isolation power supply for the digital inputs.

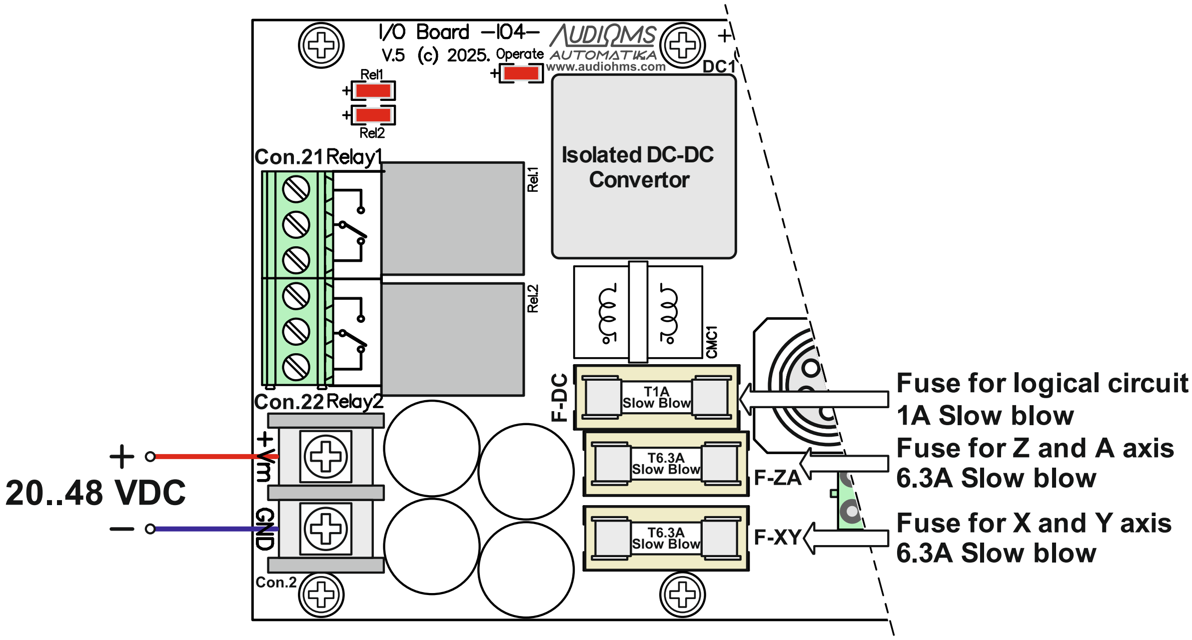


Figure 4.2 Power connection to control unit and fuse position

4.3 Connection of limit switches

The control unit SMCU4 has 5 digital inputs to which limit switches can be connected.

Figure 4.3 shows a possible way of connecting inductive switches with NPN type outputs to the SMCU4 control unit. On the main printed circuit board there is a 2W isolation DC-DC converter that provides an isolation power supply for the digital inputs. This ensures galvanic isolation of the ground of the limit switches from the ground of the digital part of the circuit of the main printed circuit board. The isolation supply voltage of limit switches is 12 VDC (without load this voltage is slightly less than 15 VDC).

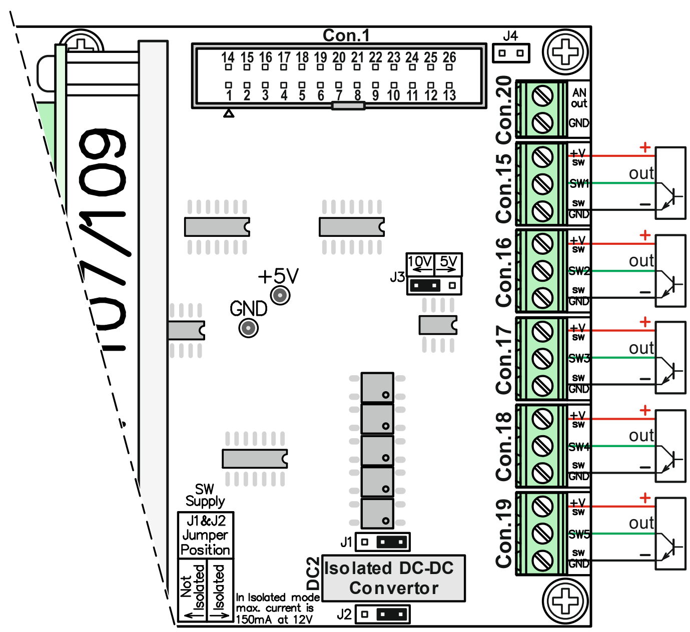


Figure 4.3 Connecting induction limit switches to the SMCU4 control unit

The recommended way of connecting the limit switches of the electro-mechanical type is given in Figure 4.4. The given example implies the use of switches of the Normally Closed (NC) type. In this way, it is possible to connect several limit switches to one digital input line. Using the NC type of switch is also better from the safety aspect, considering that a possible disconnection and loss of connection of one of the switches will be detected as a change of logical state on that digital input.

NOTE: Figure 4.4 shows an option where one switch is assigned two functions, i.e. both the referencing switch function (X home) and the limit switch function (X +).

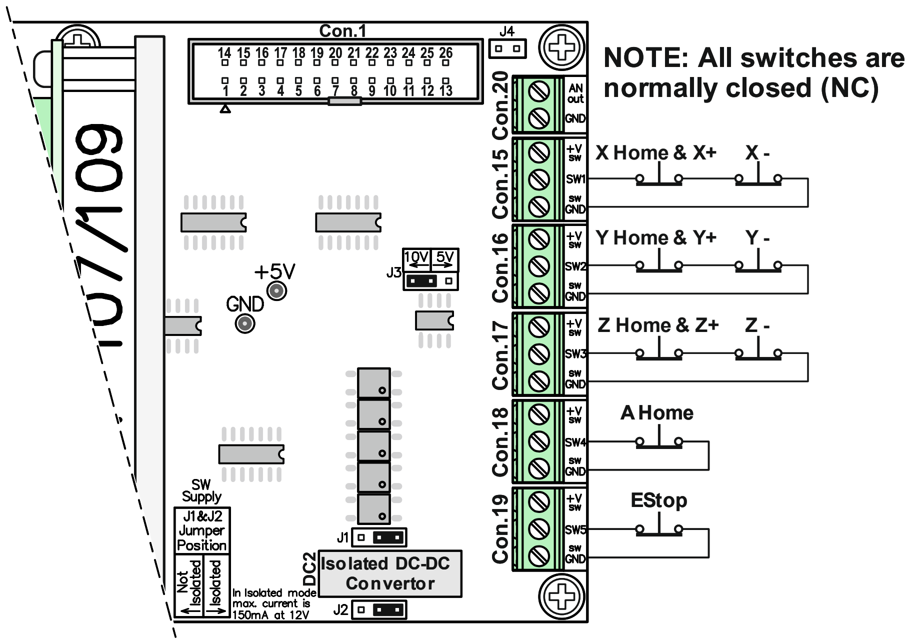


Figure 4.4 Connecting electro-mechanical limit switches to the SMCU4 control unit

Wiring for the Emergency Stop switch is shown in Figure 4.5.

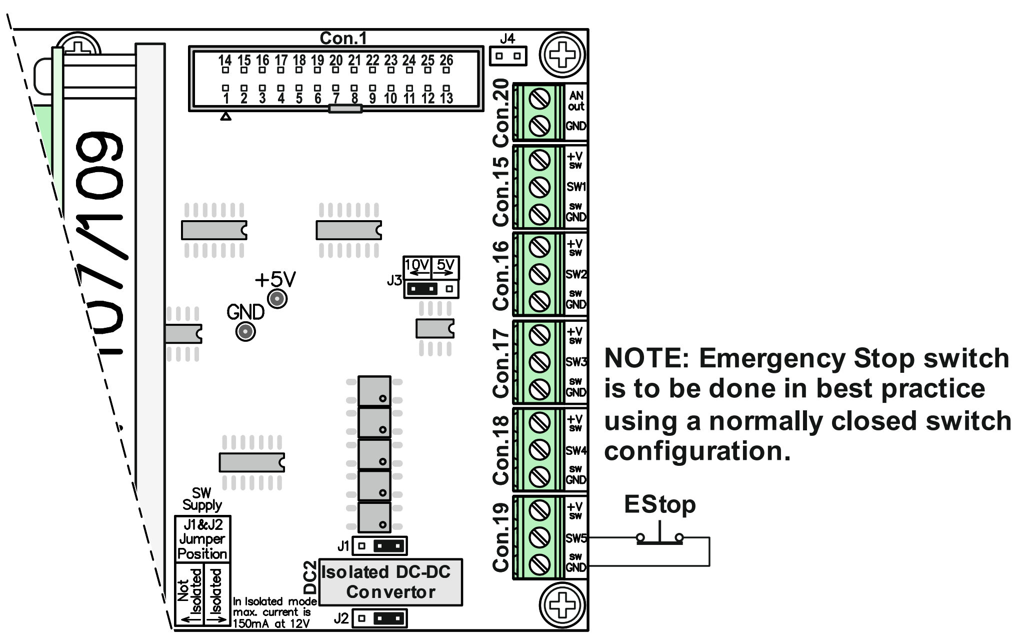


Figure 4.5 Wiring of the Emergency Stop switch

4.4 Auto Tool Height Function

Auto Tool Height measurement is one of the useful options in modern CNC control systems. The mentioned function is implemented using the G31 function (Probe function). Tool Height measurement can be done in several ways. In the following text, the two most commonly used measurement methods will be described.

The first way is Tool Height measurement using a special accessory tool that is inserted between the cutting tool and the workpiece (Figure 4.6). When the cutting tool touches the upper surface of the accessory tool, a switch is activated as a signal to the control system that contact has occurred. In this case, the switch leads are not in electrical contact with the metal parts of the measurement equipment, so that the generated signal is isolated from the metal parts of the machine. **The described method is also the recommended method of measurement**.

The second way to measure the length of the tool along the *Z* axis is by using a metal plate of known thickness (accessory tool) (Figure 4.7). There is an electrical insulating material on the underside of the accessory tool to electrically isolate the accessory tool from the machine. In this case, the switch consists of the aforementioned accessory tool and the cutting tool itself, which is placed in the chuck of the machine. In this way, the metal parts of the machine are in direct electrical connection with the control electronics. **NOTE: With this method of Tool Height measurement, it is very important to take care of wiring the system in order to avoid problems and damage to the control system**.

Figure 4.6

Figure 4.7

The digital inputs on a SMCU4 control unit have a negative supply line as common, so Figure 4.8 gives the recommended way of wiring the Tool Height measurement system. In the given example, Tool Height Measurement function is done via digital input SW4.

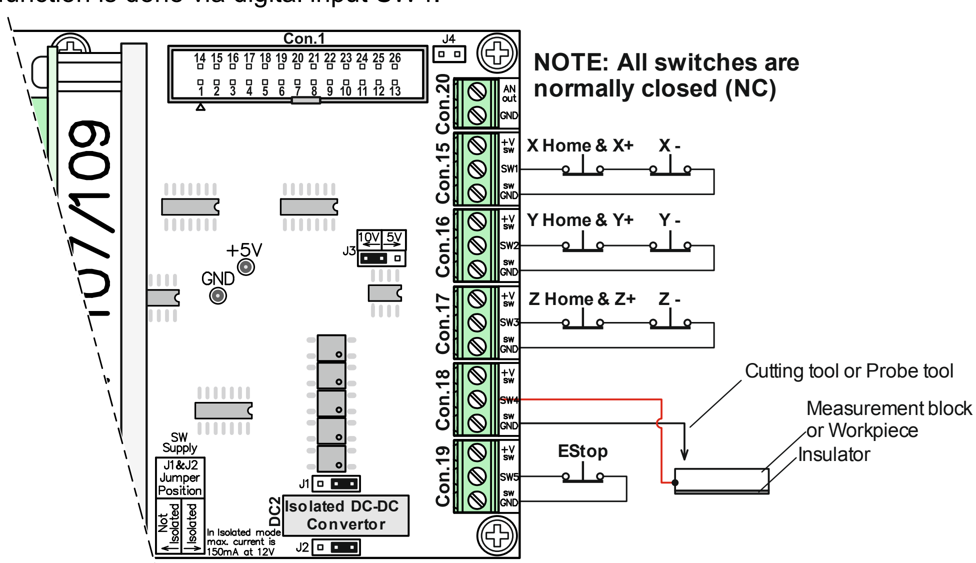


Figure 4.8

4.5 1 VFD Connection

A variable frequency drive (VFD) is usually used to control the speed of the Spindle motor on a CNC machine. On the SCM control unit, there is an analog output with which it is possible to control the VFD, i.e. the number of revolutions of the Spindle motor. A typical VFD wiring diagram is given in Figure 4.9.

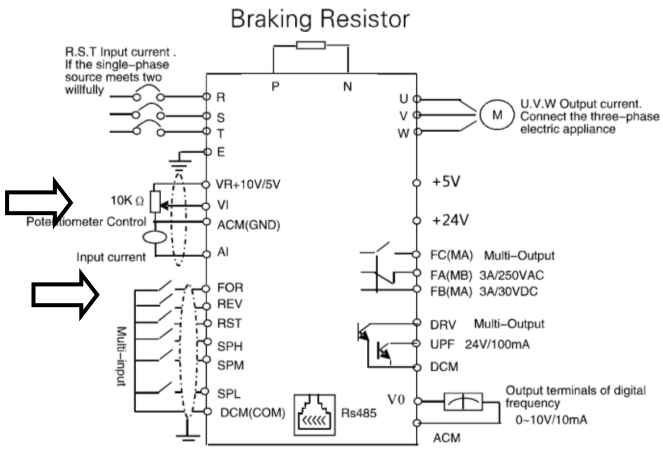


Figure 4.9 A typical VFD wiring diagram

The VFD needs to be configured so that the RPM is changed via an analog input (marked as VI on the VDF) and multi input 1 (marked FOR – Forward run and REV – Reverse run) is used to start the engine (see Figure 1.2).

Figure 4.10 shows the recommended method of connecting the VFD to the SMCU4 control unit in Forward Run mode.

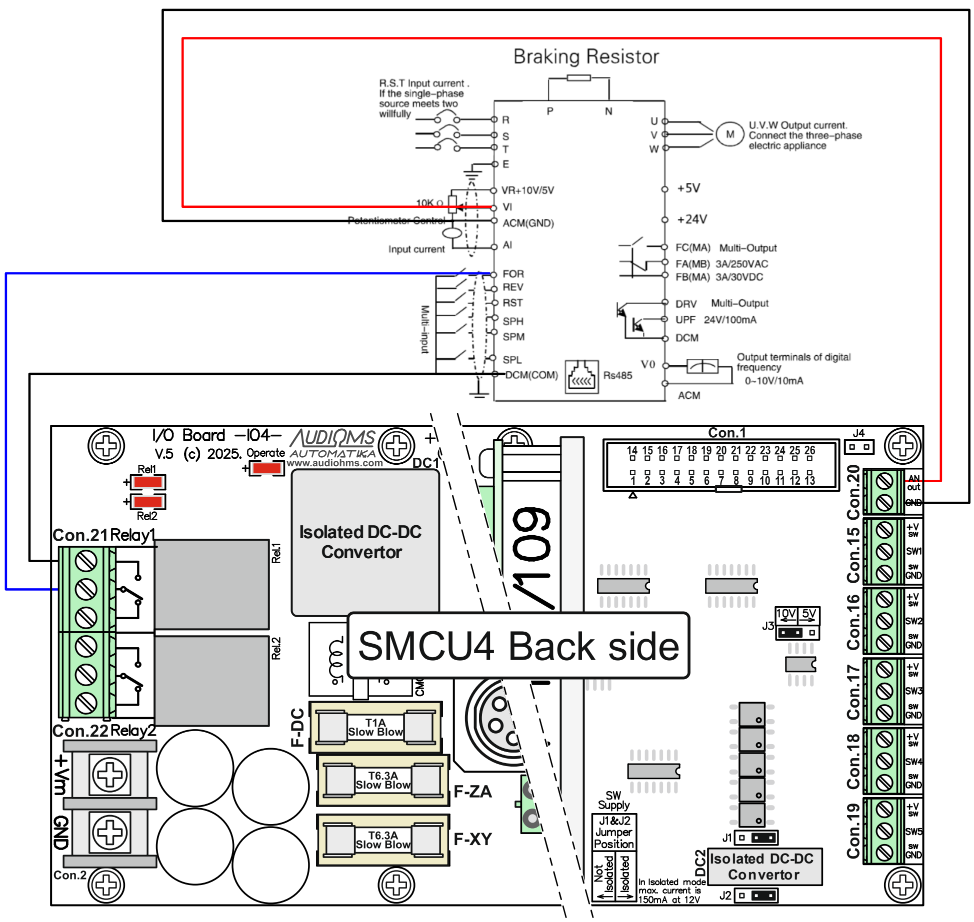


Figure 4.10 Recommended wiring diagram for controlling the VFD using the SMCU4 control unit – Forward run mode

The analog output from the SMCU4 control unit is used to control the number of revolutions of the Spindle motor, while Relay 1 is used for the Start/Stop command (Figure 4.10).

The voltage range on the analog output can be set in the range 0-5V or 0-10V. The voltage range is selected using jumper J3 (shown in Figure 4.10).

Figure 4.11 shows the recommended method of connecting the VFD to the SMCU4 control unit in Forward/Reverse Run mode.

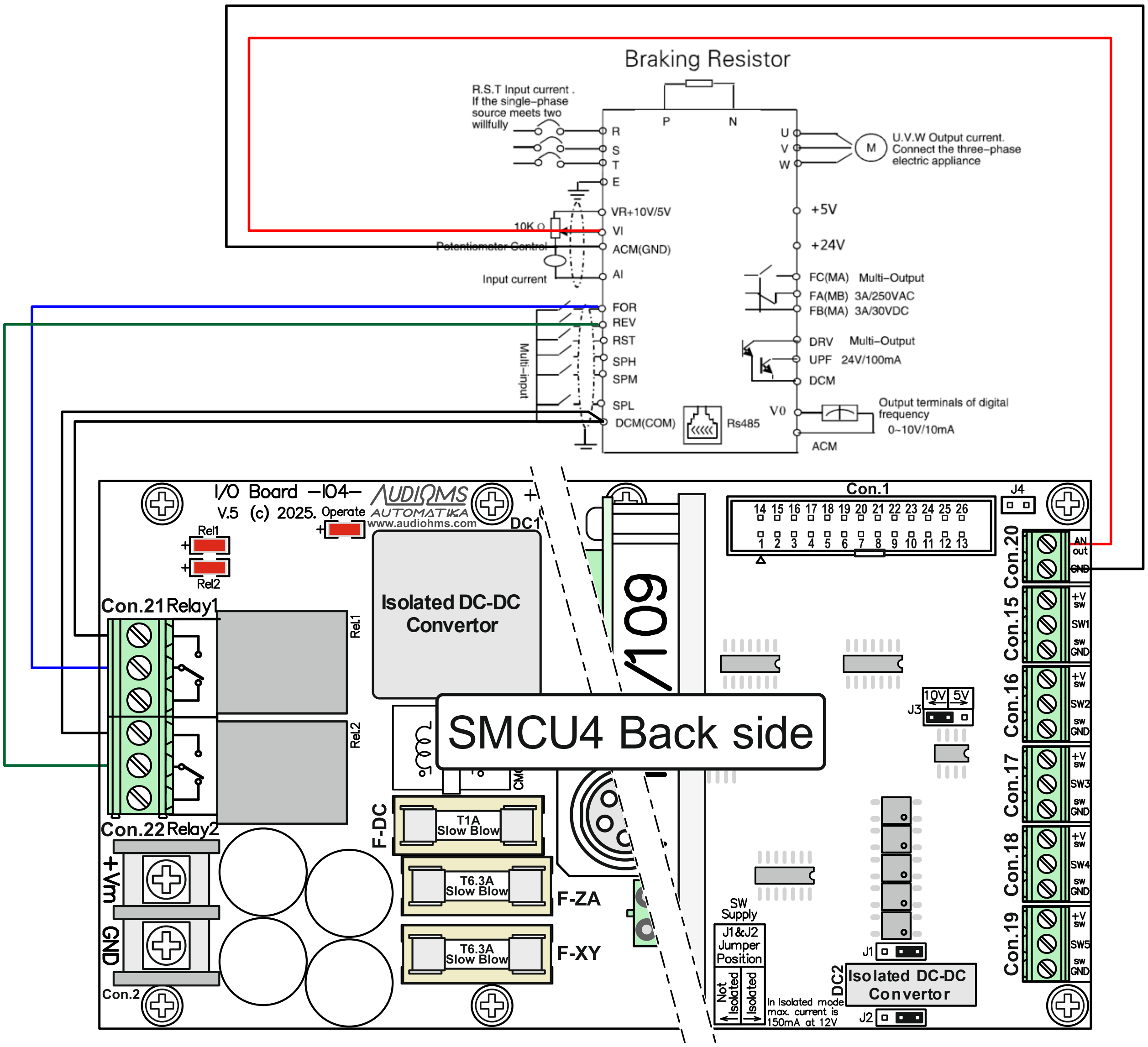


Figure 4.11 Recommended wiring diagram for controlling the VFD using the SMCU4 control unit – Forward/Reverse mode

4.6 Connection of stepper motors

On the front of the SMCU4 control unit there are 4 five-pin GX-16 connectors through which stepper motors are connected (Figure 3.1). The method of connecting stepper motors is given in Figure 4.12.

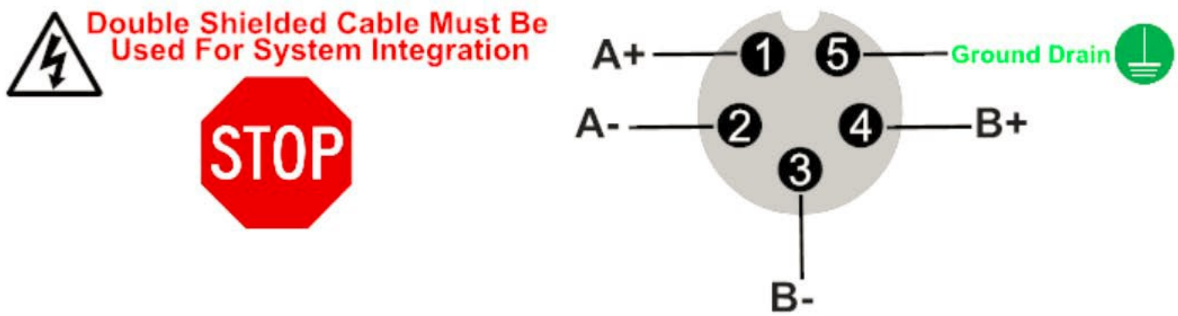


Figure 4.12 Connection of stepper motors

Setting the current through the stepper motor is done using an external resistor. The location of the current setting resistors for all 4 stepper motor drivers is given in Figure 4.13. The required resistor values for the desired set current values are given in Table 4.4.

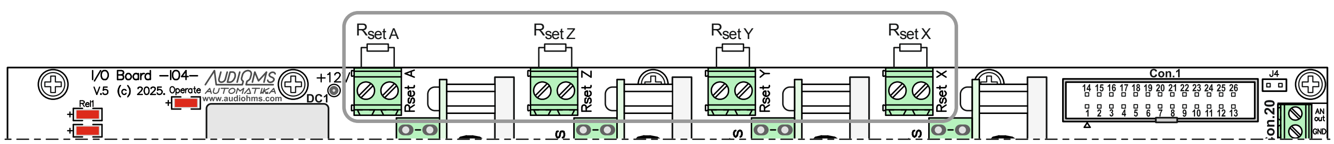


Figure 4.13 The position of the Rset resistor for adjusting the operating current of stepper motors

4.7 Setting the parameters of the MST-109 stepper motor driver

The MST-109 stepper motor driver is based on a DSP microcontroller and has built-in sophisticated options for stepper motors control. These options are, an advanced algorithm for managing the operation of the stepper motor at higher revolution speed, the selection of microsteps up to 1/256 (binary and decimally selection), then the selection of quiet operation when the stepper motor is not in operation. This makes it possible to make maximum use of the available torque of the stepper motor at higher speeds.

The selection of microsteps, as well as other operating mode options, is made using DIP switches with 8 positions, which are located on the drive board.

Setting the current of stepper motors in the range of 1.0–9.0 A is done using an external resistor (Figure 4.13).

The driver has an automatic reduction of the current flowing through the windings of the stepper motor. If there is no signal on the STEP line for more than 1 s, the coils current will be decreased to 50% of the set value. This reduces unnecessary heating of stepper motors.

The built-in soft start enables the stepper motor 1s after the supply voltage arrives, which reduces the current shock when switching power on.

NOTE: For more details on the microstep driver MST-109, see its user manual.

4.7.1 MST-109 Technical specifications

Microstep resolution	1/1, 1/2, 1/4, 1/5, 1/8, 1/10, 1/16, 1/20, 1/25, 1/32, 1/50, 1/64, 1/100, 1/128, 1/200 and 1/256 microsteps
Number of axis	1
Phase current	9 A max
Current setting	1,0–9,0 A (by external resistor)
Supply voltage	22–60 V DC max, recommended up to 55 V DC
Input control interface	Opto-isolated STEP, DIR and ENA (enable) command lines
Input current	8.5 mA at 5 V (TTL)
Input signal width	> 1 μs (recommended > 5 μs)
Dimensions	80 mm x 105 mm x 31 mm
Weight	~170 g

NOTE: Specifications are subject to change without notice

4.7.2 Stepper motor driver MST-109 parameters settings

The setting of the operating parameters of the microstep drive MST-109 is done using an 8-position DIP switch. It is set using a DIP switch (Figure 4.14):

- Microsteps selection (DIP switch positions from 1 to 4),
- Gain selection (DIP switch positions 5 and 6),
- Activating the silent mode of operation in the idle state of the stepper motor (DIP switch position 7), and
- Enable mode (DIP switch position 8).

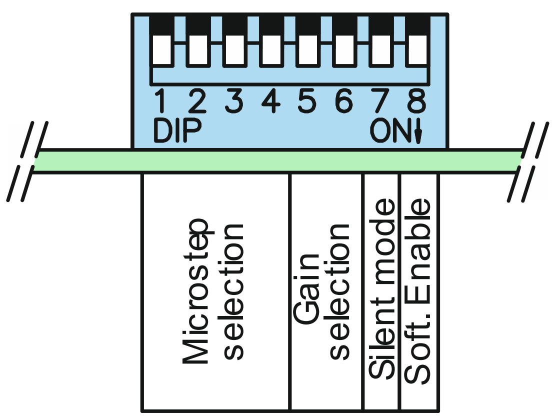


Figure 4.14 DIP switches function description

Selection of DIP switch positions:

- The “raised” (↑) position is “zero” (0) in the operating parameters selection tables, and
- The “down” (↓) position is “one” (1) in the operating parameters selection tables.

The following is a more detailed description of the setting of stepper motor drive MST-109 operating parameters.

4.7.3 Microstep selection

DIP switches in positions 1, 2, 3 and 4 (Figure 4.14) provide the choosing of 16 different microsteps option as shown in Table 4.2. Choice of binary and decimally microstep values is possible.

The last column in the given table shows how many pulses on STEP line are required to be sent to the MST-109 drive in order for the stepper motor to complete one full rotation for all available microstep selections. A stepper motor that requires 200 pulses for a full revolution in full-step mode is considered.

Table 4.2 Microstep selection

DIP switch position				**Microstep selection**	**Required number of pulses for full revolution**
1	**2**	**3**	**4**		
0	0	0	0	1/1 Full-step	200
0	0	0	1	1/2	400
0	0	1	0	1/4	800
0	0	1	1	1/5	1000
0	1	0	0	1/8	1600
0	1	0	1	1/10	2000
0	1	1	0	1/16	3200
0	1	1	1	1/20	4000
1	0	0	0	1/25	5000
1	0	0	1	1/32	6400
1	0	1	0	1/50	10000
1	0	1	1	1/64	12800
1	1	0	0	1/100	20000
1	1	0	1	1/128	25600
1	1	1	0	1/200	40000
1	1	1	1	1/256	51200

4.7.4 Gain selection

Gain is a suggestion to the built-in stepper drive current regulator for the desired mode of operation (more or less aggressive). It is possible to choose 4 different levels of amplification. DIP switches in positions 5 and 6 are used for that purpose (Figure 4.14). The choice of gain depends on the inductance of the stepper motor. Table 4.3 gives possible gain choices. The stepper motor coil inductance value can be found in the technical documentation that comes with the stepper motor.

Table 4.3 Gain selection

DIP switch position		**Gain selection**	**Stepper motor inductance**
5	**6**		
0	0	Lowest	For stepper motors with coil inductance from 1 mH to 4 mH. Large stepper motors or stepper motors where the coils per phase are connected in parallel
0	1	Middle	For stepper motors with coil inductance from 4 mH to 8 mH
1	0	Higher	For stepper motors with coil inductance from 8 mH to 12 mH
1	1	Highest	For stepper motors with coil inductance greater than 12 mH. Stepper motors with a relatively high nominal coil resistance or stepper motors where the coils per phase are connected in series

NOTE: Sometimes it is necessary to experimentally find the optimal choice of gain depending on the specific stepper motor – mechanical transmission system.

4.7.5 Selection of Silent mode

The microstep drive MST-109 provides the option of silent operation when the stepper motor do not rotate. The selection is made using the DIP switch in position 7. When the DIP switch 7 is “down” (↓), ie. is “one” (1) (Figure 4.14), then the Silent mode of operation is active. Otherwise, it is inactive.

4.7.6 Enable mode selection

The DIP switch in position 8 (Figure 4.14) provides the possibility of choosing two Enable modes of operation:

- **If switch 8 is inactive (↑) then Software Enable mode is selected**. In this mode, the ENA input on stepper motor drive MST-109 is active. If there is logical “high” at the ENA input, the drive is active and will execute the commands coming to it from the STEP and DIR command lines. In case there is a logical “low” at the ENA input, then the MST-109 drive is inactive, STEP and DIR commands are not executed and the stepper motor is not energized (this option is often used if it is necessary to manually rotate the stepper motor), and
- **If switch 8 is active (↓) then Hardware Enable is selected**. In this mode, the ENA input on stepper motor drive MST-109 is not functional. The drive is always active.

4.7.7 Examples of working parameters settings

Figure 4.15 shows two example of parameter settings on the MST-109 microstep drive.

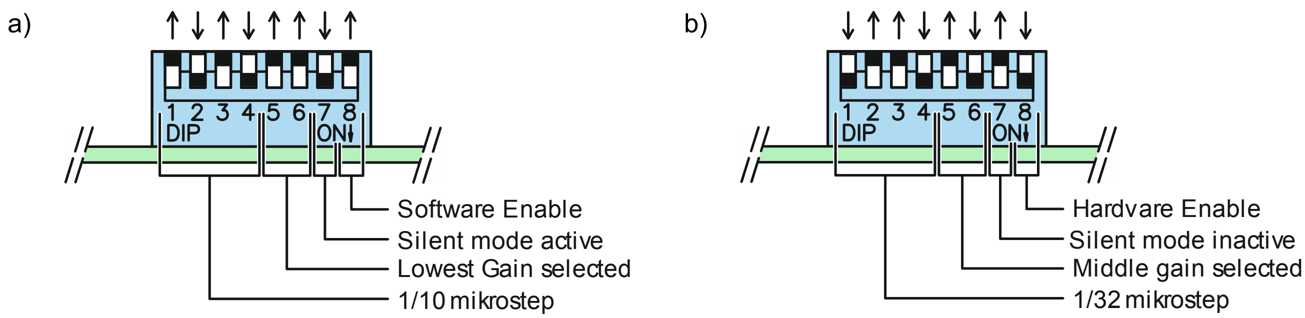


Figure 4.15

The SMCU4 control unit is delivered with the MST-109 stepper motor driver parameters set as shown in Figure 4.16. It is set: microstep resolution 1/10, Lowest Gain Selected, Silent Mode Active and Software Enable selected.

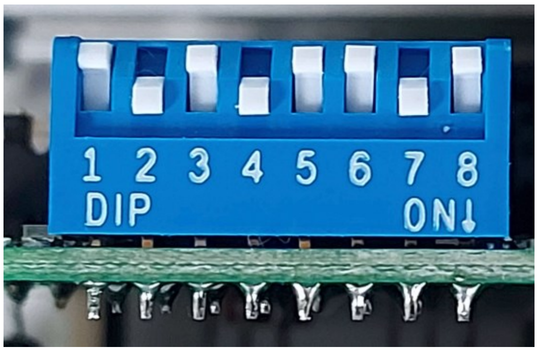


Figure 4.16

4.7.8 Stepper motor current setting

The setting of the stepper motor current is performed using an external resistor marked with R_{set} (Figure 4.13). Use 1/4W resistors with a maximum tolerance of 5%. Table 4.4 gives the recommended current set resistor values.

NOTE: Replacing the R_{set} resistor should only be done when the SMCU4 control unit power supply is turned off.

Table 4.4 Choosing of R_{set} resistor

I, A	R_{set}, Ω
1	Without resistor
1,5	33k
2,0	18k
2,5	10k
3,0	6k8 (7k5)
3,5	4k7 (5k6)
4,0	3k9
4,5	3k (3k3)
5,0	2k4 (2k7)
5,5	1k8
6,0	1k5
6,5	1k (1k2)
7,0	750
7,5	510
8,0	330
8,5	150
9,0	0

Procedure for setting the current on the stepper motor:

- Start from the minimum current value, or start without the resistor R_{set} installed.
- Gradually increase the current through the phases of the stepper motor, until the current given in the characteristics for the stepper motor is reached.
- If the motor heats up, it is necessary to reduce the set current to a level that does not cause excessive heating of the stepper motor.

In certain cases, a noise (or slight “squeal”) can be heard from the stepper motor even when the motor does not rotate. The reason for this is the PWM mode of operation of the stepper motor drive MST-109.

NOTE: The MST-109 microstep drive has built-in circuit that hardware monitors the current through the stepper motor windings. If the current through the motor windings exceeds the set current value by more than 30 %, the drive will stop working, i.e. overcurrent protection is activated. In this case, it is necessary to turn off the power supply to the drive and turn on again the power supply to the stepper motor drive.

5 Status LED

There is a status LED on the MST-109 stepper motor drive board. Table 5.1 gives a description of the possible motor drive states indicated by the status LED.

Table 5.1

Does not light up	Stepper motor drive is not powered
Blinking slow	Stepper motor is powered up, Disable mode
Constantly lights	Stepper motor is powered up, Enable mode
2 short blinks	Overcurrent detection
3 short blinks	Overvoltage protection. When the supply voltage exceeds 65 VDC, overvoltage protection is activated

6 Recommendations when using the stepper motor control unit SMCU4

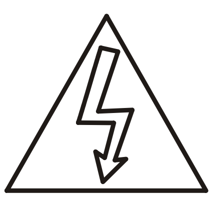
1. Recommended power supply voltage should be in the range of 20–48 V DC. Modern stepper motors have nominal voltage about 2–3 V. The recommended power supply voltage of the drive should be 10–15 times higher than nominal stepper motor voltage. It is quite enough to obtain good speed-torque characteristics of the motor.

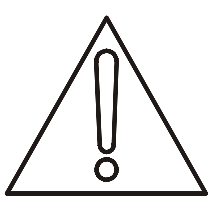
2. Length of the cable for connection between stepper motor and drive should be as smaller as possible. Recommendation is that two conductors that supply phase be twisted around the longitudinal axis (twisted pair) like telephone twisted pair. It is preferred to use shielded cable, where cable shield will be connected to the side of the drive enclosure where is the electronics (not to ground of power supply).

3. It is not recommended that contactor and other electromagnetic power switches be close to SMCU4 control unit, because it can induce strong electromagnetic discharge and strong mechanical impacts that can damage the stepper motor drives.

Before delivery all control units SMCU4 are tested on power supply voltage in range of 20–40 V DC and output current up to 7.5 A. Supply voltage that exceeds 55 V DC, incorrectly connected power supply, incorrectly connected and defective stepper motor, strong electromagnetic discharge etc. can permanently damage the control unit.

7 Safety recommendations





Connection of SMCU4 control unit, stepper motors, micro limit switches, VFD, etc. can only be performed by persons who have the necessary knowledge of electrical engineering. Potentially life-threatening voltages may be present during connection of the VFD.

To power the SMCU4 control unit, use isolated power sources that are properly grounded.

Provide enough space on all sides of the device to enable the best possible natural cooling. If necessary, provide an additional heat sink and/or forced air cooling.

The device should not be used in places where its failure could lead to danger to human safety, large financial losses, or any other losses.

Use all necessary precautions when working with this device.

The possibility that this document may contain errors is not excluded. At the same time, the manufacturer does not assume responsibility for any damage caused by the use of this device, which occurred as a result of following or not following this user manual.

8 Using control unit SMCU4 with Mach3

Demo version of the Mach3 control software can be downloaded from the official site www.machsupport.com. As it is already mentioned control unit SMCU4 is connected with PC by using parallel (LPT) port. Alternatively, external motion controller could be used. For proper operation it is necessary to perform the required settings. All settings are in accordance with the schedule of input-output pins, which is shown in Table 4.1.

Selection of the parallel port is performed in dialog box **Config ⇒ Ports and Pins** (Figure 8.1).

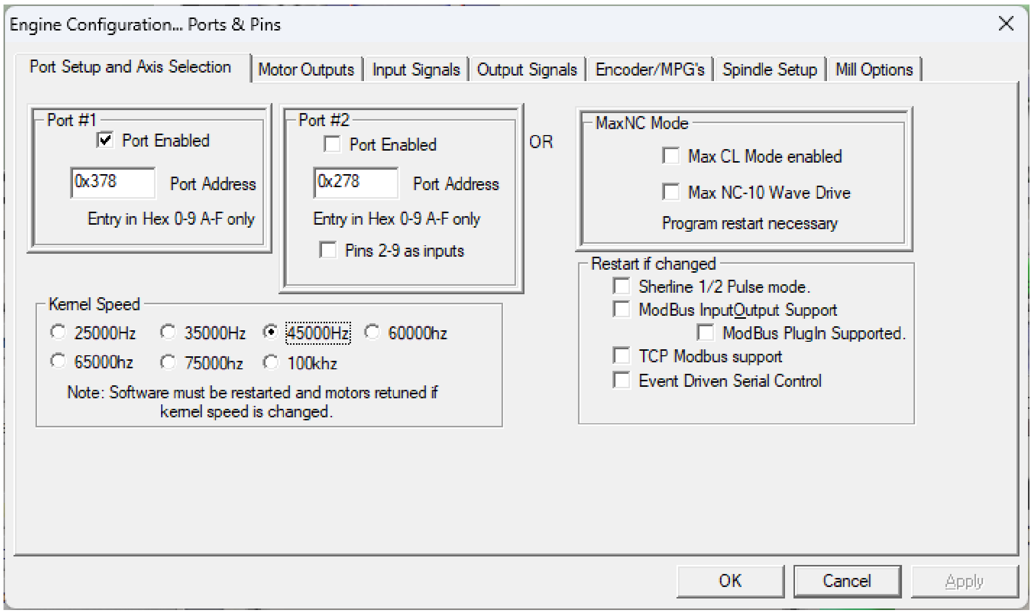


Figure 8.1

Setting of the STEP/DIR command lines for all axes is performed in dialog that opens by choosing option **Config ⇒ Ports and Pins ⇒ Motor Outputs** (Figure 8.2).

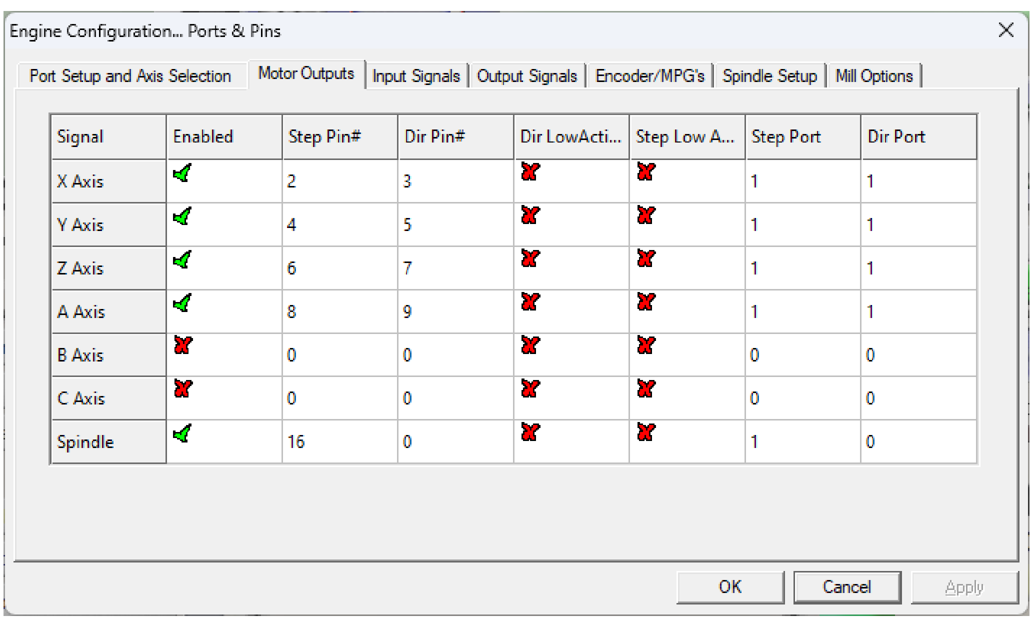


Figure 8.2

Setup for ENA (enable) command line is shown in Figure 8.7.

Setup of step motor parameters depends of great number of factors: step motor type, applied drive (choice of microstep options), type of transmission (screw spindle, timing belt, etc.), mass of the moving parts of the machine, etc. One potential setup is shown in Figure 8.3. Dialogue is opened by selecting **Config** ⇒ **Motor Tuning**.

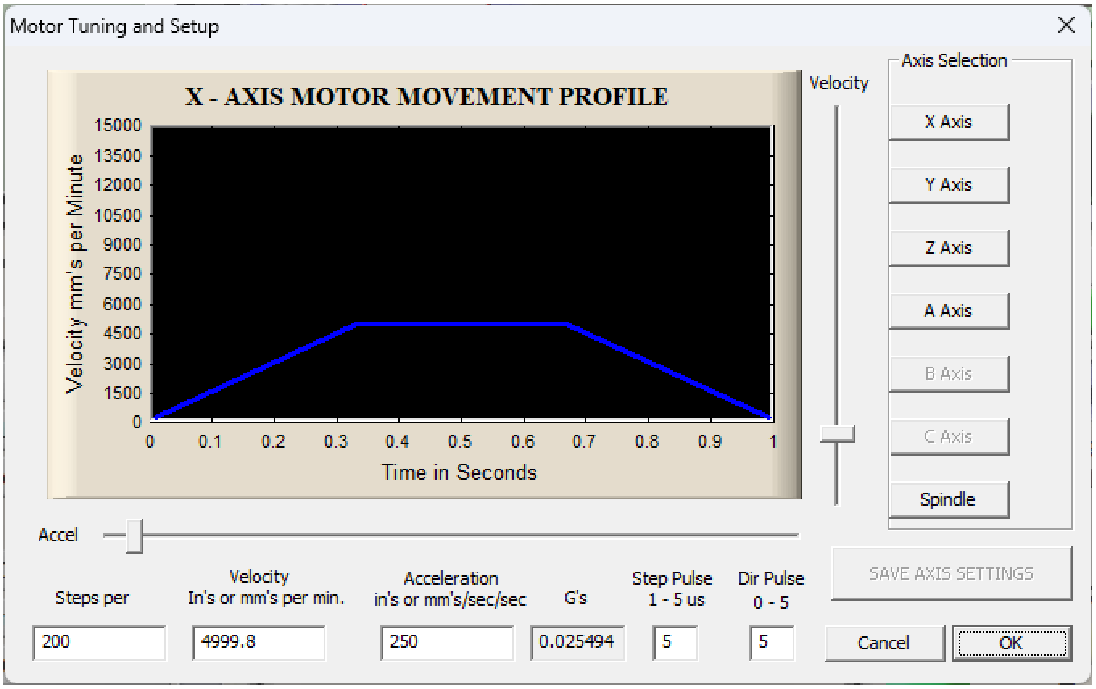
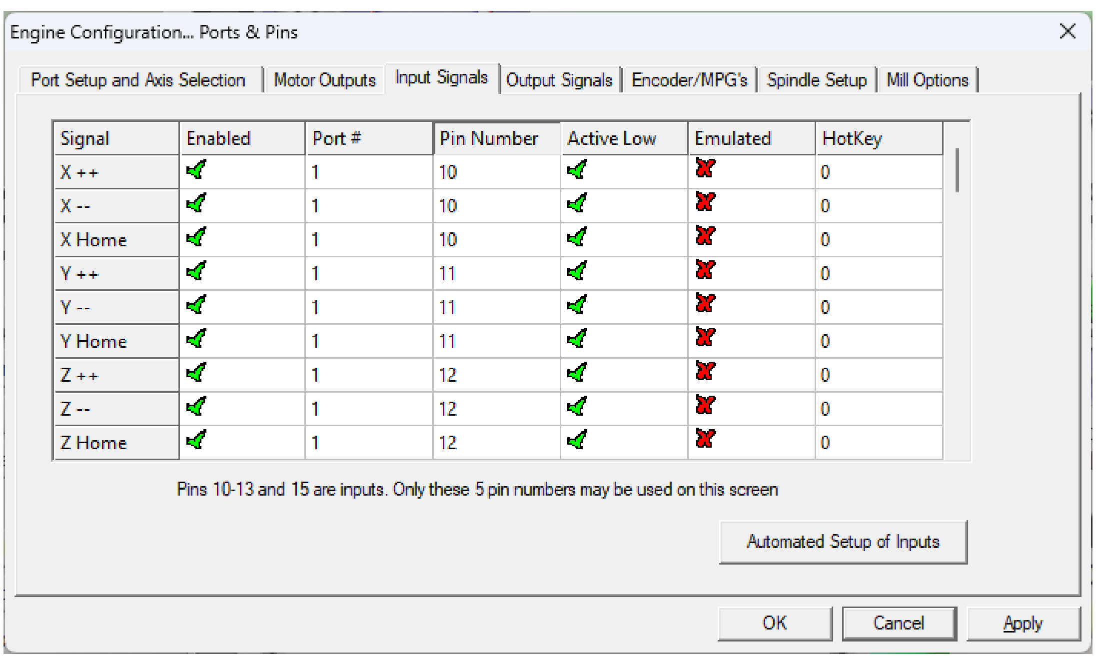


Figure 8.3

Example for the limit switches settings via option **Config** ⇒ **Ports and Pins** ⇒ **Input Signals** is shown in Figure 8.4, Figure 8.5 and Figure 8.6. Setup refers to the connection of limit switches as shown in Figure 4.4.



Signal	Enabled	Port #	Pin Number	Active Low	Emulated	HotKey
X ++	✔	1	10	✔	✘	0
X --	✔	1	10	✔	✘	0
X Home	✔	1	10	✔	✘	0
Y ++	✔	1	11	✔	✘	0
Y --	✔	1	11	✔	✘	0
Y Home	✔	1	11	✔	✘	0
Z ++	✔	1	12	✔	✘	0
Z --	✔	1	12	✔	✘	0
Z Home	✔	1	12	✔	✘	0

Figure 8.4

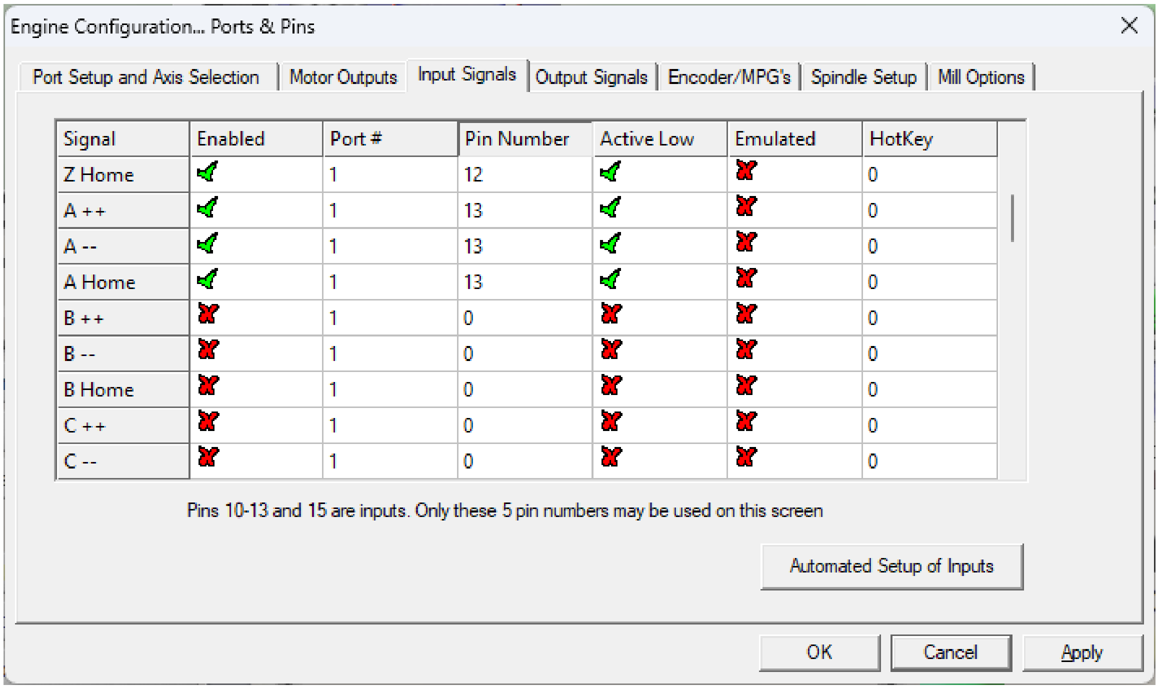


Figure 8.5

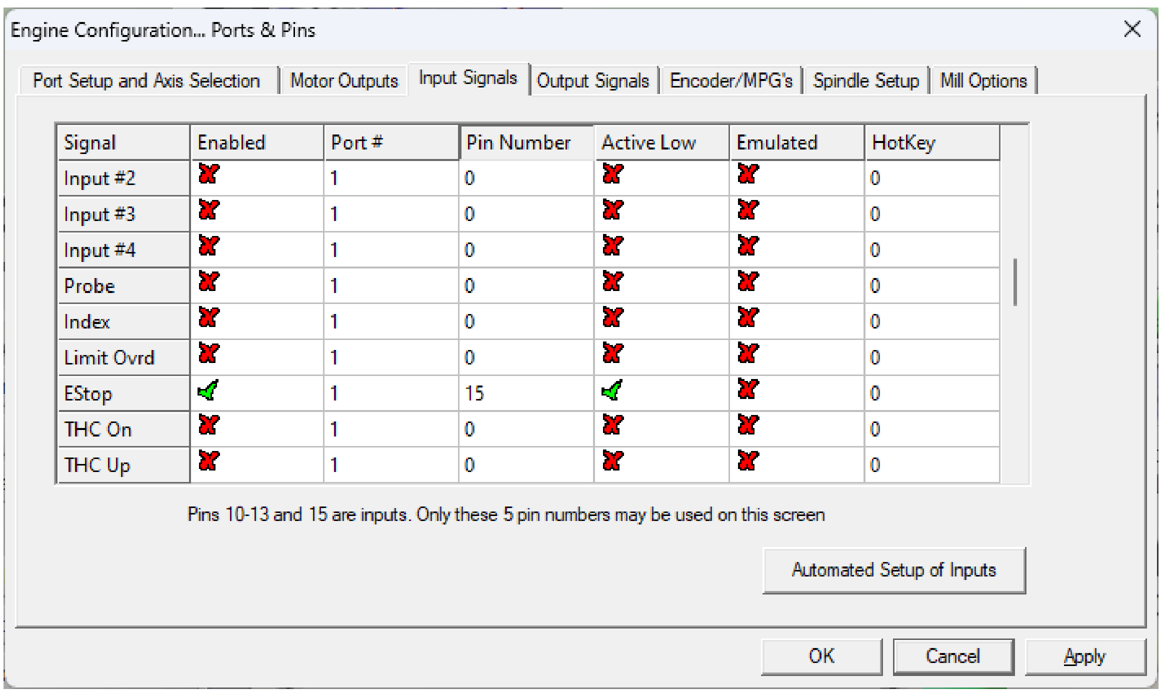


Figure 8.6

Setup of relay outputs is performed in two steps. The first, by choosing the option **Config ⇒ Ports and Pins ⇒ Output Signals** (Figure 8.7) selects outputs that is used (in this particular case **Output #2** and **Output #3**). Then it is needed to set the parameters under **Config ⇒ Ports and Pins ⇒ Spindle Setup** (Figure 8.8, area indicated by rectangle).

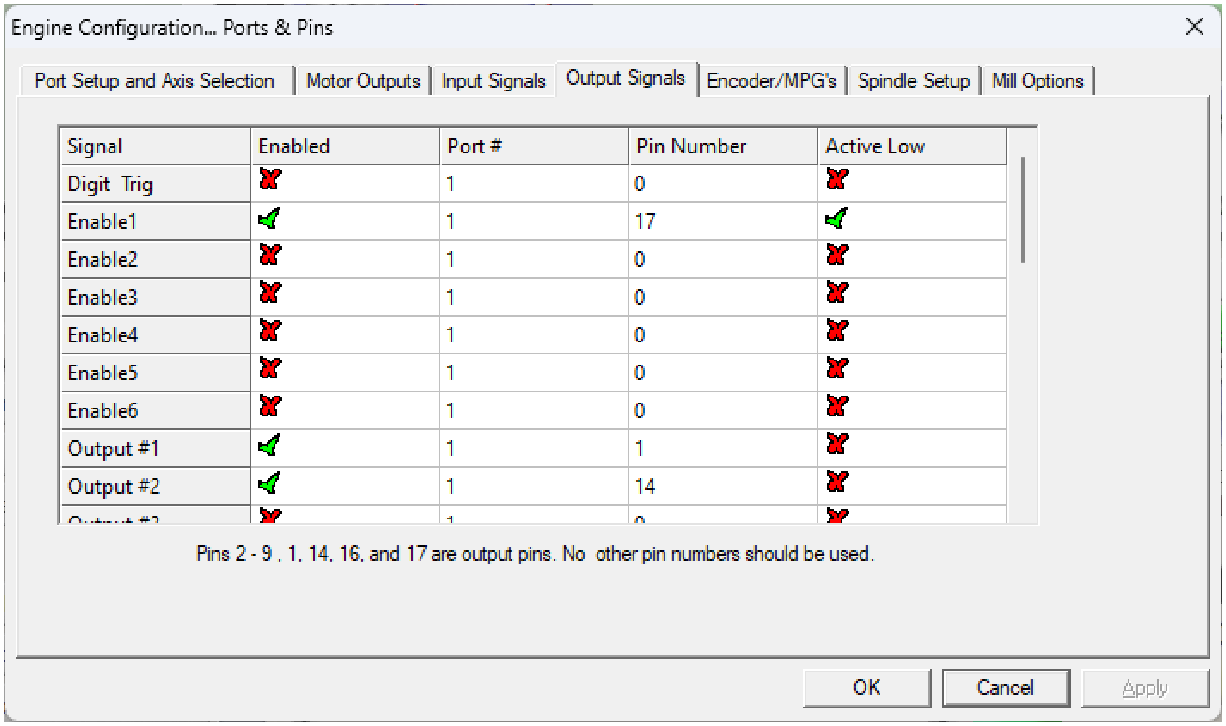


Figure 8.7

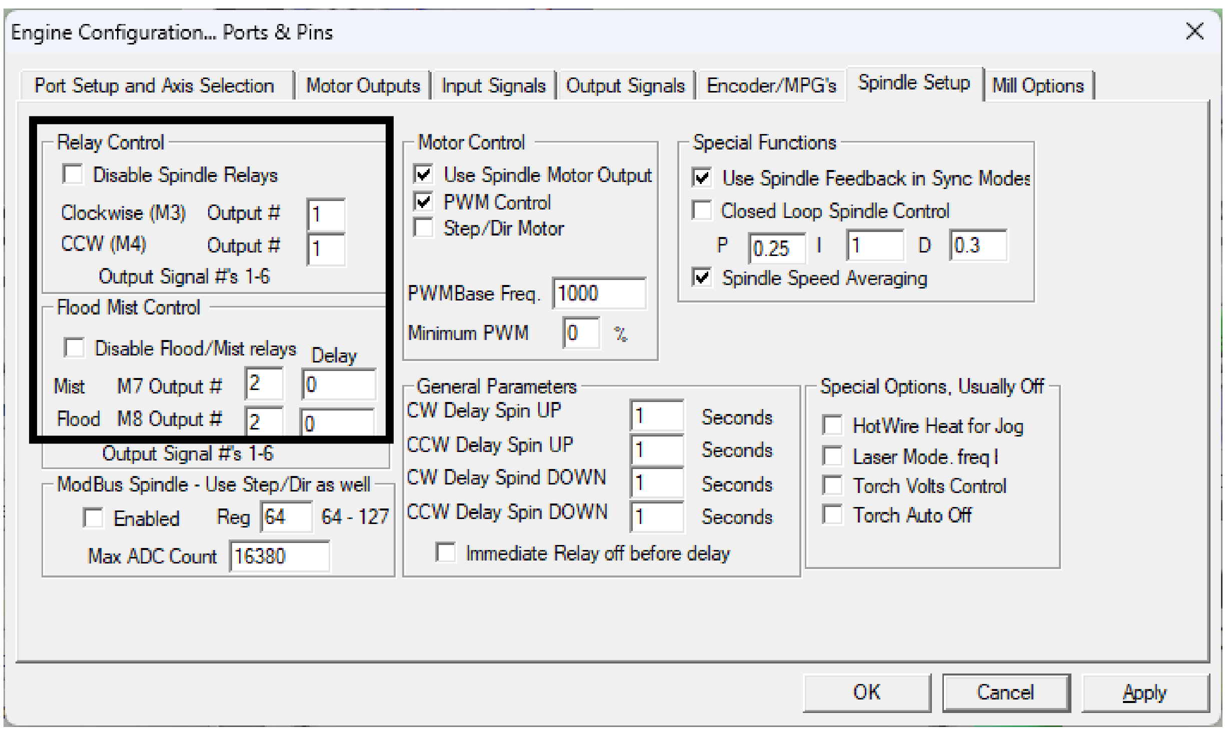


Figure 8.8

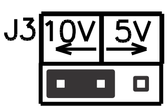
8.1 Analog output

Software Mach3 has the capability of generating Pulse-width modulation (PWM) signal. PWM is a method of control in which the frequency of the control signal does not change. Regulation is done by changing of the signal/pause ratio.

To convert the PWM signal to an analog signal (voltage level), control unit SMCU4 use active low pass filter. This filter smooth out the signal, filling in the gaps during the off periods of the PWM. The level of the analog signal depends on the signal/pause ratio. If the width of the signal is for example 10%, and width of the pause is 90%, analog voltage will be 10% of maximum voltage. This analog signal can be used for control of spindle motor revolution speed. Wiring of analog signal with spindle motor revolution speed control unit is shown in Figure 4.10 and Figure 4.11.

The use of analog output requires hardware setup of control unit SMCU4 via jumper J3 (see Table 8.1), and setting up of parameters in Mach3 software.

Table 8.1 Position of jumpers J2 and J3 for configuration of analog signal

	Jumper J3 defines the voltage level on the analog output. It can be in voltage range of 0–5 V or 0–10 V.

Software setup is performed by selecting **Config** ⇒ **Ports and Pins** ⇒ **Output Signals** as it is showed in Figure 8.9, Figure 8.10 and Figure 8.11.

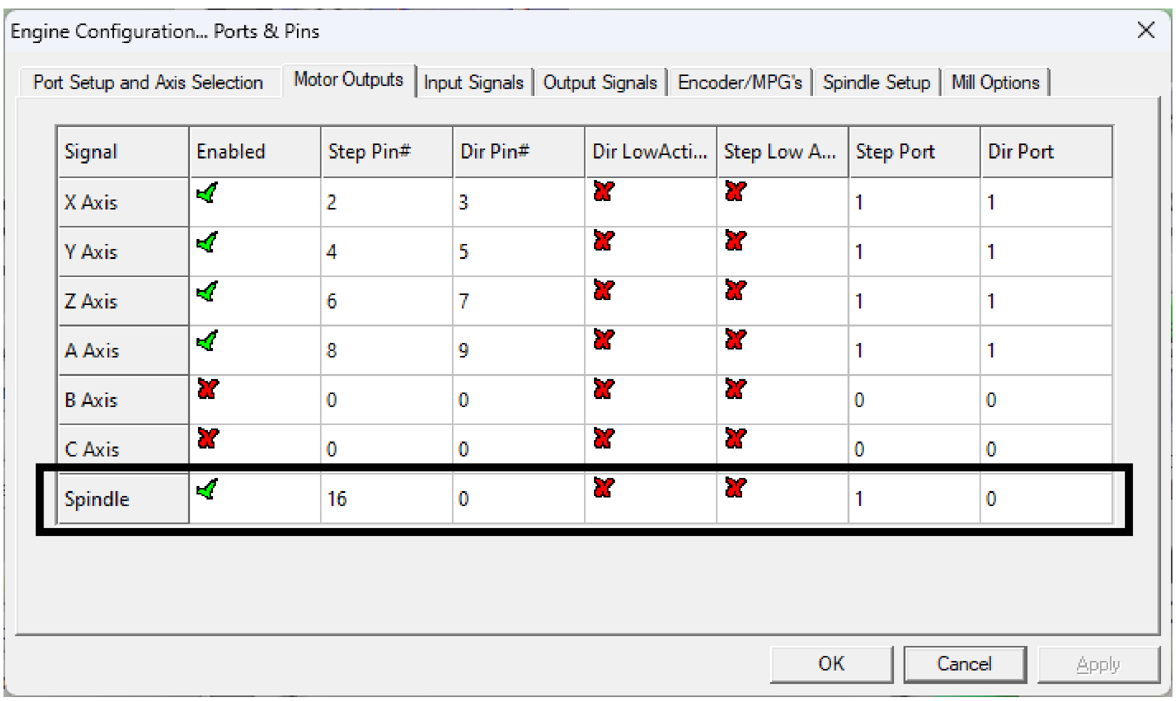


Figure 8.9

In Figure 8.11 it is seen that chosen fundamental frequency of PWM signal is 1000 Hz.

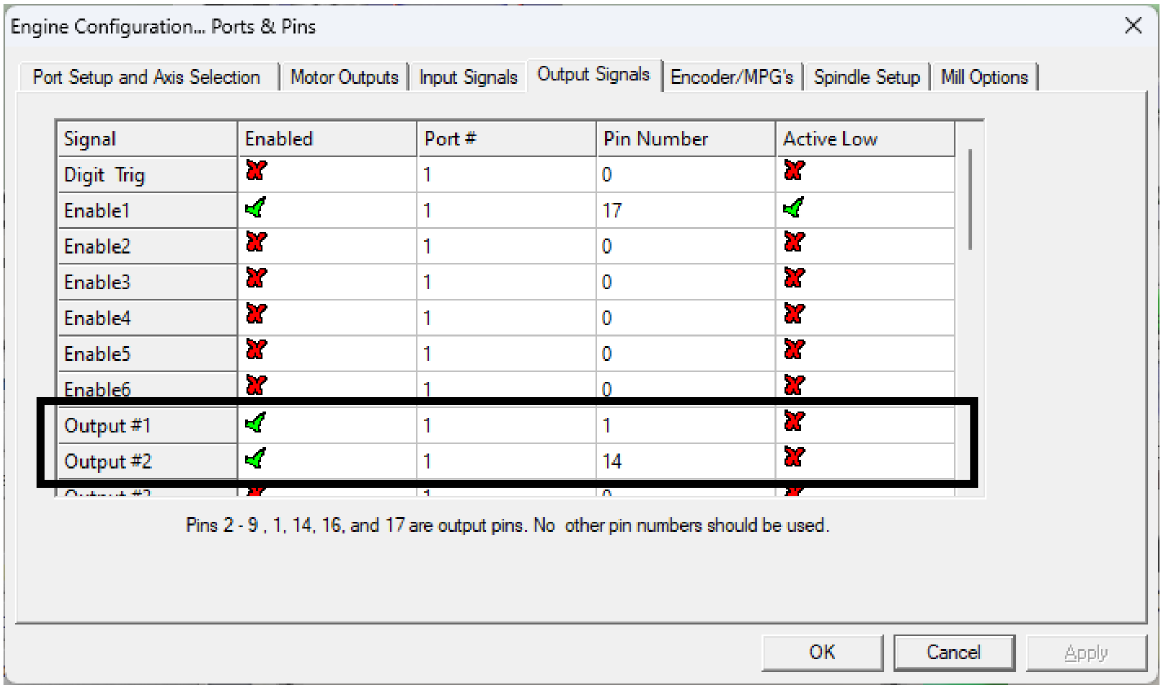


Figure 8.10

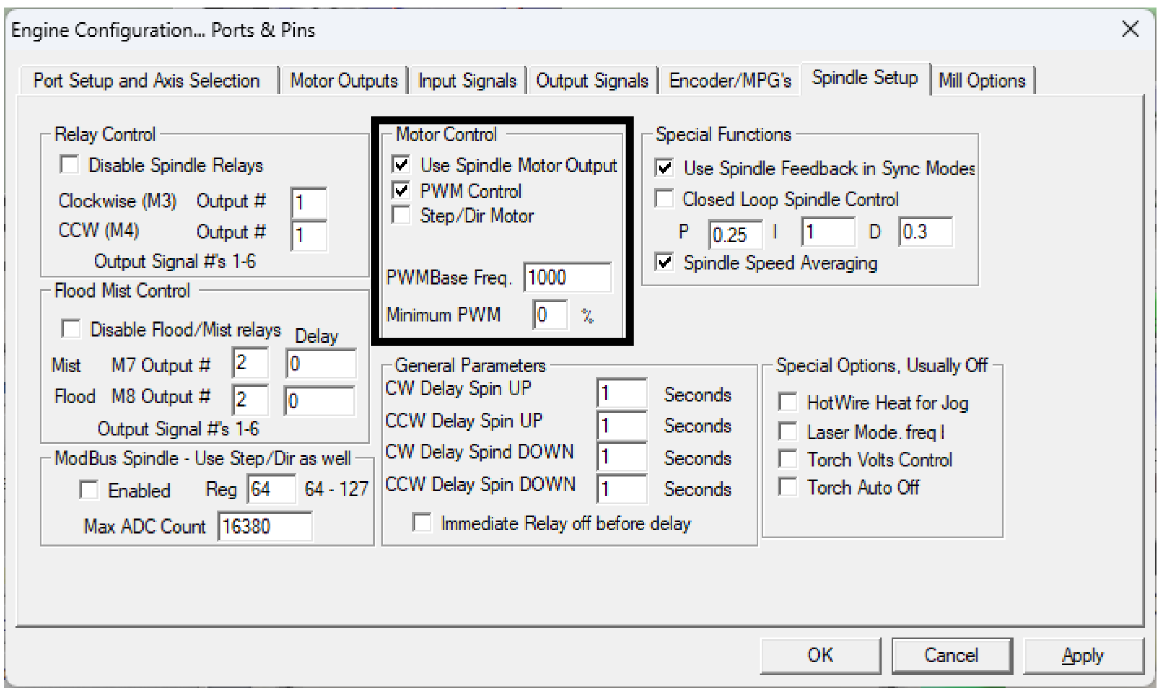


Figure 8.11

It is also important to note that Pulley Ratio is need to be set through dialog **Config -> Spindle Pulleys…** (Figure 8.12). In this example the parameters relating to the **Pulley Ratio #4** is here set from 0–8000 RPM. This means that for signal/pause ratio of 0%, RPM will be 0, for 10% it will be 800 RPM and so on, while for 100% the spindle revolution speed will be 8000 RPM.

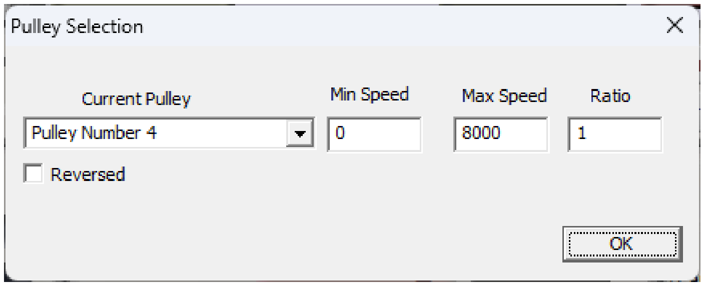


Figure 8.12

Commands related to the Spindle are on the main screen in the section called **Spindle Speed** (framed part in Figure 8.13).

In the **S** field is required to enter the desired RPM (in Figure 8.13 it is 8000 RPM). Starting the spindle is achieved by pressing the **Spindle CW F5** button or by pressing the F5 key on the computer keyboard. By pressing the **+** and **–** there is a continuous increase or decrease of RPM of the spindle for the size of specified increment.

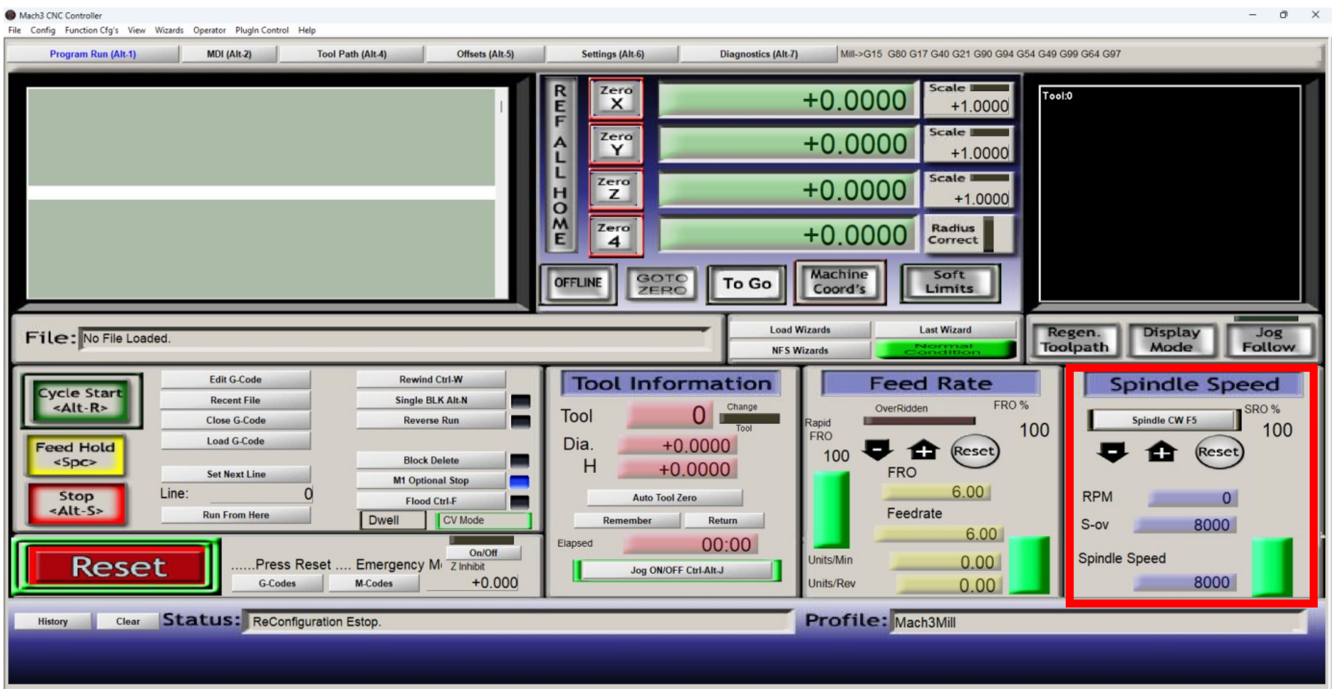


Figure 8.13

DOCUMENT REVISIONS:

- Ver. 1.0, October 2024, Preliminary version
- Ver. 1.1, January 2025, Added description for Mach3 configuration; Chapter 8