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Innovation in Neural Interface Technology

OPERATING INSTRUCTIONS FOR THE MECHANICS MODULE WITH A MEASSuRE SYSTEM WITH A VCA

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1 Purpose of this Document and Disclaimer

The purpose of this document is to provide operating instructions for BMSEED's Mechanics Module in MEASSuRE-X, MEASSuRE-Premium, and MEASSuRE-Mini to guide the user through hardware setup of the voice coil actuator (VCA), electrical connections, parameter calculations, setup, and use of the MotionLab software including macros. This module may only be used with stretchable microelectrode arrays (sMEAs) or stretchwells (SW) fabricated by BMSEED.

2 User Requirement, Safety, Liability, and Warranty

2.1 User Requirements

Only trained and qualified users should be allowed to work with the mechanics module. BMSEED LLC does not guarantee the accuracy of the measured data. A qualified user familiar with the operation of the mechanics module must assess the quality and accuracy of the obtained data using standard laboratory protocols.

Qualified users are those that:

- are familiar with the laboratory and work safety requirements to operate the module,
- have the professional knowledge and skills to use the module, and
- have read this document prior to using the module.

2.2 Safety

The following statements should be considered to avoid serious injury to those individuals performing the procedures and/or damage to the equipment:

WARNINGS

- To prevent the formation of electric arcs, as well as dangers to personnel and electrical contacts, never connect/disconnect any of the cables at the electronics enclosure or elsewhere while the power supply is plugged in an outlet.
- Power cables may be exposed to high voltages, even when the motor is not in motion.
- After turning off the power and disconnecting the equipment power source, wait at least 1 minute before touching any parts of the controller that are electrically charged or hot (such as capacitors or contacts).
- **NEVER** put any body part between the Y-adaptor and any of the metal parts around it. Serious injuries can occur.

PRECAUTIONS

- The VCA and control servo drives (Jupiter and Pluto) components temperature may exceed 75°C during operation.
- Some components become electrically charged when in operation.
- The power supply connected to this controller should comply with the parameters specified in this document.
- When connecting the Jupiter servo drive or Pluto servo drive to an approved V_{DC} power source, do so through a line that is separate from any possible dangerous voltages, using the necessary insulation in accordance with safety standards.



- High-performance motion control equipment can move rapidly with very high forces. Unexpected motion may occur especially during product commissioning. Keep clear of any operational machinery and never touch them while they are working.
- Do not make any connections to any internal circuitry. Only connections to designated connectors are allowed.
- All service and maintenance must be performed by qualified personnel.
- Before turning on the control servo drive, check that all safety precautions have been followed, as well as the installation procedures.



Always follow OSHA rules when working with the product.

Always follow the laboratory and other safety regulations issued by the state, municipality, and organization where the product is used.



For best results, always follow good laboratory practices.

Do not use the product or its software for medical applications or on humans.

2.3 Liability and Warranty

The Sales Agreement between BMSEED LLC and the customer will be provided upon delivery of the system.

BMSEED's liability and warranty in the event of damage to the product or injury of personnel is excluded when the product is: (i) operated outside its operating regime, (ii) incorrectly operated by the user, or (iii) tampered with in any way. Examples of such liability and warranty exclusions are, but not limited to:

- incorrect and inappropriate use of the product,
- operating the product when safety and protective features are defective,
- improper operation of the product,
- unauthorized or inappropriate alteration or repair of the product, or
- water or other physical damages that occur after the product was delivered.

3 Materials and Equipment

The Mechanics Module is the part of the MEASSuRE system responsible for the mechanical motion, and is the main difference between MEASSuRE-Mini, MEASSuRE-Premium, and MEASSuRE-X. These three models vary in the attainable strain and strain rate.

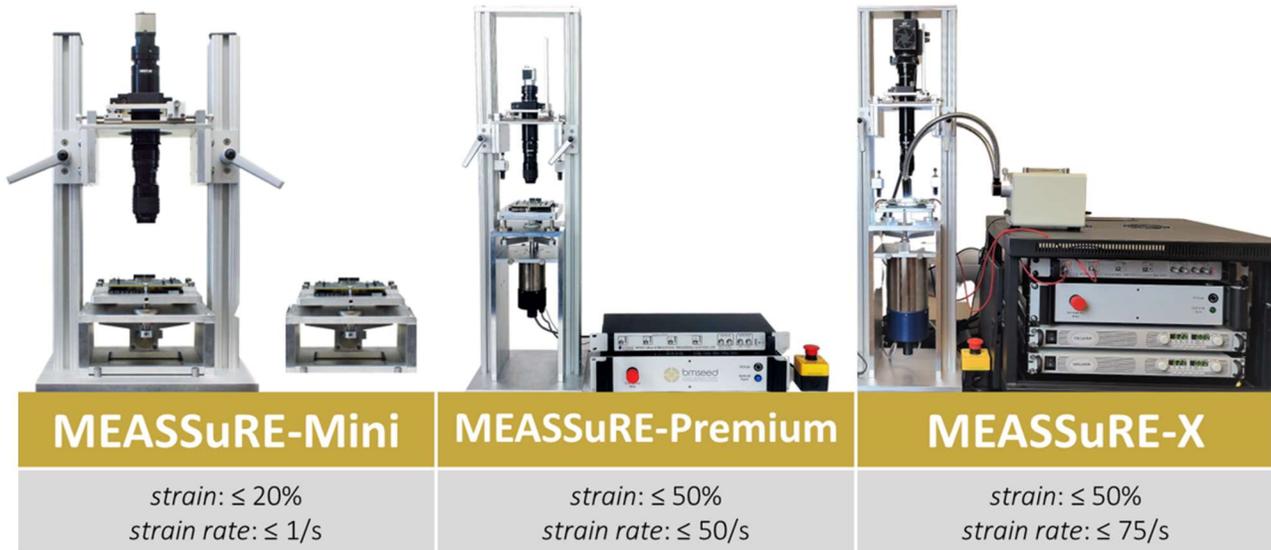


Fig. 1: The three MEASSuRE system models.

The hardware components in MEASSuRE-X allow higher speeds. The main differences in the hardware components between these three models are:

Table 1: Hardware components for the various MEASSuRE models.

Hardware component	MEASSuRE-Mini	MEASSuRE-Premium	MEASSuRE-X
VCA	BEI Kimco LAS16-23	BEI Kimco LAS28-53	BEI Kimco LAS43-88
Motor Power Supply	1 Mean Well RS-150-48	1 Mean Well UHP-500-48	2 Instek PSU 60-25 in series or 2 TDK Lambda GEN 100-15 in series
Logic Power Supply	N/A	N/A	1 Mean Well RS-15-24
Controller	Ingenia Pluto Drive PLU-8/48-C (48V, 8A)	Ingenia Jupiter Drive JUP-15/130-C (130V, 15A) or Ingenia Jupiter Drive JUP-40/80-C (80V, 40A)	Ingenia Jupiter Drive JUP-30/130-C (130V, 30A)

In MEASSuRE-Mini and MEASSuRE-Premium, the Mean Well power supply is housed in the electronics enclosure. The power supplies for MEASSuRE-X are too large. Therefore, the power supplies for MEASSuRE-X are mounted in a rack. The logic power supply in MEASSuRE-X is housed in the electronics enclosure.

4 References

Here is list of online references cited throughout this manual:

- MotionLab software - download and user manual:
 - <https://drives.novantamotion.com/mot2/downloads>
 - <https://drives.novantamotion.com/mot2/user-manual>
- Servo control drives' manuals and downloads (drawings, firmware, drive files):
 - Jupiter drive: <https://drives.novantamotion.com/jup/jupiter-product-manual>
 - EMCL2 (Embedded Motion Control Library 2) downloads:
<https://drives.novantamotion.com/emcl/downloads>
- MotionLab software – Macros, commands, and dictionary of variables:
 - <https://drives.novantamotion.com/mot2/user-manual>
 - <https://drives.novantamotion.com/emcl/command-reference-manual>
 - <https://drives.novantamotion.com/emcl/dictionaries>
- Motion position control and PID settings
 - <https://drives.novantamotion.com/emcl/0x2500-position-control-parameters-set>
 - <https://drives.novantamotion.com/emcl/profile-position-mode>

Further details about these components and operations that are beyond the scope of this manual can be found at:

- Sensata's linear voice coil actuator (VCA) with an integrated sensor
 - <https://www.sensata.com/products/motors-actuators/vca-developers-kit>
 - <https://www.sensata.com/sites/default/files/a/sensata-voice-coil-actuator-developer-kit-datasheet.pdf>

5 Hardware Setup systems

This section describes the hardware setup relevant to MEASSuRE.



Before operating the tool, always make sure that the hardware components are set up and connected properly.

5.1 Electronics Enclosure for all models of MEASSuRE

Most connections are made from the back of the electronics enclosure (shown below). The labels on the back panel of the enclosure indicate which cable to connect. We start from right to left.

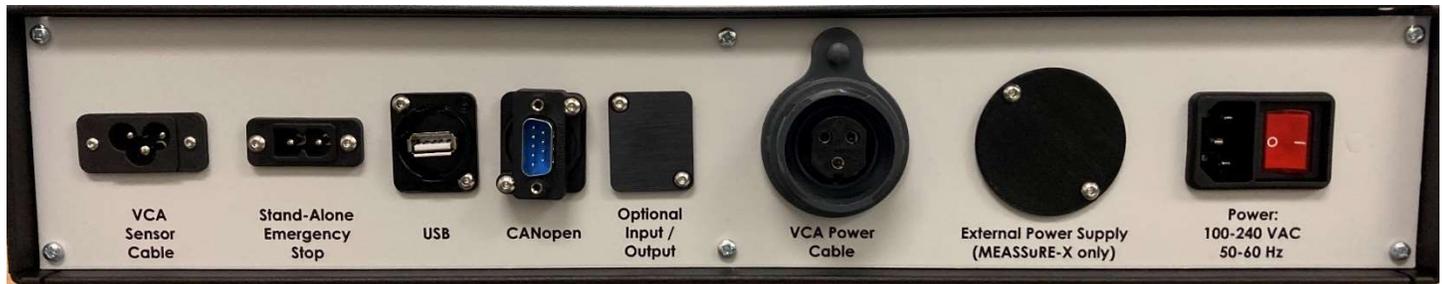


Fig. 2: All the connectors, except for the External Power Supply connector, on the rear panel of the electronics enclosure.

Power connector

- This IEC C13 connector labeled “Power” connects to the power cord. The other end of the power cord plugs into an electrical outlet.
- Turn on the electronics in the enclosure by pushing the switch at the back of the electronics enclosure; the red light should light up.



Fig. 3: AC power connector.

External Power Supply connector

- This 2-pin socket is **only used in MEASSuRE-X** to connect to the external, high voltage power supplies (see in the next subsection). When a MEASSuRE-Premium or -Mini is used, no external power supply is needed. Thus, a cover replaces the connector, as shown in **Fig. 2** above.

VCA Power Cable connector

- This 3-pin socket is connected to the VCA motor cable, which is permanently connected to the VCA. Power is provided from the controller to the VCA via these wires. Note: These wires often carry high voltage and current.

Optional Input/Output connector

- This connector slot is currently not being used and is covered. An optional input or output can be mounted here by the user.

CANopen connector

- This 9-pin D Sub socket connects to the PCAN-USB cable via a PCAN extension cable (purple as shown in **Fig. 4** below). The other end of the PCAN-USB cable connects to the computer to establish CANopen communication.



Fig. 4: PCAN extension cable (purple) connected to the "CANopen" connector on the enclosure and the PCAN-USB adapter (white) to be connected to the computer.

USB connector

- This USB-A connector is connected to a USB-A cable. The other end of the USB cable connects to the computer to establish USB communication. Note: This connector is only used when updating the servo drive firmware or troubleshooting.

Stand-Alone Emergency Stop connector

- This IEC C7 connector is **only used in MEASSuRE-X and -Premium systems with a Jupiter drive** and is connected to a stand-alone emergency stop. This is one of two emergency-stop buttons (the other one is on enclosure's front panel).

VCA Sensor Cable connector

- This IEC C5 connector is connected to the VCA sensor cable, which is permanently connected to the VCA. The I/O cable provides feedback on the position of the VCA back to the controller.



Fig. 5: Front and top view of the electronics enclosure's rear panel with cables connected.

5.2 High Voltage Power Supplies for MEASSuRE-X only

The power supplies for MEASSuRE-Mini and MEASSuRE-Premium systems are housed in the electronics enclosure. MEASSuRE-X systems requires much more power which is provided by two power supplies that are located outside the electronics enclosure mounted on a 19" rack.

Two TDK-Lambda GEN 100-15 power supplies are used in MEASSuRE-X systems. Each of the two GEN 100-15 supplies can provide up to 100V at 15A. The two power supplies are wired in series, for a maximum output voltage of 200V and a maximum current of 15A. Given the power rating of MEASSuRE X's control drive (i.e., the JUP-30/130-C) is 130V, the **voltage sum of both power supplies cannot exceed 130V**.



Never set an output voltage that exceeds 130V, i.e., the combined voltage out from both power supplies should be 130V or less ($V1+V2 \leq 130V$).



Fig. 6: Two TDK Lambda GEN 100-15 power supplies connected in series

Follow the instructions below.

- 1) Connect the cable from the power supplies (with a red and black cable sheath) to the "External Power Supply" on the back panel of the enclosure.
- 2) Plug the power cord of each power supply into electrical outlets that use separate fuses.
- 3) Turn on the power supplies by pushing the switch at the front panel. After a few seconds, the voltage display will display "OFF", which means that there is no actual output voltage from the power supply to the control drive. The power supplies will start with the settings right before the power was last turned OFF.



Fig. 7: Power supplies after turning on pressing the power switch on the left.

- 4) The standard operating mode for MEASSuRE-X is constant voltage. Set **the output voltage of each power supply to 63V** and **the current limit of each power supply to 15A** to account for any voltage spikes during fast impulse stretches.
Note 1: The max output voltage for a GEN 100-15 power supply unit is 100V.

Note 2: While the output voltage of each power supply may be set to different values, it is recommended to set each power supply to the same output voltage (as well as OVP protection values) to avoid any confusions while running experiments.

- 5) **IMPORTANT: Press the "FOLD" button (the LED should lit up) to enable the Foldback protection.** This will disable the power supplies' output if the operation mode changes from constant voltage (CV) mode, which is the normal mode, to constant current (CC) mode. This is a safety feature to protect the equipment and user.
- 6) If different operating conditions are desired, follow the instructions below.



When changing the voltage or any other setpoint on the power supply, make sure that the output is turned OFF, i.e., the LED above the "OUT" button is NOT lit.

- i. Change the voltage output setpoint and the current limit:
 - Make sure output is disabled (i.e., LED above "OUT" button is not lit, as shown in **Fig. 8**).
 - Press the preview "PREV" button on the power supply; the LED above it will light up (see **Fig. 8**). The voltage output setpoint and current limits are displayed in the voltage (left) and current (right) screens, respectively (in the example shown in **Fig. 8** below, 30V and 5A on each).



Fig. 8: Checking voltage output setpoint and current limit on the power supplies.

- While the "PREV" LED is on, turn the voltage dial until the desired voltage is reached. Turning clockwise increases the voltage; turning counterclockwise decreases the voltage. Pressing the "Fine" button allows the user to toggle between fine and coarse tuning.
 - Similarly, while the "PREV" LED is on, turn the current dial until the desired current limit is reached.
- ii. Set the Over-Voltage-Protection (OVP) and Under-Voltage-Limit (UVL) protections:

The OVP is important, particularly for very fast motions of the VCA, which protects the equipment from damage. The default **power supply OVP setpoint is 65V** on each power supply, i.e., 130V total voltage. The power supply will show an "OVP" error when the voltage on either power supply exceeds 65V (remember: the controller is rated for 130V). An audible alarm will sound, and the power supply will shut down.

IMPORTANT: The voltage on the power supply can exceed the output voltage setpoint during deceleration ("braking") when the mechanical energy of the VCA is converted to electrical energy, which is fed back into the power supply. A shunting resistor and transistor inside of the electronics enclosure prevents a MotionLab

software (i.e., the software for the servo drive) OVP from occurring by “shunting” the extra energy during deceleration away from the power supply. The shunting circuit must be enabled in the software. Thus, setting the OVP can be considered a safety protection as it limits the output voltage.

The voltage when the shunting circuit gets activated can be set in MotionLab and is set to 133V. Thus, when the voltage received by the Jupiter servo drive exceeds 133V, the shunting transistor opens the shunting circuit so that the mechanical energy from the VCA deceleration is converted to heat (the current flows through a large resistor).

It is recommended to set **each power supply’s UVL to 5V**.

To change the OVP and UVL:

- Press the “OVP/UVL” button once. Using the voltage knob, set the max voltage to **65V**. The current window display shows “OUP.” Once set, wait a few seconds until the LED turns off automatically and “Off” is displayed again.
 - Press the “OVP/UVL” button twice. The current window display shows “UUL.” Using the voltage knob, set the voltage to **5V**.
 - Repeat on the second power supply.
 - The total OVP will therefore be $2 \times 65V$ (i.e., 130V total) and the total UVP will be $2 \times 5V$ (i.e., 10V total).
- 7) Ensure that the “REM/LOC” LED is off, which means that the power supply is in local operation mode.
 - 8) Once ready, press the output “OUT” buttons on both power supplies to enable the power supplies’ output.
Note: Pressing the “OUT” button will provide power to the controller. Therefore, make sure that the controller is ready.

An alternative to a pair of TDK-Lambda GEN 100-15 power supplies can be found in **Appendix A**.

6 MotionLab Setup Instructions

The following protocol describes how to download and install the software, update the driver, update the firmware, and verify communication between the controller and the PC.

6.1 Download and install the MotionLab software

During MEASSuRE system installation and setup, the MotionLab software will be installed on one of the user's computers. If MotionLab is to be installed on a different computer or a newer version of MotionLab is to be installed, follow the instructions below.

- 1) **Contact BMSEED for the latest version of MotionLab (".msi" file).**
- 2) Double-click the installer file and follow the prompts on the MotionLab Setup installer.

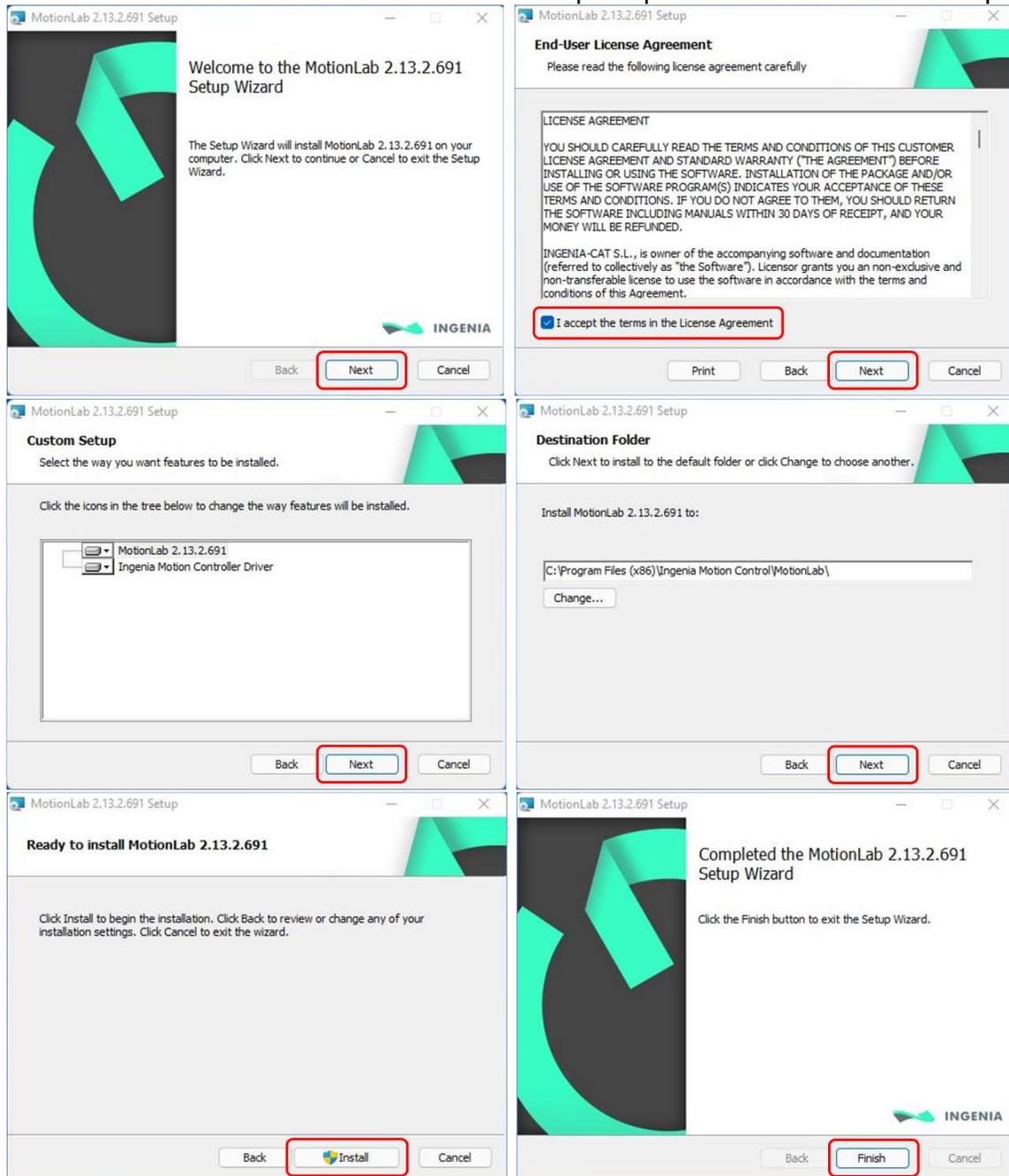


Fig. 9: MotionLab setup/installer windows.

- 3) Once the installer has finished, find the MotionLab icon on your desktop and double-click it to start the software.

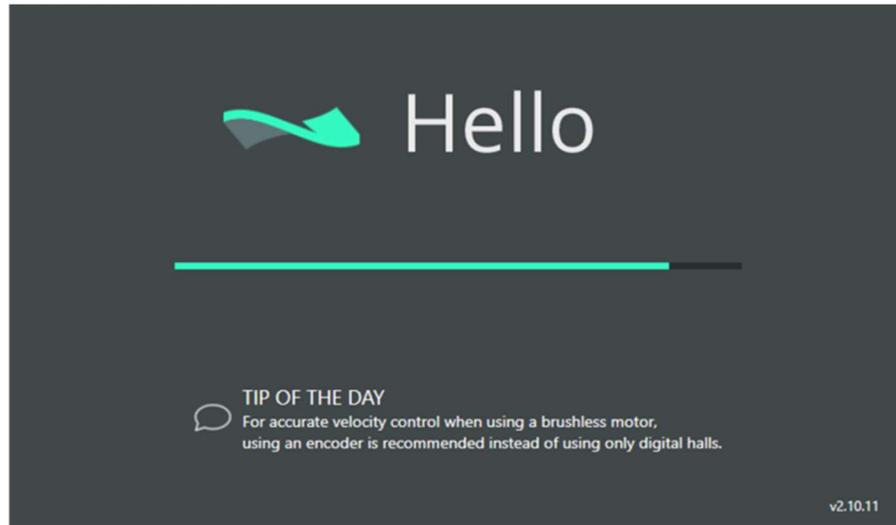


Fig. 10: MotionLab software loading window.

Remarks:

- Note that MotionLab will not detect the Jupiter or Pluto drive until the PCAN-USB or USB drivers have been installed.
- Sometimes, it is necessary to restart your PC to install the driver.
- **For VCA tech support,** contact Sensata Technologies at <https://www.sensata.com/contact-us-technical-support>.

6.2 If connecting via USB, download and install the USB driver

We recommend **connecting to the controller via a USB cable only when upgrading the firmware of the controller**. For all other operations, we recommend using the CANopen (PCAN) connector (see below) because this communication protocol is less sensitive to electromagnetic interferences.

- 1) If using a MEASSuRE-X system, plug in and turn on the power supplies. Ensure that the power supplies output is enabled. In addition, plug in the power cord to the electronics enclosure Power connector and make sure the power switch is turned on. If using a MEASSuRE-Mini or -Premium system, simply plug in power cord to the electronics enclosure Power connector and make sure the power switch is turned on. The Power LED of the Jupiter or Pluto drive should be lit green to indicate that the Pluto has power. The Run LED should be continuously blinking green to signal that the device is in its Pre-Operational state.

For more information about the servo drive's LED lights, visit <https://drives.novantamotion.com/jup/signalling-leds>

- 2) Connect the control drive and the PC using the USB cable.
 - The first time you connect the controller drive, Windows may ask for the necessary drivers.
 - Select "Search automatically for updated driver software." This window should find the appropriate drivers online.

- The USB driver should install automatically once the Pluto or Jupiter servo drive is powered up and connected to the computer.
- If the automatic search did not find the drivers, select "Browse my computer for driver software." Choose the folder where you saved the drivers beforehand.



Fig. 11: Driver installation window.

- Note: If the above window does not automatically pop up, go to the Device Manager to install the driver manually. Right-click "Ingenia USB Controller (COM#)" under "Ports & COM (LPT)," and select "Update Driver Software." Select "this time only", then click "Next." Select "install from a list or specific location", then click "Next." Use "Browse" to select the location where you earlier saved the USB driver files.

6.3 If connecting via CANopen, download and install the PCAN-USB adapter driver

The PCAN driver should be installed prior to connecting the Pluto or Jupiter servo drive to your computer.

- 1) Go to https://www.phytools.com/PCAN_USB_Adapter_p/ipeh-002021.htm, which is the website of the PCAN-USB adapter's manufacturer (i.e., PhyTools).
- 2) Click the "Downloads" tab and select "Device driver setup for Windows" to download the drivers for different versions of Windows.
- 3) Locate the zip file containing the PCAN-USB drivers and double-click it. Double-click the application file "PeakOemDrv.exe" and follow the on-screen instructions to install the drivers.
- 4) Follow step 1) described in the USB driver connection instructions (**Section 6.2**).
- 5) Connect the control drive and the computer using the PCAN-USB adapter cable. The DB9-end of the adapter cable is connected to the rear panel of the electronics enclosure, and the USB-end connected to the computer.
- 6) The Jupiter or Pluto drive should be connected to the computer and ready to use.

6.4 Download and install the firmware

Occasionally, the firmware of the servo drive (i.e., Jupiter and Pluto drive) will need to be updated. You will know if a firmware update is available for the connected drive if the text **"New FW Available"** is displayed next to the servo drive as shown in **Fig. 12** below.

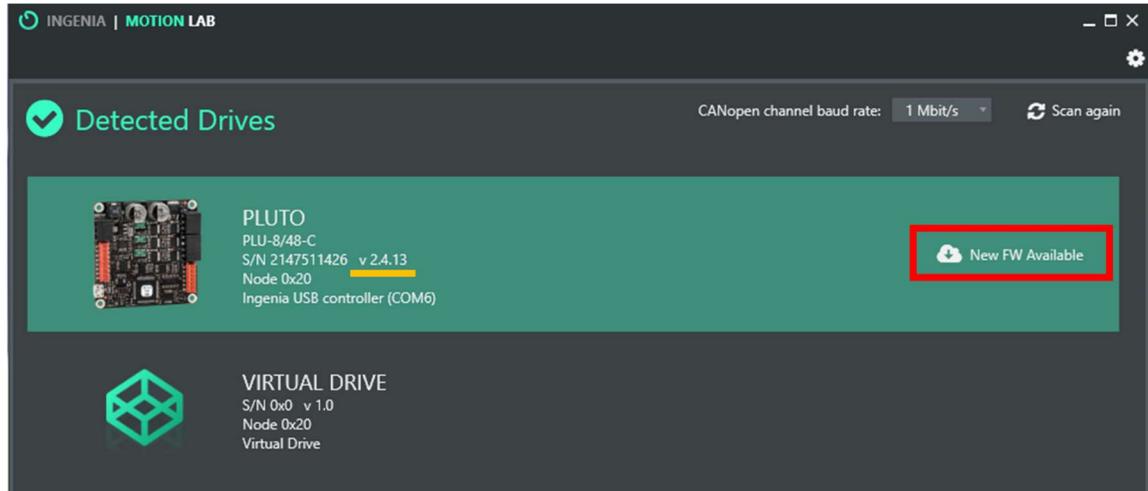


Fig. 12: Detected Drives window after MotionLab loads displaying the current firmware version.

If this is the case, follow these steps:

- 1) Connect the control drive (through the connector in the rear panel of the electronics enclosure) using **USB communication**.
Note: Connecting to the Jupiter or Pluto drive using the PCAN-USB adapter directly or using a PCAN extension cable usually results in an error that does not allow the firmware to be updated.
- 2) Load the MotionLab software.
The communication listed at the bottom of the detected drive should appear as "Ingenia USB controller (COM#)."
- 3) Click the "New FW Available" button as shown in **Fig. 12**.
Note: There is no need to manually download the firmware ".hexenc" file.
- 4) In the pop-up Update Firmware window, click "Update Firmware."

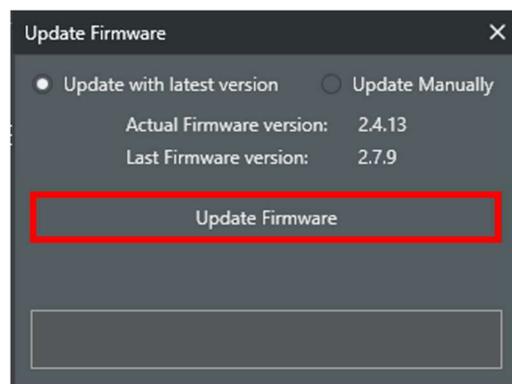


Fig. 13: Update Firmware window showing the current ("actual") firmware on the drive and the most recent ("last") firmware version available for download.

- 5) In the pop-up warning message click “Ok.”

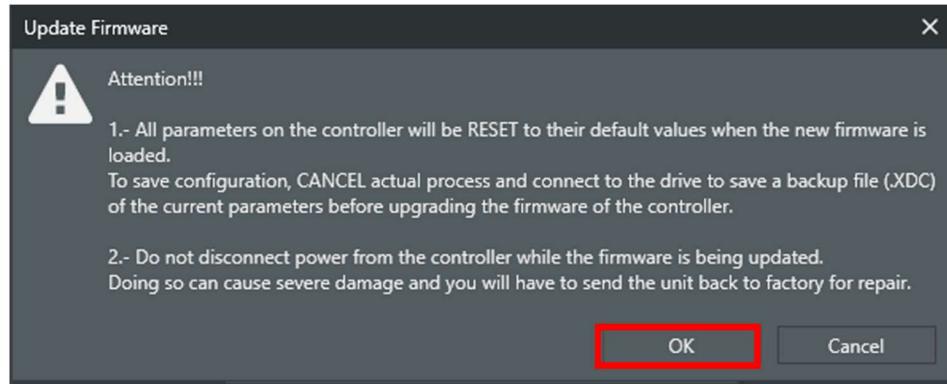


Fig. 14: Warning message when updating the firmware.

- 6) After a few seconds the firmware should be updated and the status “Drive updated successfully!” should now be displayed.

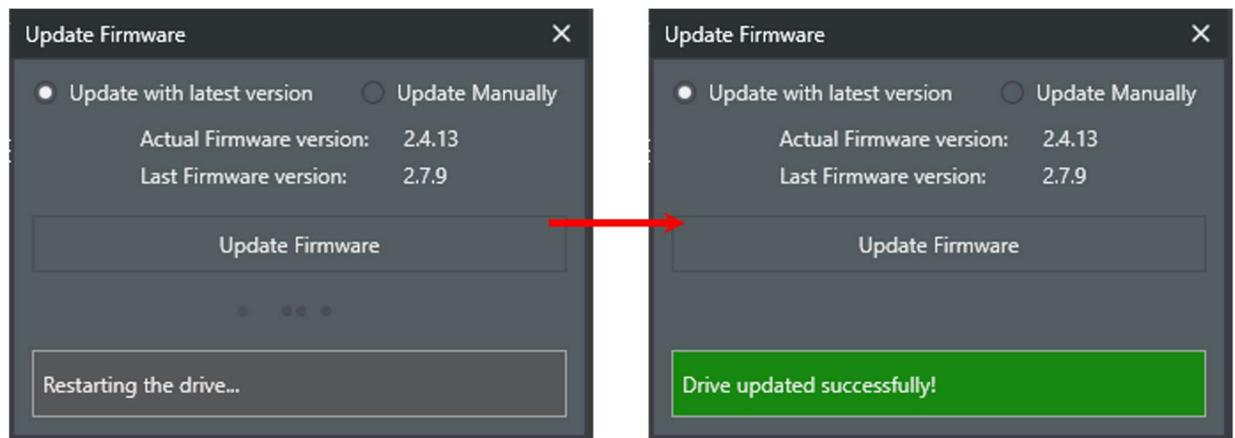


Fig. 15: Update Firmware window after successfully updating the firmware.

- 7) The detected drive should now display the updated firmware and the firmware status should now display “Update FW.”

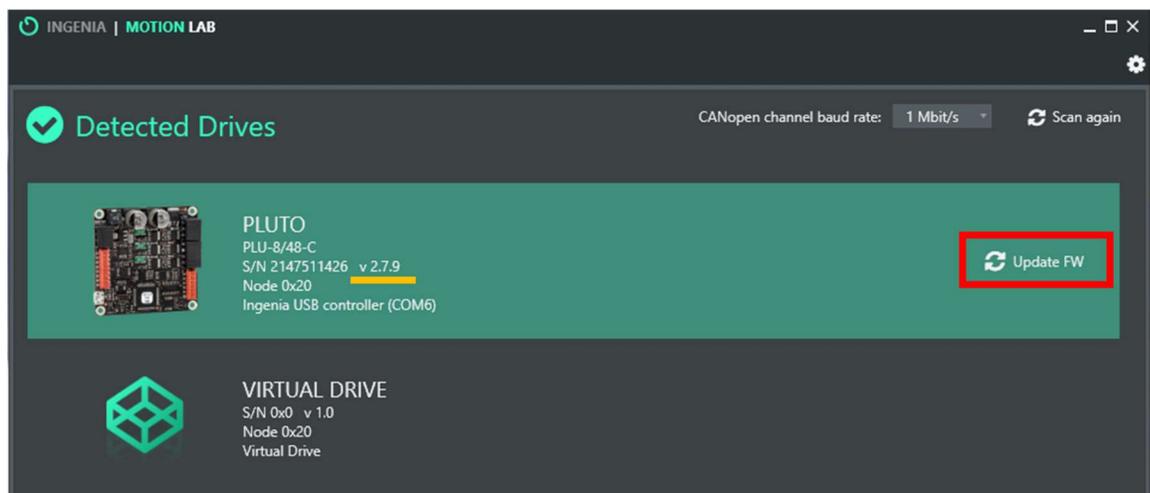


Fig. 16: Detected Drives window showing the updated firmware version.

The firmware can also be manually updated (i.e., the user must select the firmware “.hexenc” file to be loaded on the drive). These steps can be found in **Appendix B**.

6.5 Download and load the corresponding XML Device Drive (XDD) File

Updating the firmware following the protocol shown in **Section 6.4** above automatically uploads the correct XML Device Drive (XDD) file to the drive as well. It is recommended to verify that the correct, recommended XDD file is loaded to the Jupiter or Pluto drive. Follow these steps:

- 1) Connect to the control drive (Jupiter or Pluto) you want to verify or configure.
- 2) In the Drive Overview section, click on "Additional drive information."

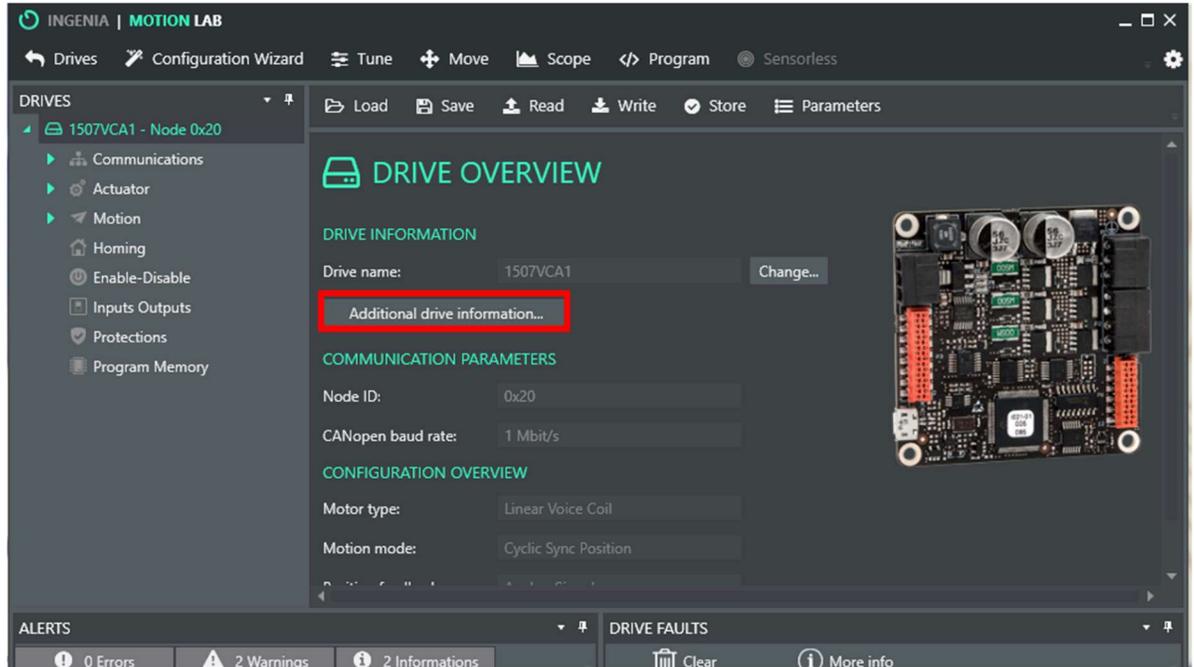


Fig. 17: Main MotionLab window after connecting to a drive.

- 3) The pop-up window will list the recommended XDD and used XDD. It is necessary for these two files to match for proper performance of the VCA.

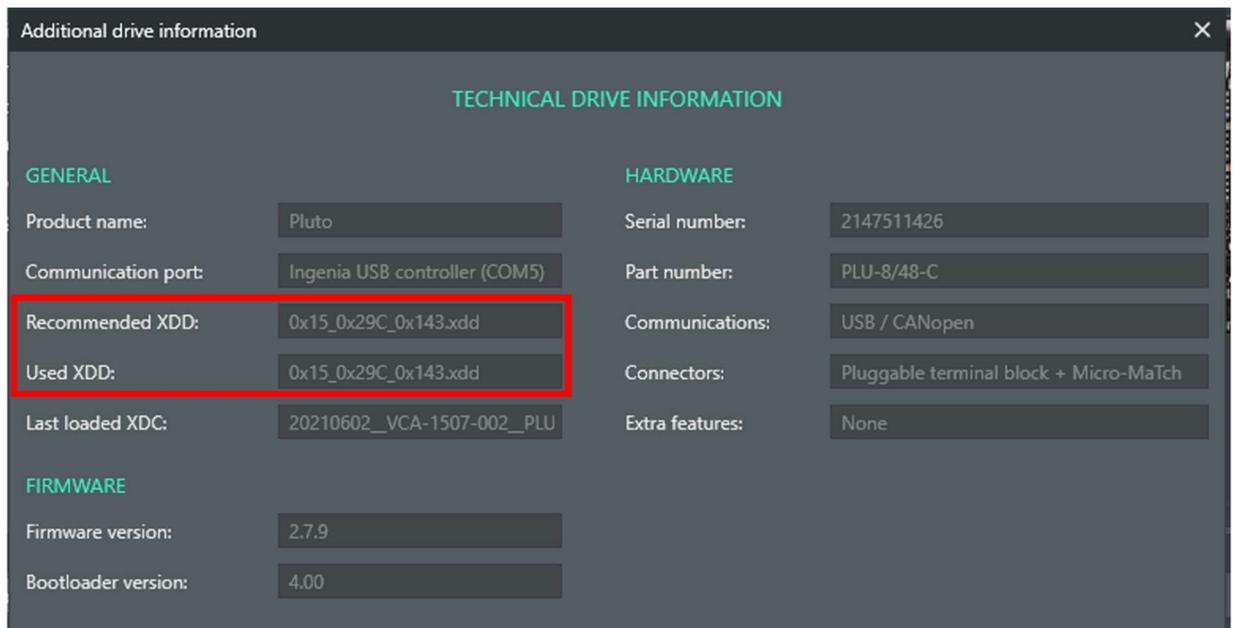


Fig. 18: Additional Drive Information window showing the recommended and used XDD files.

- 4) If the “Recommended XDD” matches the “Used XDD,” the correct XDD is loaded and there is no need to manually update the firmware.

However, if the “Recommended XDD” does not match the “Used XDD,” the appropriate XDD file must be manually uploaded. Follow the steps found in **Appendix C**.

6.6 Load the corresponding Drive Configuration (XDC) Files

The XDC file contains all parameter values for the VCA and controller, such as the resistance and inductance of the coil, the PID settings, the mapping of the position sensor, etc. **The XDC file is specific to your MEASSuRE system and will be provided by BMSEED.** It is important to load the Drive Configuration (XDC) file each time you start MotionLab so that all the appropriate VCA parameters are set for MEASSuRE system and target application.

- 1) **Contact BMSEED for your system-specific drive configuration file (“.xdc” file extension).**
- 2) Click on “Load” at the top left of the window.

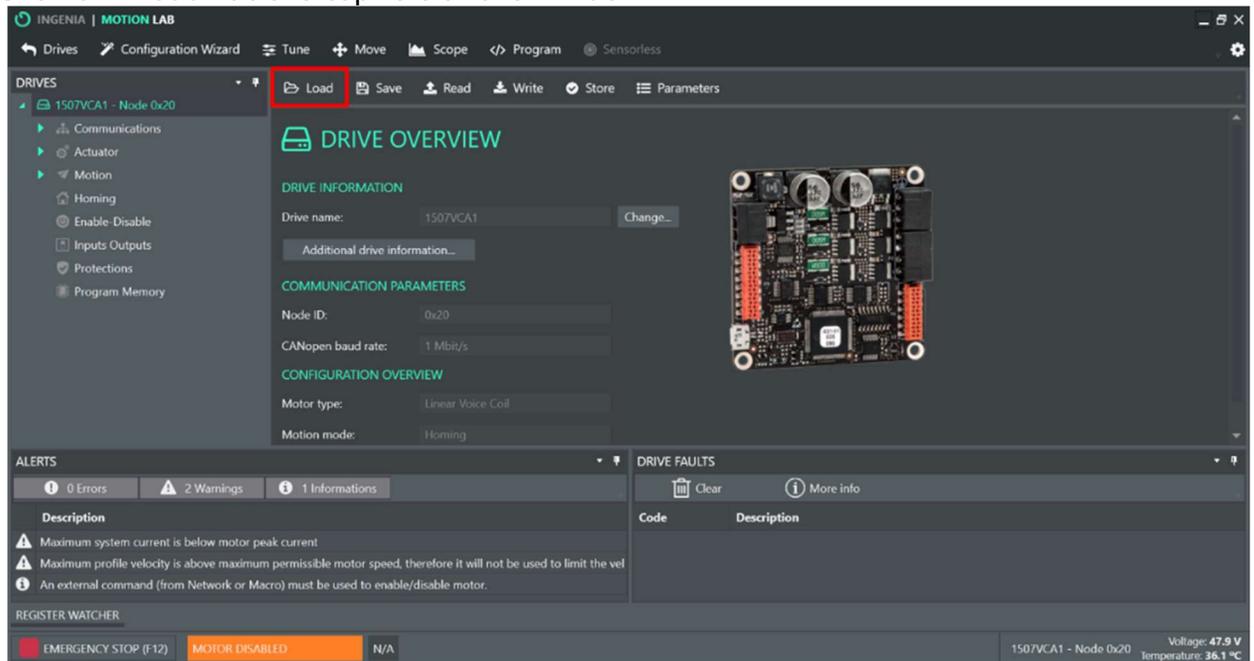


Fig. 19: Loading a drive configuration (XDC) file.

- 3) Find the drive configuration file (XDC) in your computer, select it and click “Open”.
- 4) A warning message will appear. Click “Ok.”

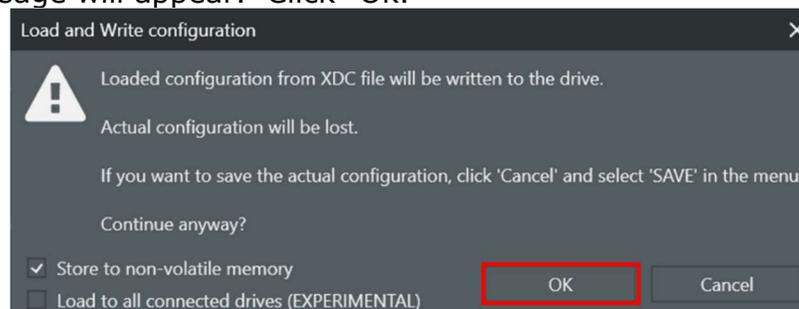


Fig. 20: Warning message when loading an XDC file to drive.

5) The Jupiter or Pluto servo drive parameters should now be updated and ready for use.

Note: Loading an XDC configuration file automatically writes the new parameter values to the servo drive. Thus, there is no need to click the “Write All” button.

6.7 Verify the USB or CANopen communication

After installing the drivers, go to your computer’s Device Manager.

If using USB communication, expand the “Ports (COM & LPT)” list. The connected Jupiter or Pluto drive should be displayed as “Ingenia USB controller (COM#).” This confirms that there is communication between the controller and the computer and shows that the drives have been correctly installed.

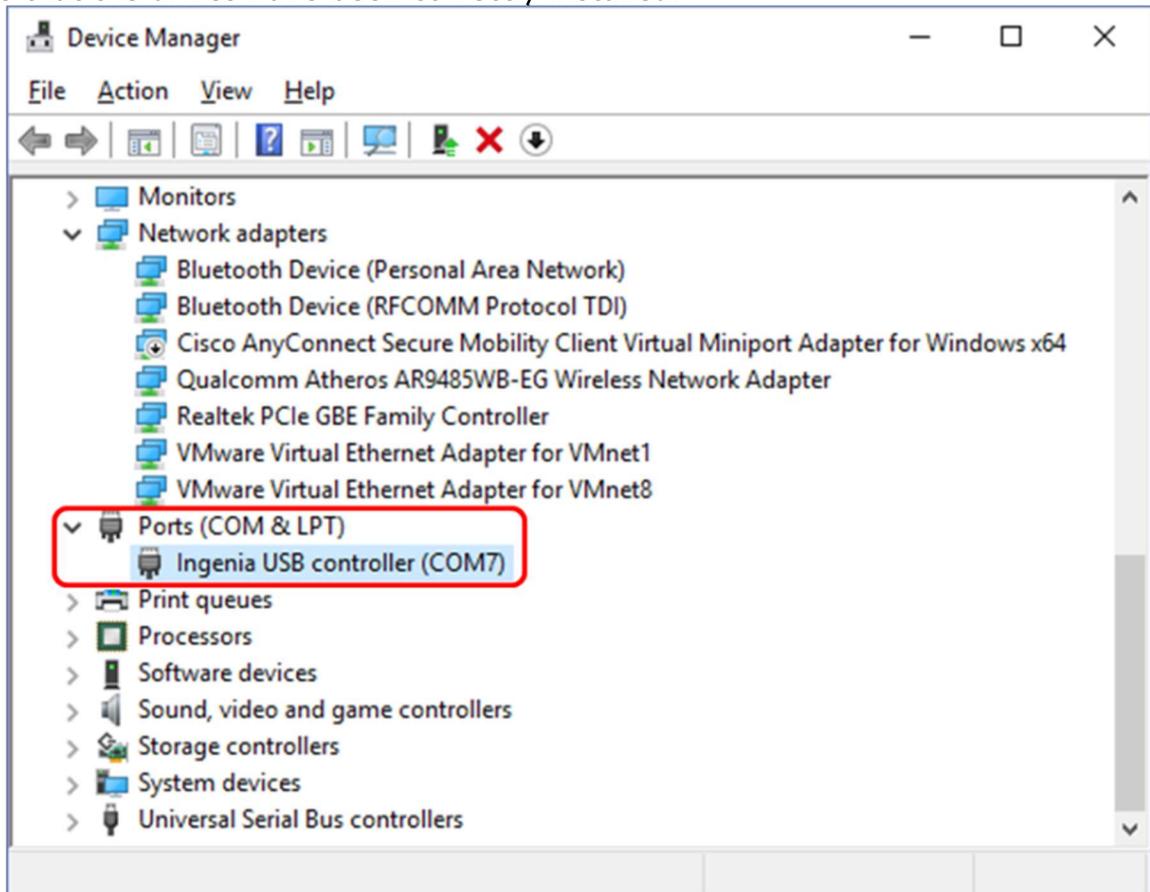


Fig. 21: Device Manager window showing the USB connection to the control drive.

Note: You must have a USB cable connected to the Jupiter or Pluto servo drive and have it powered up. Otherwise, the drivers will not show up in the Device manager window.

If using CANopen communication, expand the “CAN-Hardware” list. The connected Jupiter or Pluto drive should be displayed as “PCAN-USB.”

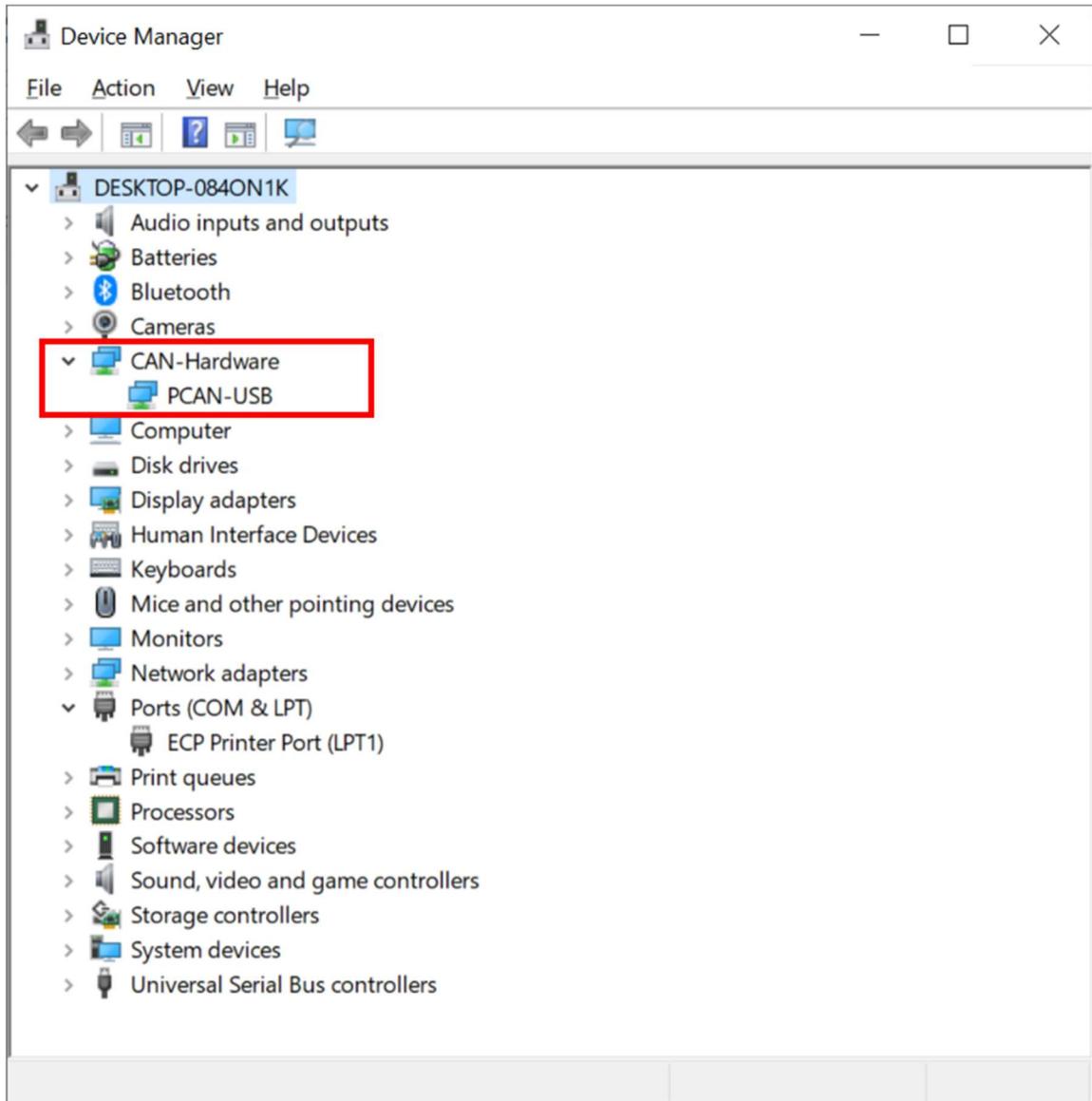


Fig. 22: Device Manager window showing the CANopen connection to the control drive.

6.8 References

For more information, visit the following websites:

- MotionLab software manual:
<https://drives.novantamotion.com/mot2/user-manual>
- Manual to understand the Jupiter or Pluto commands or parameters:
<https://drives.novantamotion.com/emcl/command-reference-manual>

7 Basic Operating Instructions

This section describes the basic functions of the MotionLab software that controls the VCA. This manual describes the operation of **MotionLab version 2.13.2.692**. Keep in mind that older and newer versions of the software might look a bit different.

7.1 Starting the MotionLab software

- 1) Make sure the hardware is properly set up (**Section 5**).

Note: If running a MEASSuRE-X, double-check that the voltage output on each power supply does not exceed 63V. While not necessary or a safety issue, it is recommended to set the output voltage of both power supplies connected in series to the same value. Similarly, the OVP and UVL protections on each power supply are recommended to be the same. Having the same setup on both power supplies will help avoid confusion while running the MEASSuRE-X system.
- 2) Start the Ingenia MotionLab software by clicking on the “MotionLab” icon on your desktop. The MotionLab window should open (as shown in **Fig. 12**).
- 3) Select the Pluto or Jupiter servo drive connected to your computer, depending on the configuration of your MEASSuRE system.
 - If the Jupiter or Pluto drive does not show up on the list of detected drives, click “Scan again” on the top right. If it still does not appear, check your wiring, particularly the USB or CANopen connection, to ensure proper communication.
 - You may have forgotten to flip the power switch on the rear of the enclosure to the “on” position. Flip the switch and click on “Scan again” in the GUI.
 - If multiple control drives are connected to the computer, you can use the Serial Number (S/N) to distinguish between them.
- 4) The GUI has three sections:

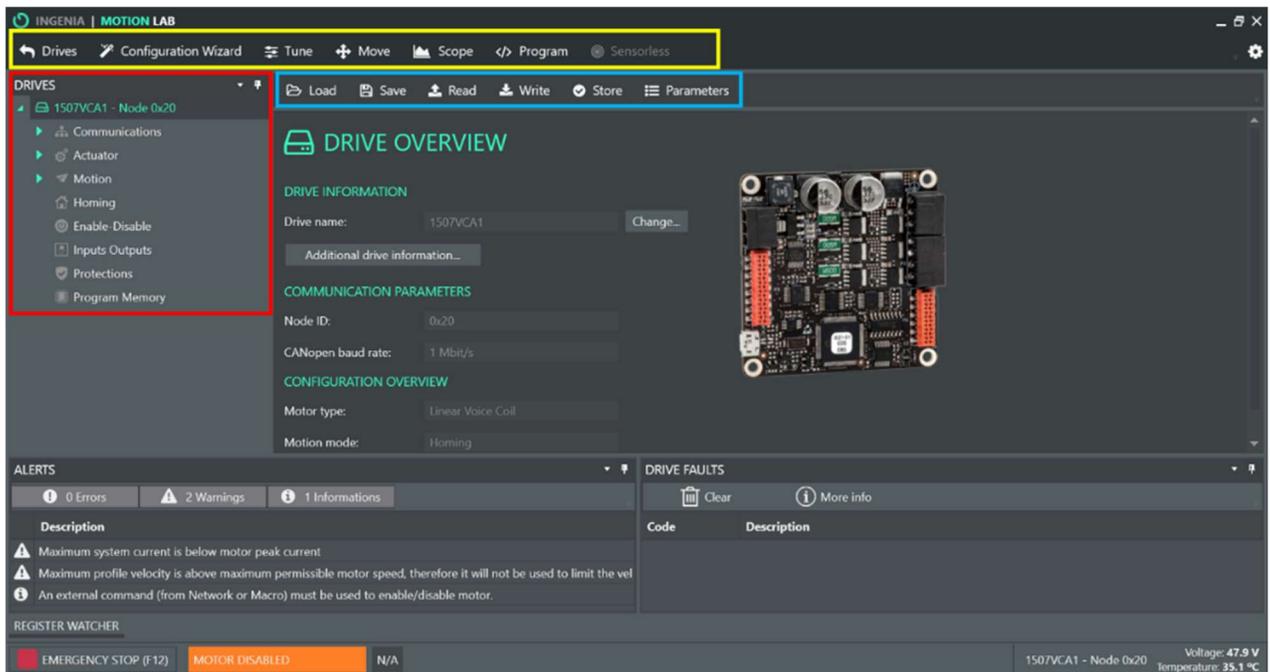


Fig. 23: MotionLab window with its three main menus highlighted.

- Section 1 (yellow): The function launcher
 - Here you can find the Tune, Move, Scope and Program tabs.
 - The Tune tab can be used to optimize the position and torque control gains that control the VCA motion. BMSEED provides optimized PID gains, which are loaded in the controller. Therefore, the user does not need to perform the initial control optimization.
 - The Move, Scope and Program functions are described below.
- Section 2 (blue): XDC configuration menu
 - Here you can find button to load an XDC file, save an XDC file, and write updated parameters to the servo drive.
- Section 3 (red): The drive configuration page tree
 - Important control drive, actuator, position limits, control, and protection settings can be found here.
 - Some parameters in Sections 1 and 3 overlap (can be updated in either).

5) We will focus here on the Move, Scope, and Program tabs (highlighted in yellow in **Fig. 24**). The Tune menu (green highlight) will be explained in **Appendix D**.

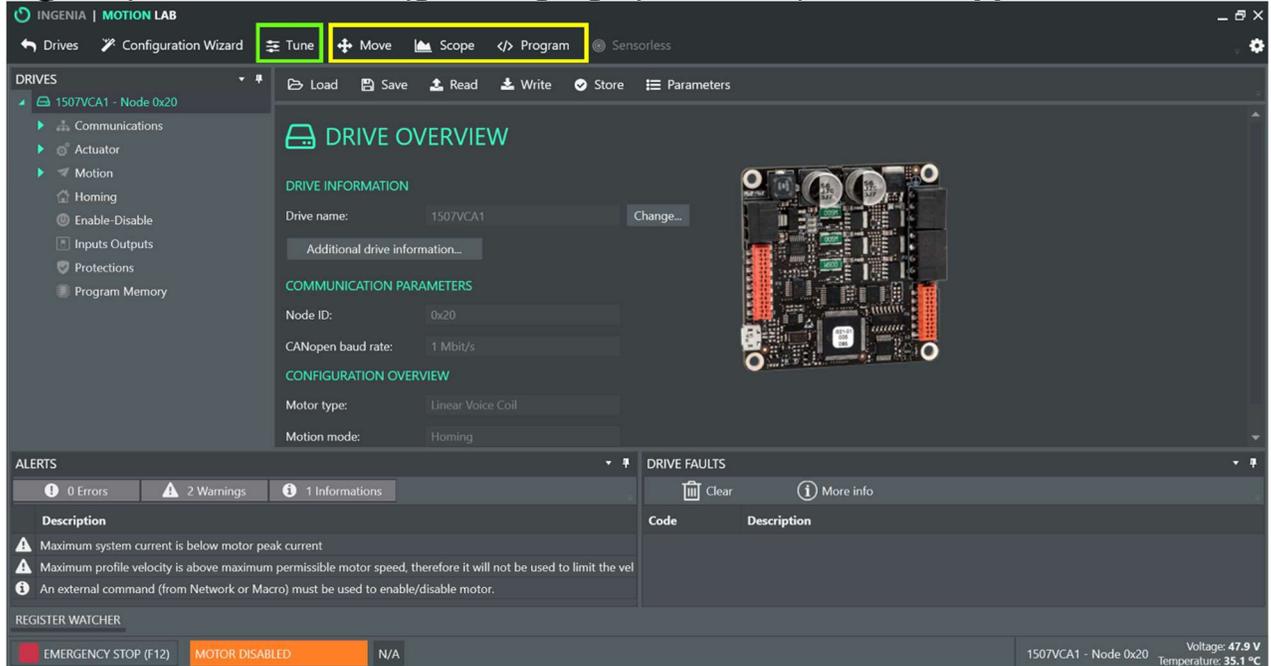


Fig. 24: The Move, Scope, and Program menu buttons.

7.2 Recommended Checks Prior to Use

7.2.1 Checking the communication between the VCA and the control drive

Prior to controlling the VCA, it is important to check the communication between the VCA and control drive through MotionLab. Perform the following checks:

- 1) In the "Inputs Outputs" window, test that the servo's Analog Input 1 signal responds to manually moving the VCA's movable platform up and down (orange box in **Fig. 25** below).
Expected response: voltage should increase as the platform is raised and vice versa.

- 2) In the “Inputs Outputs” window, test that the servo’s digital General Purpose Input 1 signal responds to pressing the “VCA go” button on the front panel (cyan box in **Fig. 25** below).

Expected response: when pressed, the state should change to “On.”

If the General Purpose Input 1 is not responding, this indicates an issue with the VCA go button. Make sure there are no apparent issues with the wiring and connections inside the enclosure, specifically the internal DC-DC converter and screw block terminal with all wiring connections.

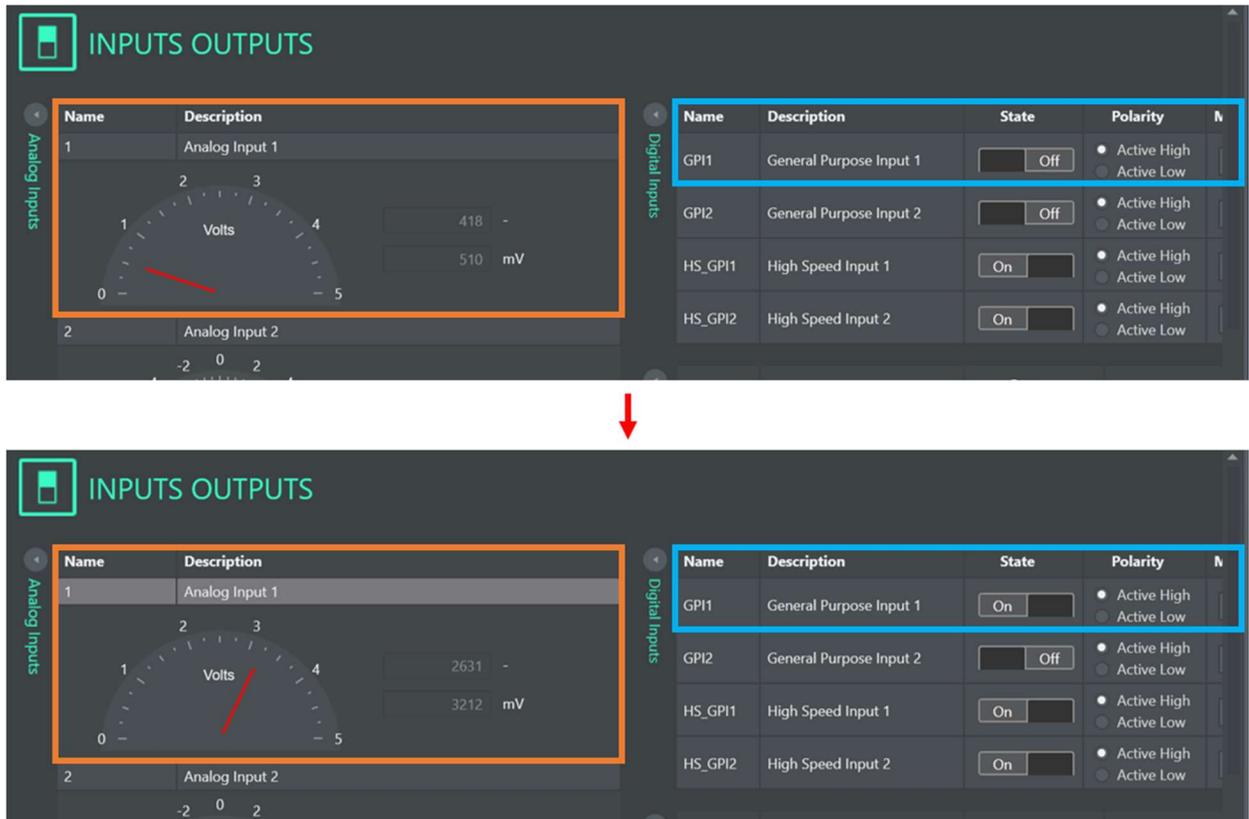


Fig. 25: Testing the Analog Input 1 and General Purpose Digital Input 1.

- 3) In the “Analog Signal” window under “Actuator,” test that the actual position responds to manually moving the movable platform (shown in **Fig. 26** below). Expected response: the position should increase when raising the platform and decrease when lowering the platform.

If the Analog Input 1 or the actual position readings are not responding, this indicates an issue with the VCA sensor cable. Make sure that the VCA sensor cable is properly connected to the back of the enclosure. If this fails, the wiring inside the enclosure between the VCA sensor cable connector and servo drive I/O connector must be checked. Another potential cause could be an issue with the external soldered connection between the VCA sensor cable and the IEC C6 ‘extension’ cable.

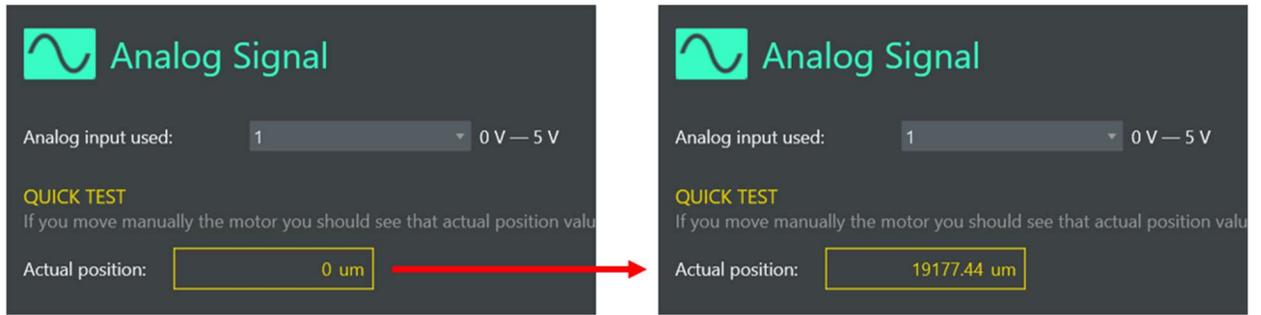


Fig. 26: Testing the actual position (i.e., analog signal) of the VCA.

7.2.2 Verifying the input voltage from the connected power supplies

The input voltage from the connected power supply(ies) should be verified as well. This voltage is displayed on the bottom right of the MotionLab window (in **Fig. 27** below).

If testing a **MEASSuRE-X**, make sure the power supplies are turned on and their output is enabled.

- Set each power supply's output voltage to 30V and check that the measured voltage on the lower right corner displays roughly **60V**.
- Lower the output voltage of one power supply to 15V and ensure that the displayed voltage updates to roughly **45V**. A decrease in the applied voltage takes a few seconds to be displayed.

If testing a **MEASSuRE-Premium** or **MEASSuRE-Mini**, ensure that the measured voltage on the lower right corner of the MotionLab window matches the rated voltage of the power supply inside the enclosure. For both models, the output voltage should be close to **48V**. However, the models' power supply's rated current is different:

- If using a MEASSuRE-Premium, the MeanWell UHP-500-48 is rated for 10.45A.
- If using a MEASSuRE-Mini, the MeanWell RSP-150-48 is rated for 3.2A.

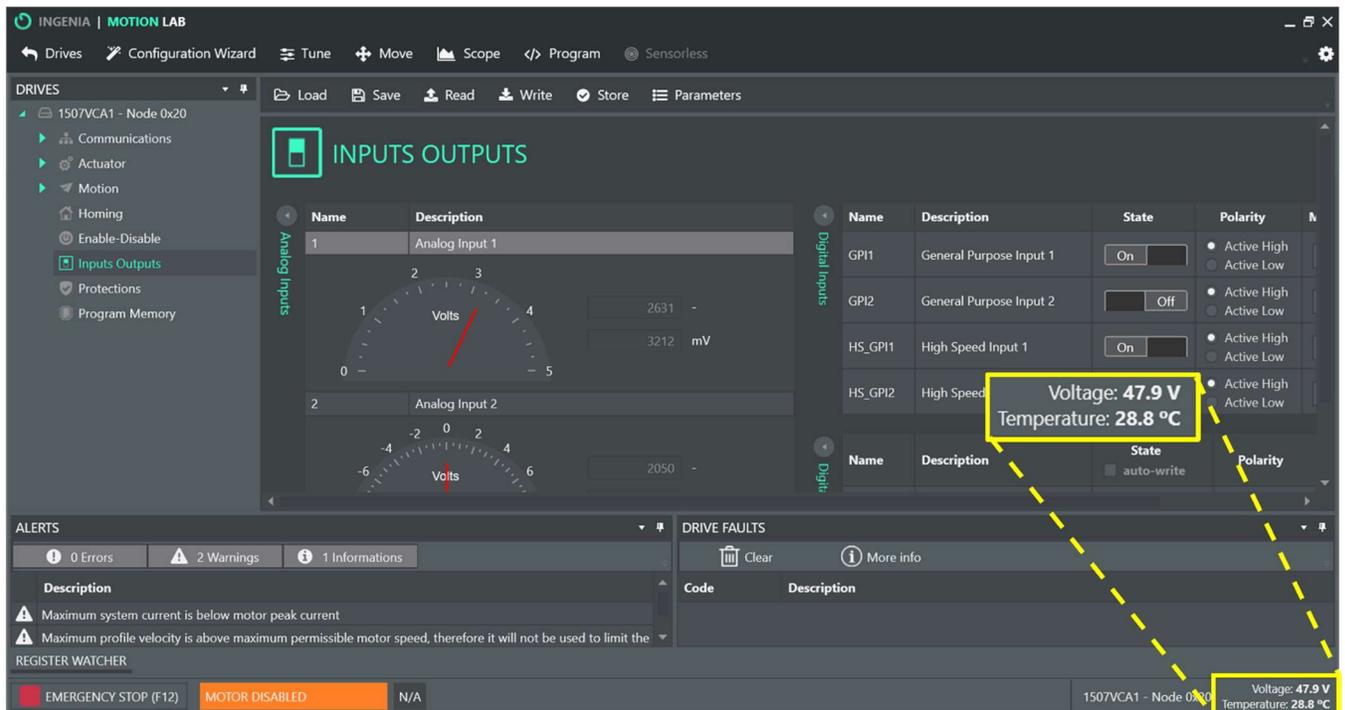


Fig. 27: Input voltage and measured temperature (e.g., with a MEASSuRE-Premium).

Potential issue: If the voltage reading does not respond accordingly, double check the wiring to the control drive's supply and shunt connector. If using a MEASSuRE-X, check that the power supplies' outputs are enabled and examine the supplies' output cable.

7.2.3 Checking the control drive temperature

The temperature of the control drive should be monitored as well. Like the input voltage, the measured temperature is also displayed on the bottom right of the main MotionLab window (**Fig. 27**). Prior to being run, it should be close to room temperature.

7.2.4 Checking the system protections

The current, voltage, and temperature protections must be verified as well. Note that **all values listed under Protections are set by BMSEED prior to MEASSuRE system installation**, but it is good practice to double check them. You can find these parameters in the "Protections" section of the Drives communication section on the GUI. Typical protections and motor parameters can be found in **Appendix E**.

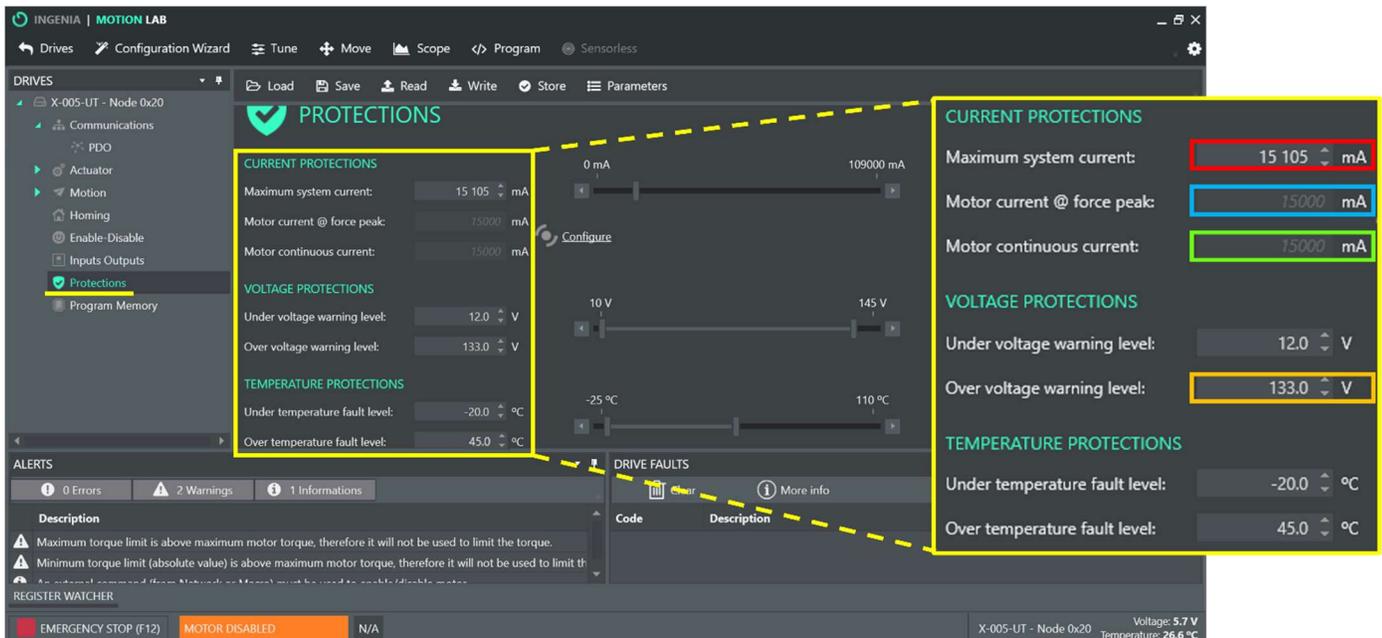


Fig. 28: Protections settings section (e.g., with a MEASSuRE-X).

- 1) Maximum System Current: This parameter (red box in **Fig. 28**) regulates the maximum current that is drawn from the power supply (or supplies) and sent to the VCA. **While this parameter does not trigger a fault in MotionLab when the demanded current** (calculated from the torque demand data and force sensitivity under Motor Parameters) **exceeds this value, the applied (i.e., actual) current will be capped at this value.** This means that, for example, if the max system current parameter in MotionLab is set to 10A and the current limit on the power supplies' is set to 15A, the current supplied to the VCA will not exceed 10A.
 - a. If this value is too small, VCA performance could be significantly affected since not enough power (current × voltage) might be supplied to (i.e., torque generated by) the actuator.

- b. The maximum system current value depends on the **power limitations of the MEASSuRE system control drive (e.g., Jupiter vs. Pluto) and the connected power supplies**. The amount of current demanded by the VCA depends on the target strain and strain rates.
- c. Double-check the default values for the different models of MEASSuRE:
- MEASSuRE-**X**: **15,105 mA**
 - MEASSuRE-**Premium**: **10,450 mA**
 - MEASSuRE-**Mini**: **1,505 mA**
- d. For MEASSuRE-X systems, this parameter is set to a value slightly larger than 15A, which corresponds to the maximum current the power supplies can produce. It is recommended to set this parameter to a lower value if the expected current demand is significantly below 15A. For example, if the actual current drawn from the power supply is 8A for a given stretch, the user can set the Maximum System Current to 9A to limit the exposure of the controller and VCA to higher currents. This is a safeguard to prevent damaging system components due to unexpected errors.
- 2) Motor current @ force peak and Motor continuous current: These value (blue and green boxes in **Fig. 28**) cannot be changed here. The displayed values match the settings and can be changed under Motor Parameters (blue and green boxes in **Fig. 29**). These values are set based on the **power limitations of the MEASSuRE system's control drive (e.g., Jupiter vs. Pluto) and the connected power supplies**.

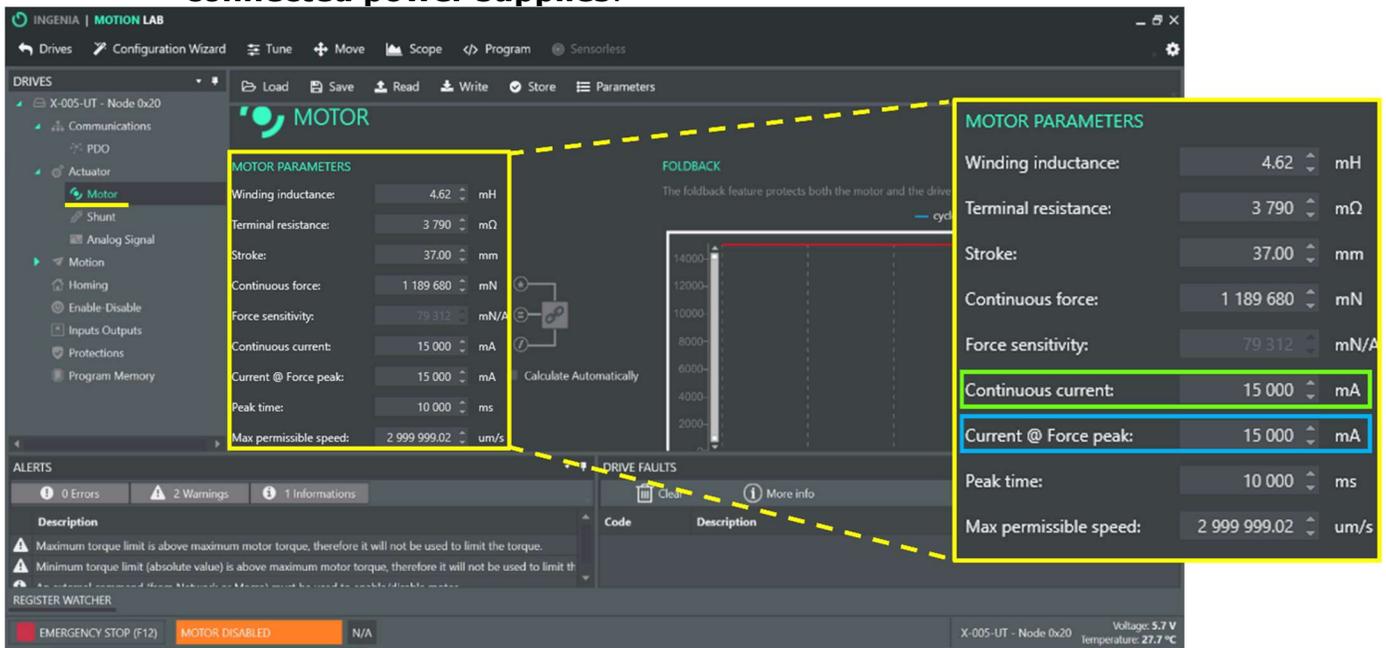


Fig. 29: System motor parameters (e.g., with a MEASSuRE-X).

Double-check the default values for the different models of MEASSuRE:

- MEASSuRE-**X**: **15,000 mA** for both parameters
- MEASSuRE-**Premium**: **10,000 mA** for both parameters
- MEASSuRE-**Mini**: **1,111 mA** for both parameters

- 3) Under voltage warning level (UVWL): If the input voltage to the control drive is below this value, a fault will trigger, and the actuator will be disabled. For all types of MEASSuRE systems, this value is typically set to **12V**.
 If using a MEASSuRE-X, the MotionLab UVWL and the external power supplies' UVL are independent of each other, but they operate similarly. If the set output voltage of either of the power supply units is set to $<5V$ (i.e., the default power supply UVL value), the supply's alarm will be triggered, and its output will not be enabled. Only after increasing the set output value of the power supply to $\geq 5V$ the supply's output will be enabled. If the combined output voltage of both power supplies is lower than the set UVWL (i.e., default of 12V), a "Fault" will trigger in MotionLab, and the VCA will not be enabled even if voltage is being provided to the servo drive by the power supplies.
- 4) Over voltage warning level (OVWL): If the input voltage to the control drive is above this value, a fault will trigger, and the actuator will be disabled. This value (orange box in **Fig. 28**) is set depending on the **power limitations of the MEASSuRE system control drive (e.g., Jupiter vs. Pluto) and the connected power supplies**. For instance, if using a JUP-30/130-C drive and power supplies limited to 200V (as in MEASSuRE-X systems), the OVWL should be set to approximately 130V, which is the Jupiter drive's voltage limit. It is recommended to set the OVWL slightly larger than the actual hardware limit to account for brief voltage spikes that appear during very fast impulse stretches. Thus, for the MEASSuRE-X in this example, the OVWL should be set to 133V.
 During very fast impulse stretches, voltage spikes that may exceed MotionLab's OVWL. If this is the case, one of the following will occur: 1) if this is a MEASSuRE-X system with a shunt resistor, the shunt resistor will activate, or 2) if there is no shunt resistor (as in -Premium and -Mini systems), a fault will trigger in MotionLab, disabling the VCA.
 Double-check the default values for the different models of MEASSuRE:
- MEASSuRE-X: **133 V**
 - MEASSuRE-Premium: **50 V**
 - MEASSuRE-Mini: **50 V**
- If using a MEASSuRE-X, the MotionLab OVWL and the external power supplies' OVP are independent of each other, but they operate similarly and can be considered safety precautions. If the voltage spikes are larger than the external power supplies' OVP, the supplies' alarm will trigger, disabling their output.
Note: Although the UVWL and OVWL are labeled as "warnings" in MotionLab, they trigger faults that prevent the VCA from being enabled if the input voltage is not within an acceptable range. Thus, the input voltage cannot be less than the UVWL or greater than the OVWL.
- 5) Under temperature fault level: If the control drive temperature is below this value, a fault will trigger, and the actuator will be disabled. For all models of MEASSuRE, this value is set to **-20°C**.
- 6) Over temperature fault level: If the control drive temperature is above this value, a fault will trigger, and the actuator will be disabled. For all models of MEASSuRE, we typically set this value to **45°C**. When in use the control drive's temperature should remain at temperatures below 35°C.

7.3 “Move” menu

To access this menu, click the “Move” tab.

- The “MotionLab-Move” window will pop up. It allows the user to control the movement of the VCA using various modalities.
- In this manual we will focus on the following three modalities:
 - **Homing**: Here, you can set your reference point. This should always be the first command you run when starting a session with the VCA.
 - **Position**: This menu allows you to control the position of the sMEA relative to the fixed indenter. You may type in the desired target position value, use a sliding bar to control position, or specify a displacement step.
 - **Oscillation**: When a sinusoidal profile is desired, this menu should be used as it allows you to specify a baseline, amplitude, and frequency for this type of position profile.



Fig. 30: Tabs in the MOVE sub-menu.

7.3.1 Homing modality

The homing procedure defines the zero position (in counts or μm) for the position sensor within the VCA.



It is important to home the VCA each time you use the MEASSuRE system because all movements of the VCA initiated from the Position, Oscillation, or Program (Macro) tab use this 0-position as the reference point for all motions.

- 1) In the Move window, click “Homing” in the top menu.

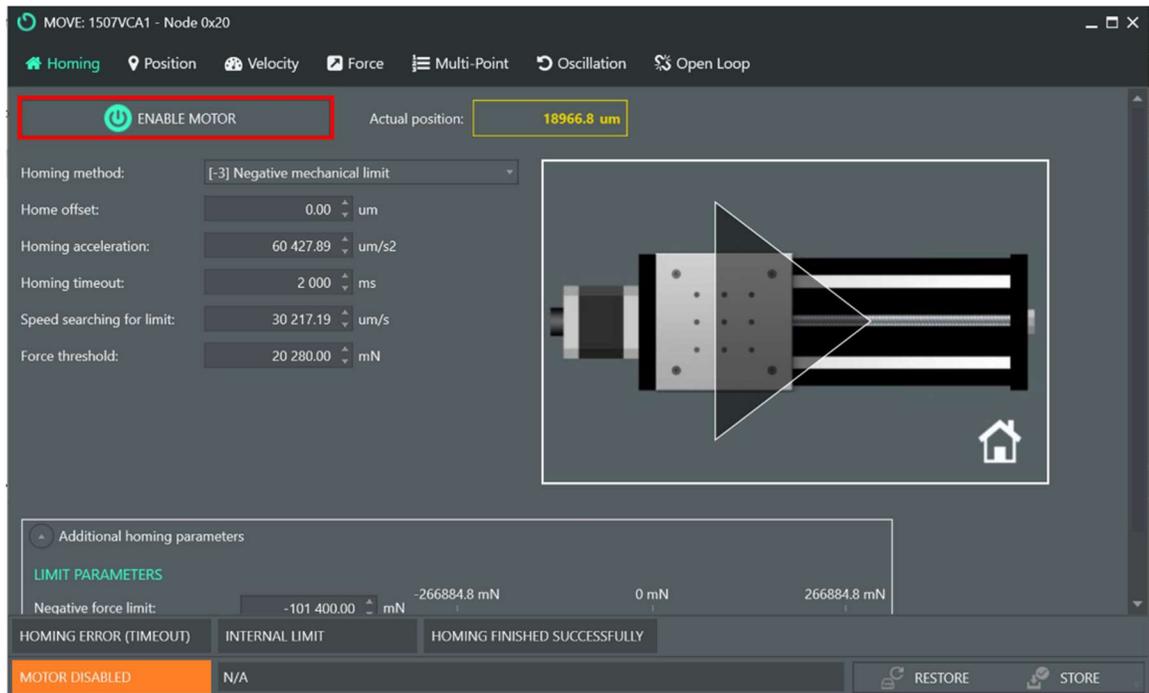


Fig. 31: Homing tab with the “Enable Motor” button highlighted.

- 2) There are several homing methods options. BMSEED's standard is to select "[-3]: Negative mechanical limit." This commands the VCA to move the movable platform with the sMEA down in the z-direction until it reaches a physical or mechanical limit, which will be the new reference point (i.e., the 0- μm position).
- 3) Before homing, if not already there, place the homing block underneath the Y-adapter as shown in **Fig. 32**.



Fig. 32: Homing block underneath the Y-adapter.



If using a MEASSuRE-X, the power output of both power supplies needs to be enabled by pressing each supply's "OUT" button (i.e., green LED should be lit).

- 4) Click "Enable Motor" to start the homing procedure.

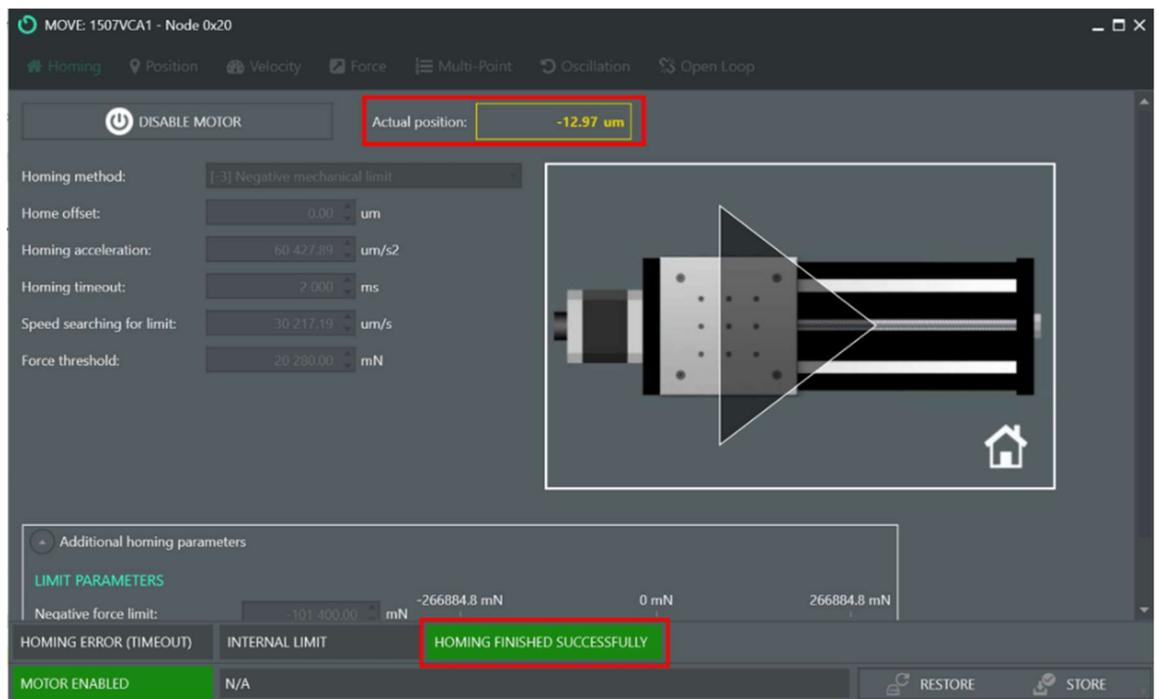


Fig. 33: Homing tab after the VCA has successfully homed.

- The VCA will "home" and the "Actual Position" tab should show a value of 0 μm (or counts) or a value close to it, as shown in **Fig. 33**.
- The indicator "Homing Finished Successfully" indicator should turn green.

- 5) Click "Disable Motor" to end the homing procedure.
 - The actual position should remain close to 0 μm .

7.3.2 Position modality

The position tab allows users to move MEASSuRE's movable platform up or down to specific positions.

- 1) In the Move window, click "Position" in the top menu to control the VCA movement.
- 2) The following options should now be displayed.

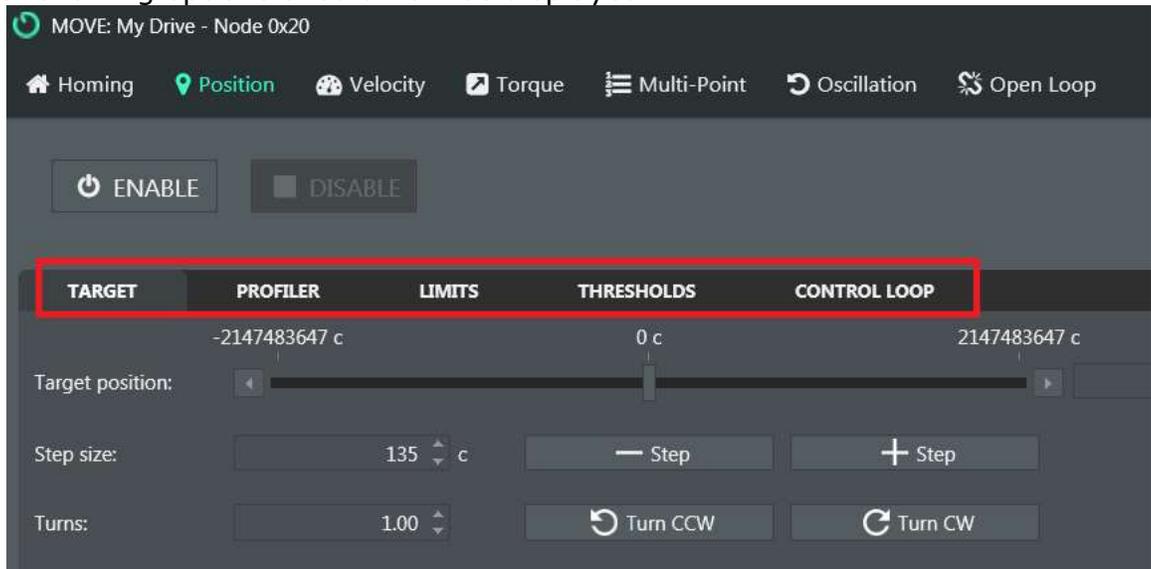


Fig. 34: Position tab with the various sub-tabs highlighted.

- 3) There are five sub-tabs in the Position window: Target, Profiler, Limits, Thresholds, and Control Loop.

i. Target tab

The tab allows the user to specify the location to which the VCA is moving. There are three ways to specify the target position:

- a. Type in the target position (red box in **Fig. 35**) and press Enter. The VCA will immediately move to this new position when you click "Enable".
- b. Adjust the manual increment (yellow box in **Fig. 35**) and press the "- Target Position" to move the VCA down, or the "+ Target Position" button to move the VCA up. Each time the user clicks the "- Target Position" or the "+ Target Position" tab, the VCA moves by the incremental distance specified. This method allows the user to reach the target position slowly and gradually in small increments without worrying about overshooting.
- c. Move the slider (blue box in **Fig. 35**) to the desired position, and the VCA will move to that position. This option is **not recommended** as position is not easy to precisely control.

When you "Enable" the VCA, the VCA will move to the specified position immediately. In addition, a plot of the "Actual Position", "Demand Position", and "Target Position" will be initiated in the lower half of the screen (**Fig. 35**).

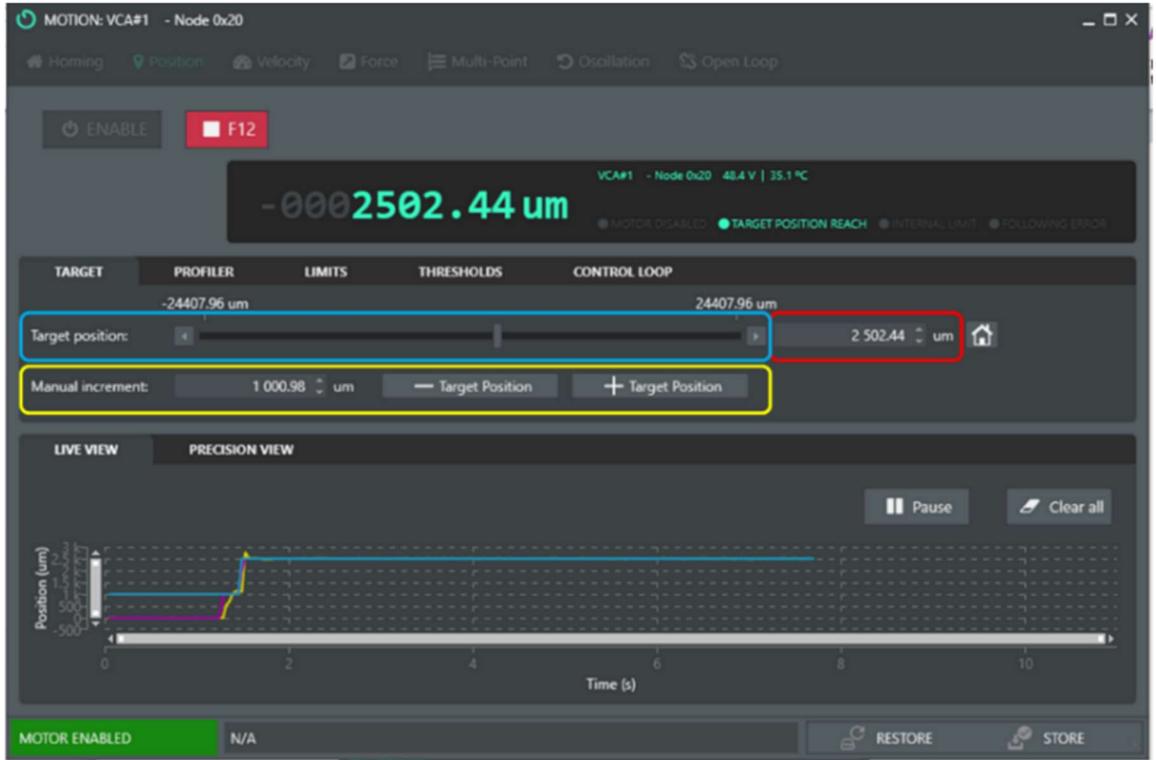


Fig. 35: Position tab with the Target sub-tab selected.



Prior to enabling the VCA, ensure the VCA is physically able to move to the set position. If the VCA is not physically able to move (e.g., homing block underneath it) to the set position, the VCA will try to do so by ramping up the power (current) to its maximum. Prolonged time at a high current could result in permanent damage to the VCA.

Note: If using a MEASSuRE-X, the VCA will only move if the voltage outputs of the external power supplies are enabled (i.e., "OUT" LEDs are lit).

ii. Profiler tabs

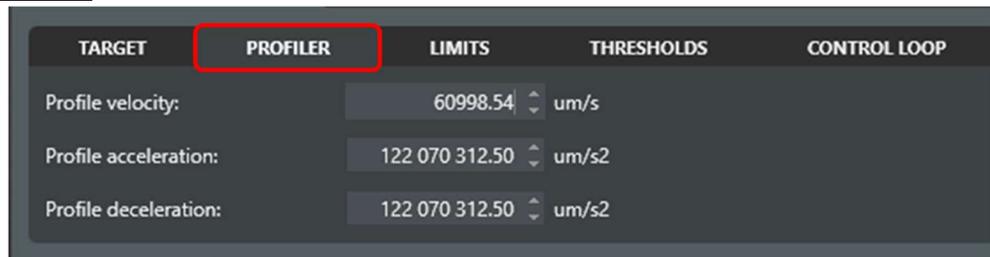


Fig. 36: Position tab with the Profiler sub-tab selected.

The "Profiler" tab allows the user to control the velocity, acceleration, and deceleration during the motion. These parameters may be changed while the VCA is running.

iii. Limits tab

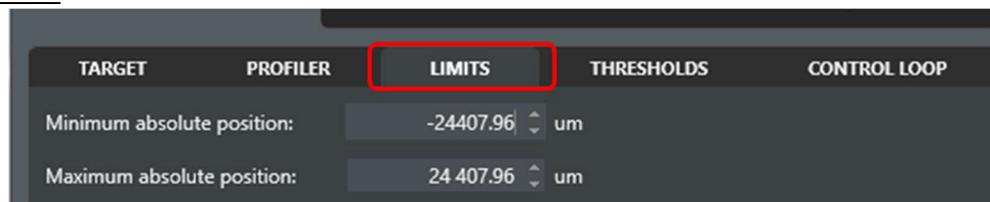


Fig. 37: Position tab with the Limits sub-tab selected.

- The “Limits” tab allows the user to set the minimum and maximum absolute positions of the VCA. This could be used as a safety feature to restrict the VCA’s movement.
- The values of the minimum and maximum position depend on the homing method. When homing to the actual “negative mechanical limit” (i.e., the bottom platform) without the use of the homing blocks, the “Minimum absolute position” should be set to 0 μm .

iv. Thresholds tab

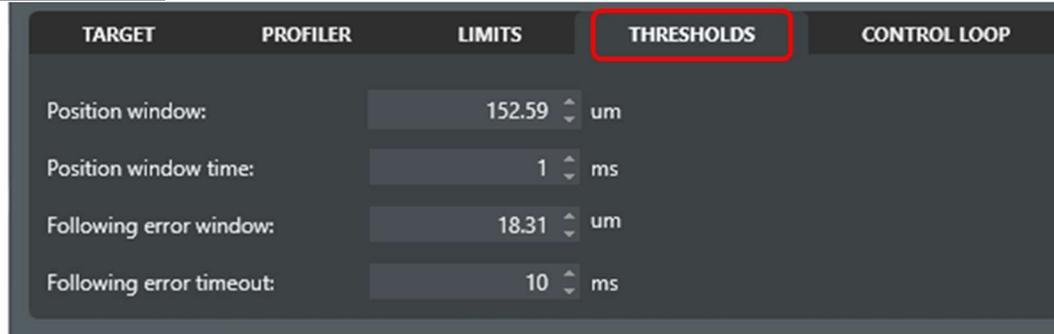


Fig. 38: Position tab with the Thresholds sub-tab selected.

- The “Thresholds” tab allows the user to set the “position window” and the “position window time” that specify when the controller considers that the target position to be reached.
In the example above (**Fig. 38**), the controller will consider the target to be reached if the VCA is within 152.59 μm of the target position for a duration of 1ms.
- Similarly, the user may set the “following error window” and “following error timeout” to specify what is considered an error, which will trigger the “Following Error” indicator to turn on.
In the example above (**Fig. 38**), the following error will be triggered if the VCA position is outside of the target position by more than 18.31 μm for a time longer than 10ms.

v. Control Loop tab

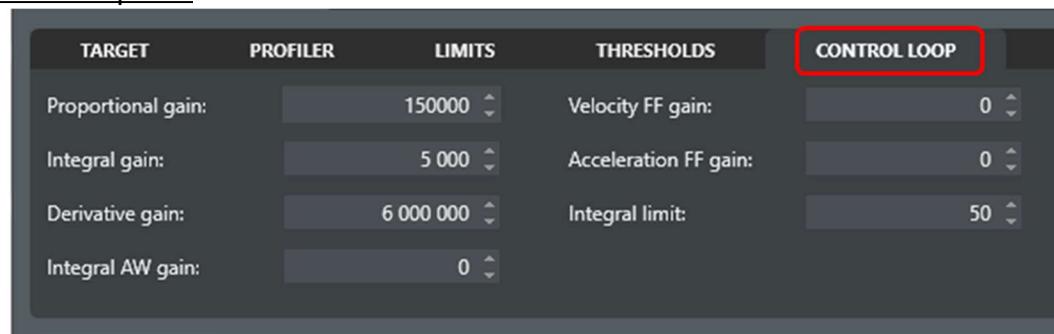


Fig. 39: Position tab with the Control Loop sub-tab selected.

The “Control Loop” tab allows the user to change the settings of the PID controller. The parameters are used in the control loop of the controller. Typical position control, as well as torque control, parameters for the models of MEASSuRE can be found in **Appendix E**.



Be careful when changing the PID values of the controller as they directly affect how accurately and fast the VCA reaches the target position. For instance, excessively large values of the gains can result in instabilities, and excessively small values can result in the target position not being reached or too slow motions.

7.3.3 Oscillation modality

In the Move window, click “Oscillation” in the top menu for cyclic movements.

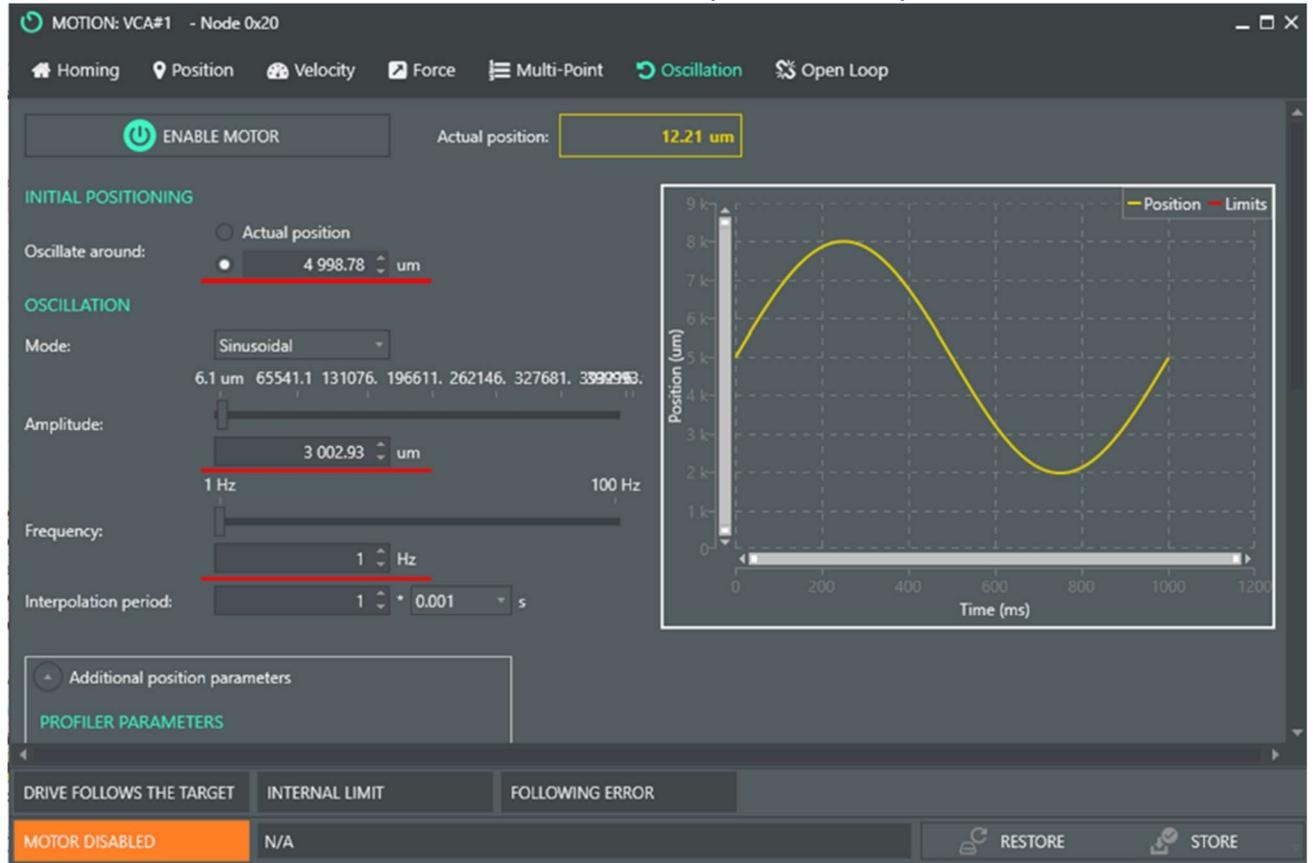


Fig. 40: Oscillation tab with some parameters highlighted.

There are two main sets of parameters to define:

1) Initial Positioning

- Oscillate around: This is the baseline position of the cyclic movement. You may choose “Actual Position” to have the motor oscillate around its current position, or you may type the position you want to set as the baseline.

2) Oscillation

- Mode: The user can choose between sinusoidal and square cyclic movements.
- Amplitude: This sets the amplitude of the oscillation around the baseline. It is recommended to type the target amplitude instead of using the slider.
- Frequency: number of oscillations per second (in Hz); the minimum value is 0.02Hz.
- Interpolation period: set to “1” * “0.001 s” for a smooth profile.
- Additional position parameters: These parameters are the same as discussed for the Position modality (**Section 7.3.2**).

Remarks:

- When the motor is enabled, the VCA will move to the baseline, and then start the oscillations.
- To stop the oscillations, click "Disable Motor." The VCA shaft and movable platform will drop immediately.



It is generally recommended to stretch the sMEAs by running macros. When running oscillation ensure the homing block has been removed underneath the Y-adapter. **Only enable** the VCA when there is no homing block since it could block the VCA from physically reaching the baseline and current will quickly ramp up.

7.4 "Scope" menu

The Scope window is used to graphically display and save VCA parameters (in .csv format) in real-time or for a specified time duration. On the top menu, the user can select to enable up to four different charts (enabled charts highlighted and with an orange underline in **Fig. 41**). Enabled charts are then displayed in the main, central area of the window (cyan box). In addition, the top menu bar contains buttons to switch between "Polling" and "Monitoring" modes (red box), clear the previous recordings of VCA parameters, and start the recording or arm the trigger. At the bottom of the window, the Channels section (green box) allows the user to specify which VCA parameters to record. The plot color and chart location for each VCA parameter can be set here.

To switch between the two different modes (i.e., Polling and Monitoring), the user must click on the downwards-pointing triangle next to the gear icon (red box in **Fig. 41**).

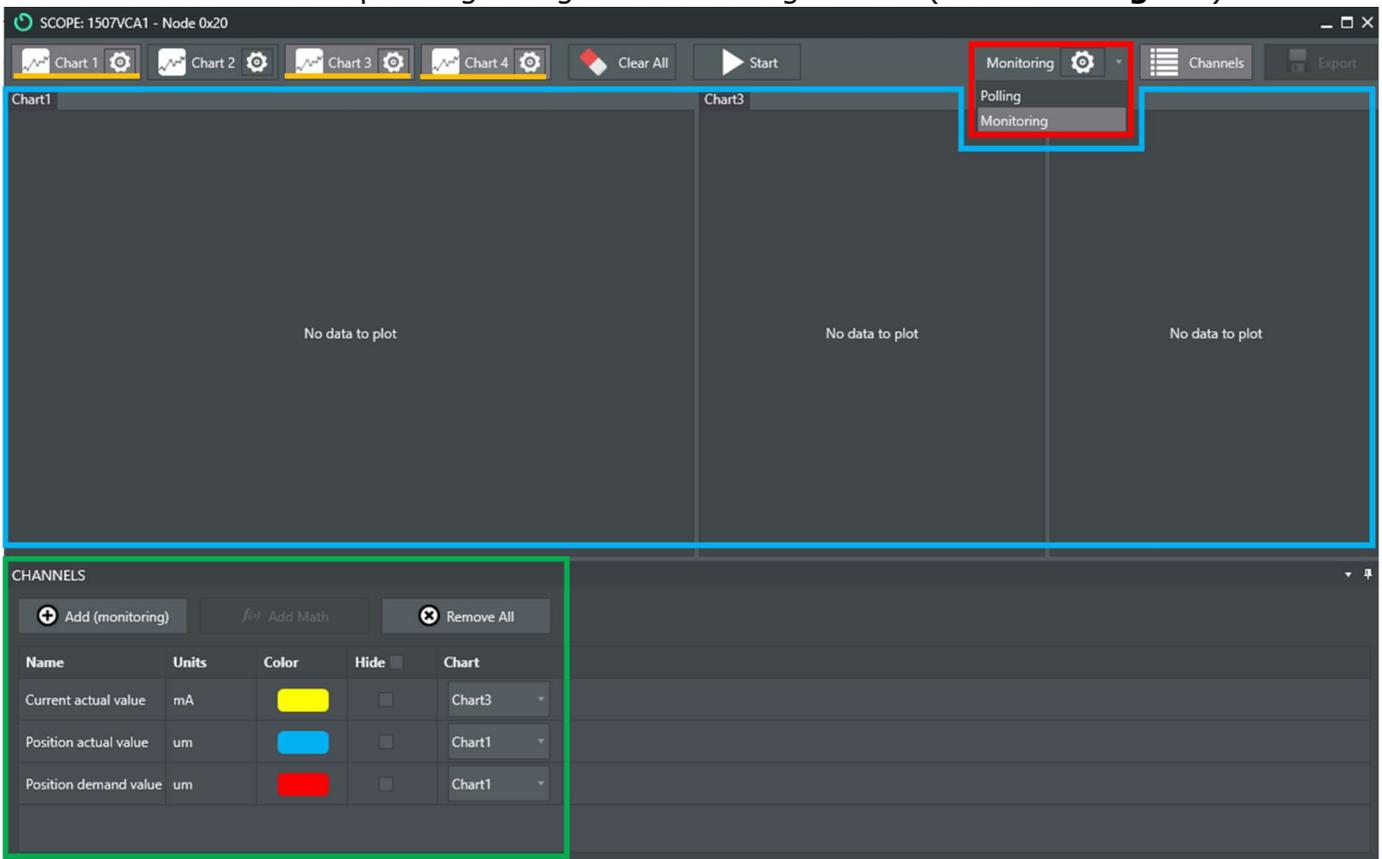


Fig. 41: Scope window with its main sections highlighted.

7.4.1 Polling mode

In “Polling” mode the data will be plotted in real-time, but with reduced accuracy. Click on the gear icon to set the different Polling mode parameters:

- **Sampling rate:** 25ms per data point is the minimum sampling period (i.e., the highest sampling rate) in Polling Mode. Thus, this mode is not suitable for movements that are faster than this time scale.
- **Time scale:** This represents the range of the x-axis of the display window. When the recording time exceeds the Time Scale (in this example, 60s), the display window will start ‘moving,’ and only the most recent data are displayed.

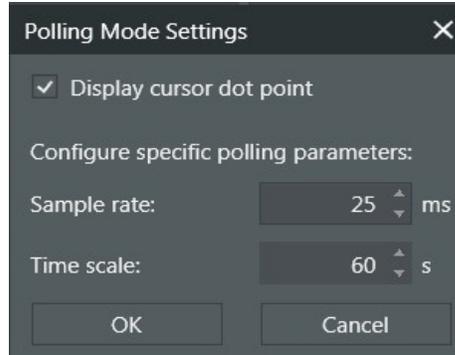


Fig. 42: Polling Mode Settings window.

7.4.2 Monitoring mode

In “Monitoring” mode, the data will be collected for a specified time at higher sampling rates and displayed when the data acquisition has finished, which usually takes a few seconds. The recording time and total number of data points (fixed internally in the control drive) determine the resolution of the displayed data.

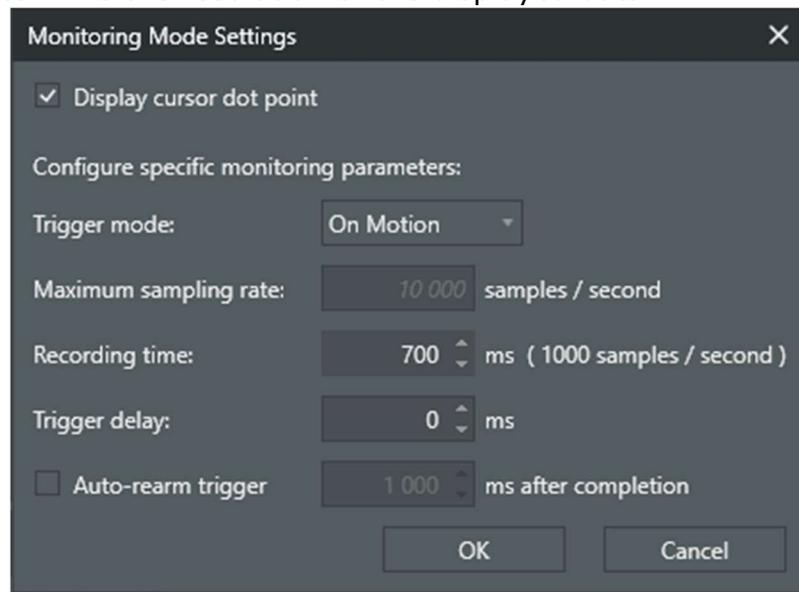


Fig. 43: Monitor Mode Settings window.

Click on the gear icon to set the different Monitoring mode parameters:

- **Trigger mode:** Setting it to “On Motion” will start the recording automatically once a motion is detected. This is the recommended setting.

- **Maximum sampling rate:** This value is fixed and is displayed to the user.
- **Recording time:** The user may specify the duration of the recording. The resolution of the data depends on the recording time as the maximum number of recorded data points cannot be exceeded. We recommend setting the recording time to a value that produces a sampling rate of 1000 samples/second.
- **Trigger delay:** This parameter specifies how long after a trigger has been detected the monitoring data recording will start. This parameter is typically set to 0 ms.

Important: It is worth noting that the resolution of the control drive is 1kHz. Thus, even though the Scope's maximum sampling rate is higher, the recorded data will not have a resolution above 1kHz. If the sampling rate is larger than 1000 samples per second (shown in parenthesis next to "Recording time:"), the recorded VCA data profiles will have a step-like appearance. Thus, it is recommended to set the recording time to a value that will result in 1000 samples recorded per second, which seems to vary depending on the computer connected to the servo drive. In some computers a recording time between 700 and 800ms yields this sampling rate. In other computers a recording time of approximately 1400ms should be set.

7.4.3 Setting up the channels or data to be displayed

Up to four VCA parameters can be recorded on polling and monitoring modes. Furthermore, up to four charts can be used to display these VCA parameters, and each chart allows you to plot from one to all four parameters. Follow these steps to select the parameters to display:

- 1) Click the "Add" button in the lower left of the Scope window.

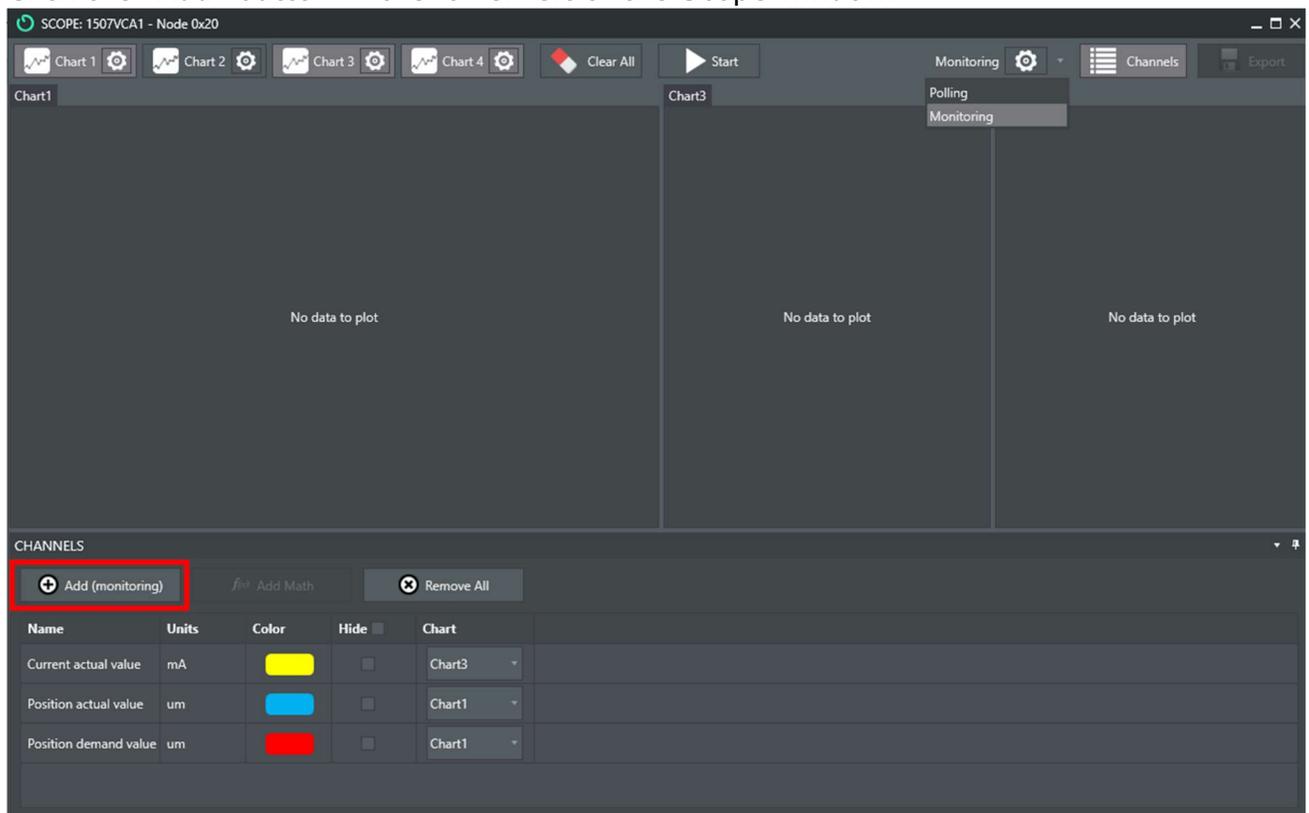


Fig. 44: Scope window with the enabled channels highlighted.

2) The “Add Channels” window below will pop up. All parameters that the user can monitor are listed in alphabetical order, from “Analog Input 1” (left) to “vl velocity demand.”

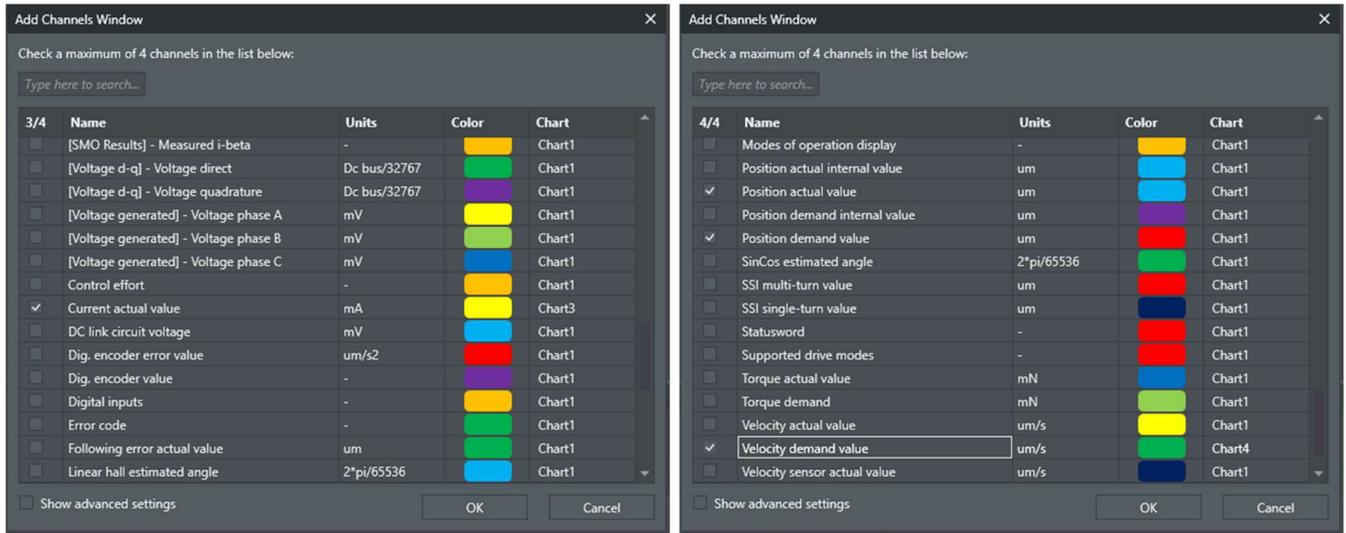


Fig. 45: Add Channels window with some channels selected.

3) Place a checkmark on the parameters you want to visualize and click OK. In the screenshot in step 1 above, the following parameters are plotted:

- Position actual value, in μm (blue)
- Position demand value, in μm (red)
- Current actual value, in mA (yellow)
- Velocity demand value, in $\mu\text{m/s}$ (green)

4) The color of each displayed parameter may be changed by double-clicking on “Color.” A selection of colors will appear as shown in the image below.

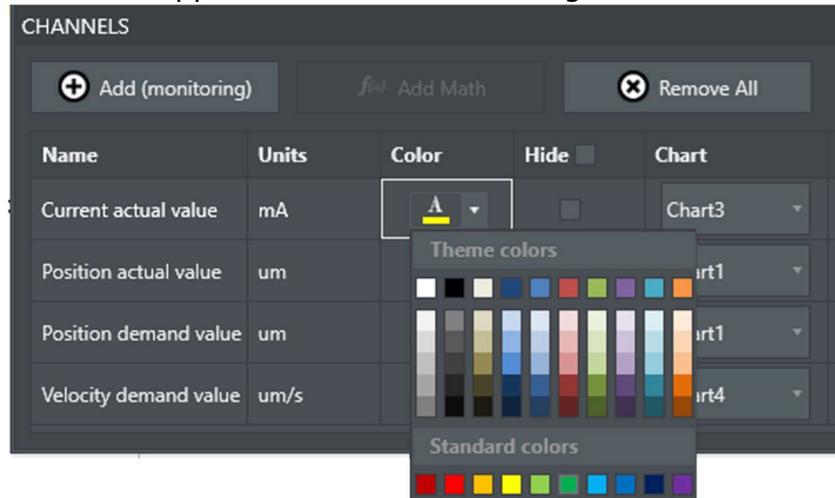


Fig. 46: Formatting the plot color of the enabled Scope channels.

5) Specify the chart number in which the data are to be displayed. Click on the drop-down menu at the end of the row of each parameter and select the chart number. The choices are Chart 1, Chart 2, Chart 3, or Chart 4.

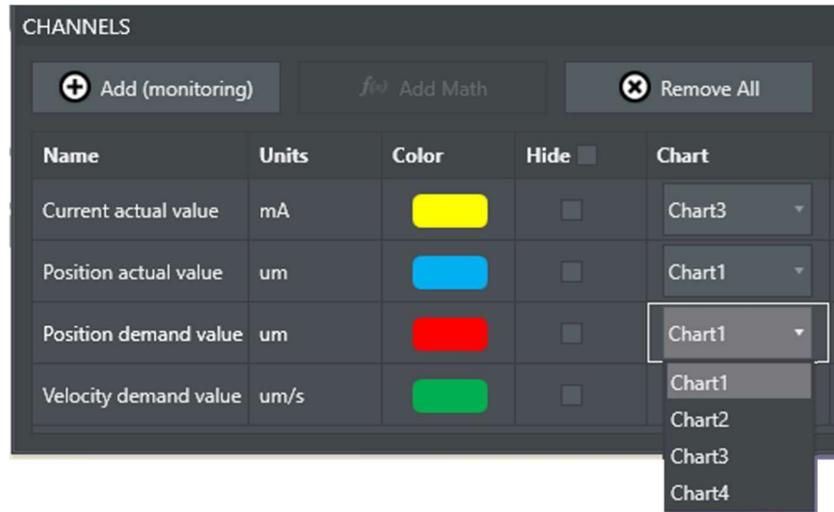


Fig. 47: Specifying on which chart the enabled Scope channels will be displayed.

- 6) To set the vertical axis limits, click on the gear icon next to the chart number. The following window will pop up.

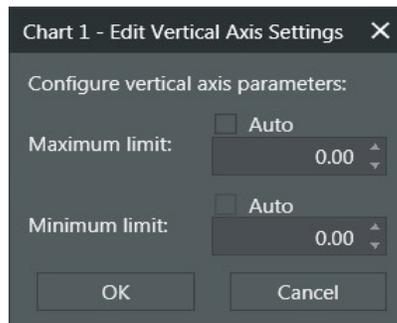


Fig. 48: Editing the charts' vertical axis.

The user can select the minimum and maximum limits for the displayed data on the vertical axis. Choosing "Auto" sets the smallest value of all collected data points as the Minimum Limit, and the largest value as the Maximum Limit. The horizontal axis is always time.

- 7) To re-arrange the charts, click on the label of the chart you want to move and keep the left mouse button pressed. The user can then drag the chart to the desired location using the central icon that resembles a "+" sign as the chart is moved to different regions of the Chart section.
For instance grabbing Chart 3 from **Fig. 44** and dragging it around the area currently covered by Chart 1, will result in re-positioning the Chart 3 to different locations depending on which position (highlighted in dotted cyan, green, red, and yellow squares in **Fig. 49** below) is selected.

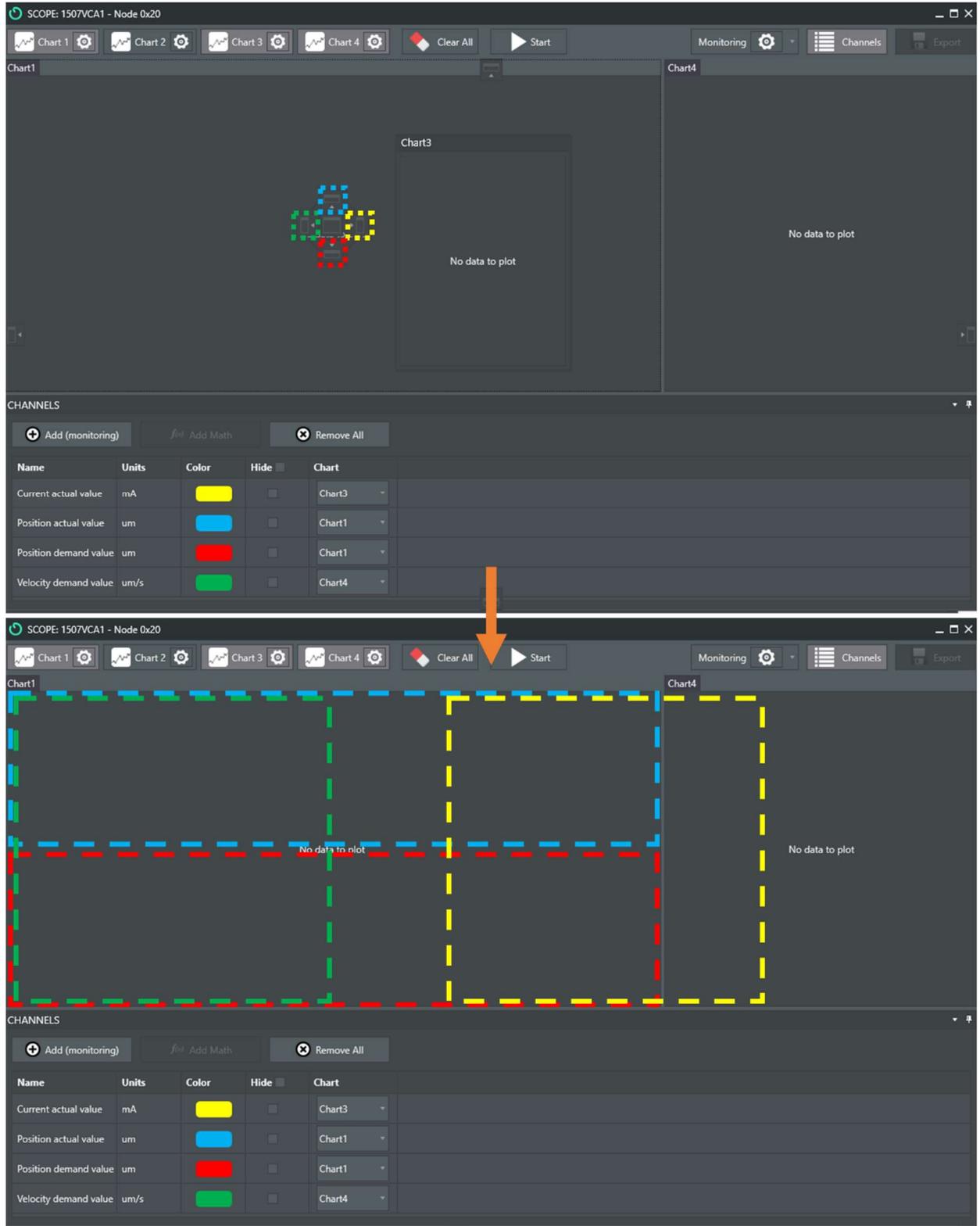


Fig. 49: Positioning the charts in the Scope window.

7.4.4 Recording and saving the data

Once the setup is ready and all parameters have been set, follow these steps to collect and save VCA data:

- 1) Click “Start” to start collecting and displaying the data.
 - In polling mode, the data are immediately collected and displayed.
 - In monitoring mode, MotionLab waits for the motion trigger to activate prior to data collection. Once collected, data will be displayed after a few seconds.
- 2) Once the VCA has been enabled and data collected, the selected parameters will be plotted. You may move the cursor along the curve to get specific plot values.

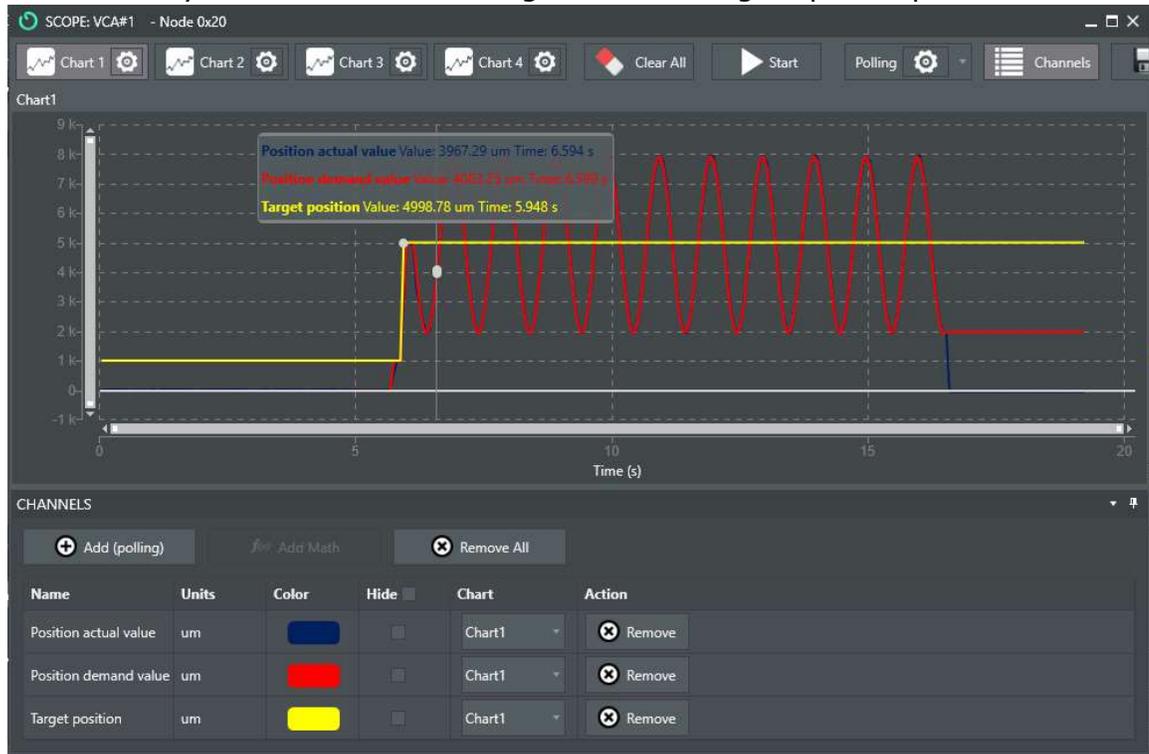


Fig. 50: Scope window with plotted data.

- 3) Click the “Export” button on the top right of the Scope window to save the plotted data into a csv file.

7.5 “Program” menu

The purpose of the Program window is to access and run commands via macros. Macros allow the execution of several commands in sequence. Running the VCA using macros is the preferred method to perform stretches with MEASSuRE.

To open the Composer window, click “Program” in the top menu of the main MotionLab window. Here you will be able to create your own mini-programs or macros, which consist of a set of commands to control the VCA. Refer to **Section 8** for instructions on how to use macros provided by BMSEED and descriptions of these macros.

Note:

- Refer to the online manual for information on how to create your own macros (<https://drives.novantamotion.com/mot2/program>).

7.6 Setting parameter units

MotionLab allows the user to set units for velocity, acceleration, position, force, and torque used when operating the controller with the GUI. The following steps will show how to change these units.



IMPORTANT: When running macros, units for all parameters are set (for instance, position must be specified in counts). Changing the MotionLab GUI units has no effect on the units used when operating the control drive with macros. When running macros, double-check the units used.

- 1) Click on the "Settings" icon on the top right of the main MotionLab window.
- 2) Click on "Units". The following window will pop up.



Fig. 51: Units window showing the conversion factor.

- 3) Set the units for position, velocity, acceleration/deceleration, and force.

Note: The Converter Tool section below shows the conversion from counts to microns. This value is based on the stroke parameter set under the Actuator section.

8 Operating Instructions using Macros

This section describes the use of a set of MotionLab macros that controls the VCA. This manual describes the operation of a sample macro file, which contains subsets of macros to perform the following actions and stretches:

- Pause the VCA motion until the “VCA go” push button is pressed/released (i.e., macro #1)
- Set default VCA parameters (i.e., macro #2)
- Static stretches up to 15% strain (i.e., macros #6 through #11)
- Impulse stretches (i.e., every other macro from macro #18 through #30)
- Cyclic stretches (i.e., every other macro from macro #34 through #40)

These macros are described in greater detail in **Section 8.3**. BMSEED provides these macros. However, these macros can be modified, and new macros can be created based on your needs.

8.1 Creating a MotionLab Macro using the Mechanics Data Sheets

BMSEED provides Excel workbooks specific to MEASSuRE systems. These workbooks contain all the information needed to run the VCA and contain the following sheets:

1. “Strain Position”: This sheet contains the mapping between VCA position and the applied strain. This mapping depends on the flush position (i.e., the position at which the sMEA membrane and top surface of the indenter make contact) and the VCA stroke, which is experimentally determined for each system.
The mapping between applied strain and relative displacement from the flush position can be found in **Appendix F**.
2. “Impulse”: This sheet contains values for the parameters that define the impulse stretches. Multiple target strain-strain rate pairs are listed, along with corresponding parameters (e.g., profile velocity, acceleration, and position control gains).
A sample table showing parameters for multiple strain rates, in addition to an overview of trapezoidal velocity profiles calculations, using a MEASSuRE-X VCA can be found in **Appendix G**. A sample table showing position control gains and starting positions for strain-strain rate pairs for a MEASSuRE-X VCA can be found in **Appendix H**. Strain rates capabilities and limitations for MEASSuRE systems are further described in **Appendix I**.
Note: The user is not limited to the listed strain-strain pairs. New target strain-strain rate pairs can be added by the user, and BMSEED can aid in determining optimal parameters.
3. “Cyclic”: This sheet contains values for the parameters that define the cyclic stretches. Multiple strain-oscillations frequency pairs are listed, along with corresponding parameters including baseline position, amplitude, and position control gains among others.
Note: Like the impulse stretches, the user can add new strain-oscillations frequency pairs and BMSEED can aid in determining optimal parameters.
4. Additional tool-specific sheets (if any): Depending on the user target application and requested stretches, additional sheets may be provided by BMSEED.

These VCA-specific mechanics workbooks allow the user to easily create/update MotionLab macros. On the three standard sheets (i.e., Strain, Impulse, Cyclic), there is an “**Update Macro File**” button on the top that asks the user for a MotionLab macro file to update using the parameter values currently on the spreadsheet. Values for all static, impulse, and cyclic stretch macros are updated on a newly created MotionLab macro file (i.e., the original file remains) when clicking this button.

To upload all MotionLab stretch macros using this functionality follow these steps:

- 1) In the VCA-specific Excel workbook, click the **“Update Macro File”** button located at the top of each sheet in the workbook as shown below. This button only needs to be pressed once in any of the three sheets. The user input window will pop up.

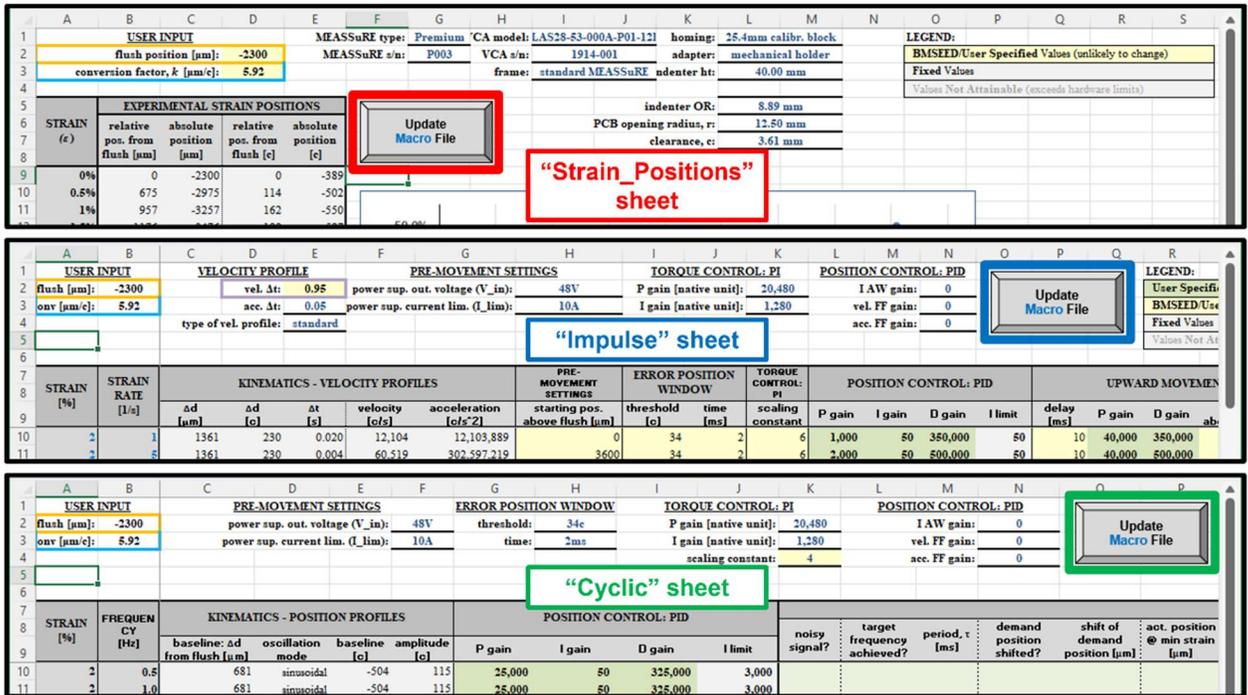


Fig. 52: The “Update Macro File” on the top of all three sheets.

- 2) Click the **“Set specified values”** button (Fig. 53 below) to use the user-specified cyclic stretches frequencies and impulse stretches strain rates.

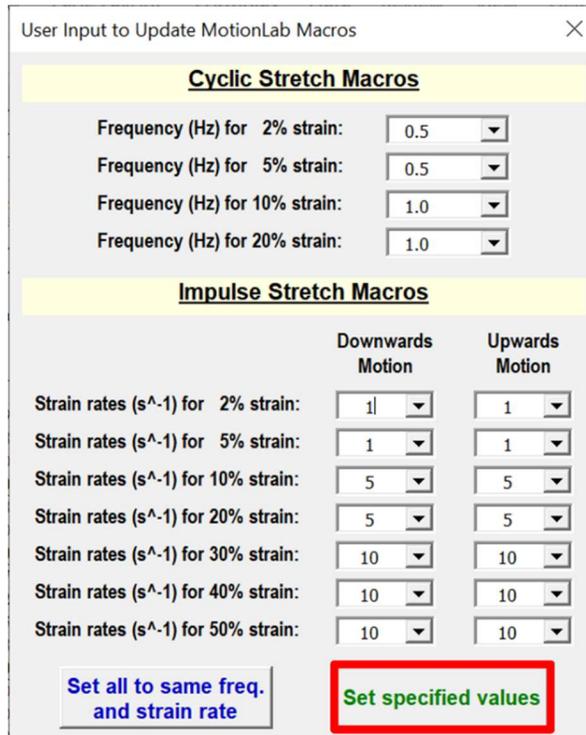


Fig. 53: User input window when Updating the MotionLab macros.

- 3) In the “Browse for the macro file (.ximf)” window, select the macro file that will be edited and serve as the reference when updating VCA parameter values.

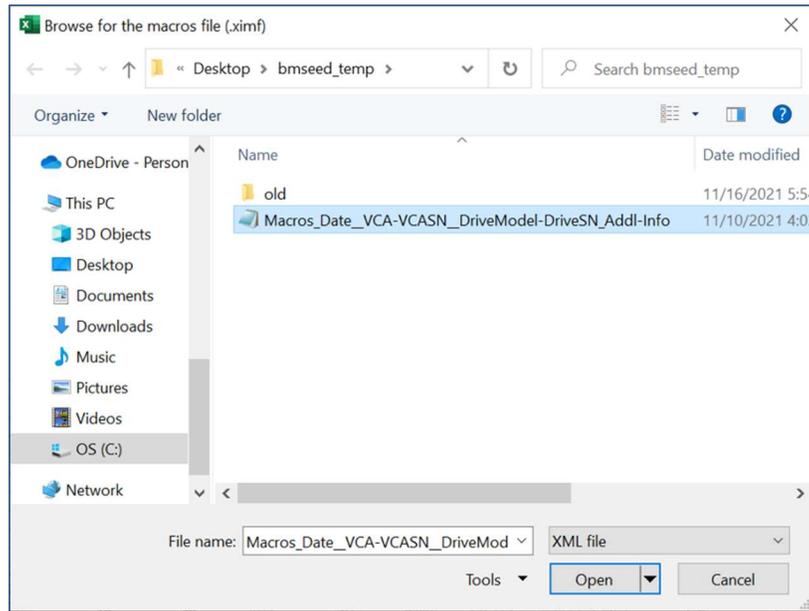


Fig. 54: Selecting the macro file which values will be updated.

- 4) After a few seconds the Excel Visual Basic macro will finish executing, and the newly created MotionLab macro file (.ximf) will now appear in the same directory the original MotionLab macro file was located. This file is ready for use in MotionLab.

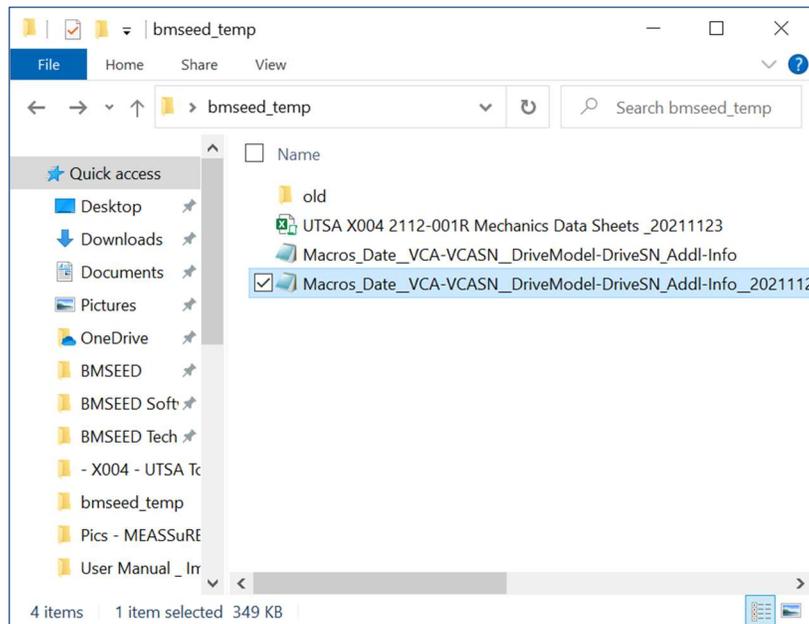


Fig. 55: The original and newly created (updated) MotionLab macro files.

- 5) It is good practice to load the MotionLab macros (see **Section 8.2**) and verify that the updated parameters, as shown in MotionLab, match those listed in the Excel workbook.

8.2 How to load and run macros

- Click "Program" on the main menu.
This will open the Composer window. When you open this window for the first time, you will see all 64 slots for macros. All macros up to macro 59 should be green, indicating they are empty.
 - Macro 0 is always loaded and run when the control drive and VCA is powered up. Thus, it is recommended to keep this macro empty.
 - Macros 60 to 63 are reserved memory, so the user is not allowed to modify those four macros.
- Click "Load" on the top menu bar. Select and open the macro file (".ximf") that contains all the written macros. A warning message will appear. Click "OK."

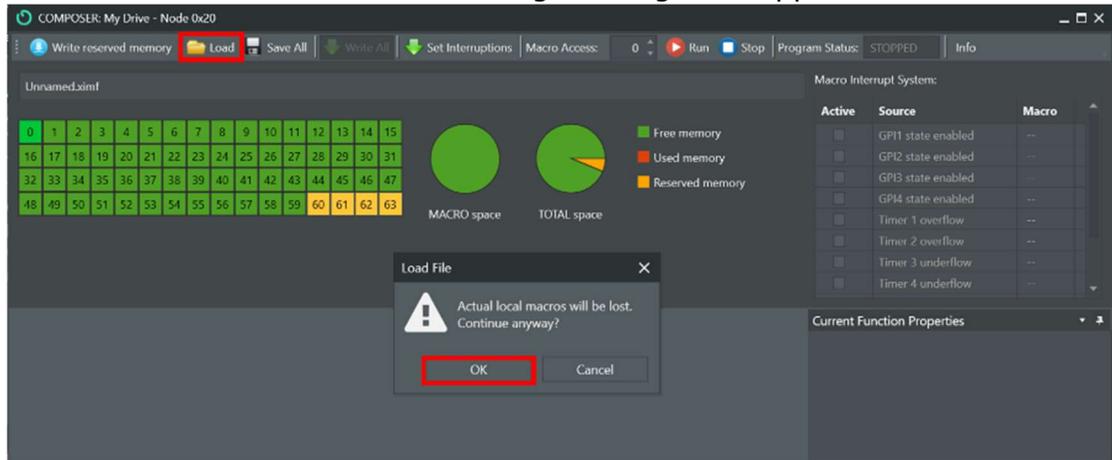


Fig. 56: Loading macros in the Composer window.

- Click "Write All." A warning message will appear. Click "OK."

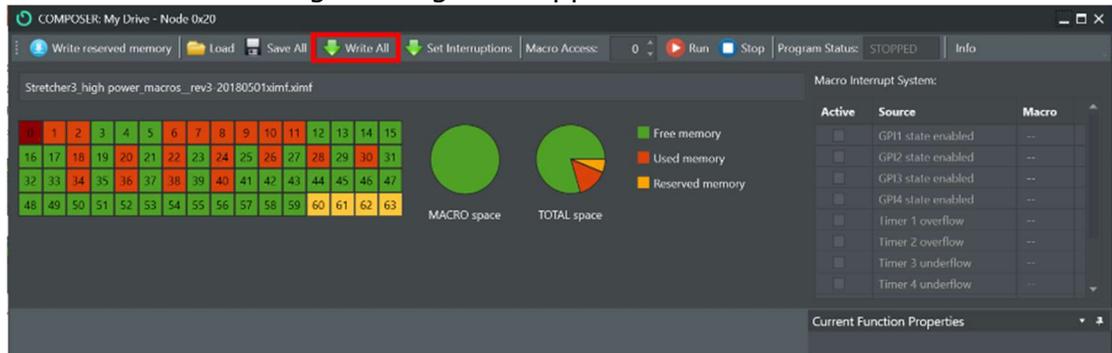


Fig. 57: Writing all macros to drive in the Composer window.

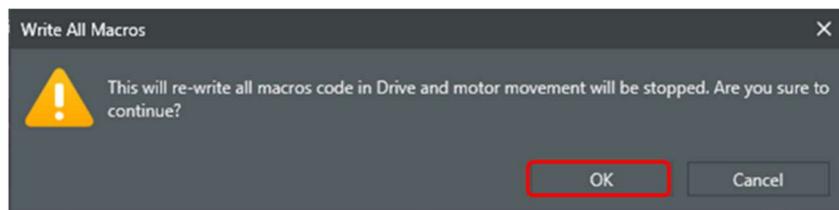


Fig. 58: Warning message when writing all macros.

This process should take less than a minute, depending on the size of the used memory. You should see active (i.e., non-empty) macros colored in dark orange.



Fig. 59: Loaded macros are now filled in orange.

Clicking "Write All" will write all the macros in the ".ximf" file into the control drive. Every time the servo drive is powered off, the macros are deleted. A summary of the actions that the macros perform is provided below. More details are provided in

Section 8.3.

- Macro 0: Macro used during power-up; **do not change this macro.**
- Macro 1: Pauses the VCA motion until a push button is pressed.
- Macro 2: Sets various VCA parameters including position control PID gains, torque control PI gains, limits, and error thresholds.
- Macros 6-11: Static stretches; the VCA moves to set positions and remain there until the "VCA go" push-button is pressed.
- Macro 18: Impulse stretch to 2% strain.
- Macro 20: Impulse stretch to 5% strain.
- Macro 22: Impulse stretch to 10% strain.
- Macro 24: Impulse stretch to 20% strain.
- Macro 26: Impulse stretch to 30% strain.
- Macro 28: Impulse stretch to 40% strain.
- Macro 30: Impulse stretch to 50% strain.
- Macro 34: Cyclic stretch to 2% strain until push-button is pressed.
- Macro 36: Cyclic stretch to 5% strain until push-button is pressed.
- Macro 38: Cyclic stretch to 10% strain until push-button is pressed.
- Macro 40: Cyclic stretch to 20% strain until push-button is pressed.

4. You may then click on the macro of interest. See below for a screenshot when selecting Macro 30. A brief description of the function of the macro (red box in **Fig. 60** below) is provided, as well as the executable code (blue box). The underlines display which macro is currently active.

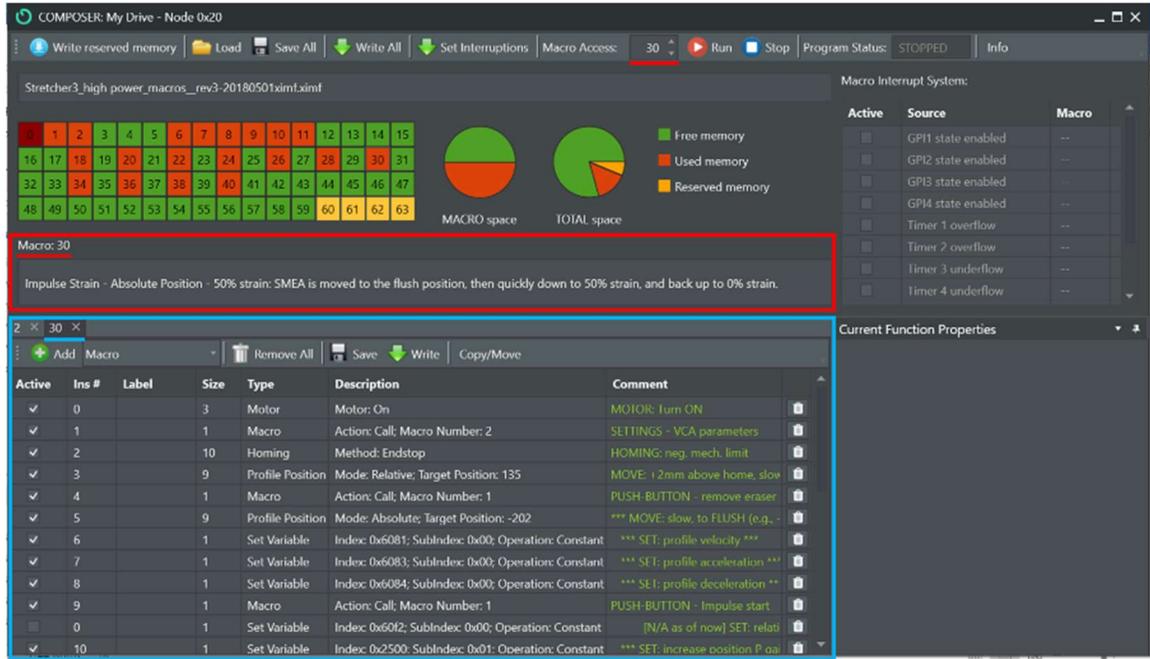


Fig. 60: Composer window with the macros description and commands highlighted.

- You can then click on the "Run" button to run the macro.



Fig. 61: Top menu bar of the Composer window.

- If the macro runs until the end, the VCA will be disabled and will sit on the homing block.



IMPORTANT: At any given time, you can abort the macro while it is running by clicking the "Stop" button on the Composer. Please make sure to take all safety precautions to protect yourself, as well as the sample being stretched, as the shaft of the VCA will drop because the power to the VCA becomes disabled.



Fig. 62: Top menu bar of the Composer window while a macro is running.

8.3 Brief description of macros

Here we list in detail the actions that each macro performs:

8.3.1 Default macro – Macro 0:

It must be empty. This macro is loaded and run every time the control drive and VCA are powered.

8.3.2 Reserved memory – Macros 60 to 63:

Users cannot access or modify these macros. These macros are reserved for proper functionality of the control drive.

8.3.3 Push-button macro – Macro 1:

This macro serves as a pause mechanism, and thus, it may be considered somewhat of a safety feature. The user needs to push and release the “VCA go” button on the top right of the front panel for the program flow (i.e., VCA movement) to resume. For instance, in the case of an impulse stretch the macro would hold position and perform the impulse motion only after the button is pressed. In the case of a cyclic stretch, the VCA will keep oscillating following a sinusoidal until the button is pressed. This macro is frequently called by other macros.



Fig. 63: Front panel of the electronics enclosure showing its three buttons.

8.3.4 Set default VCA parameters macro – Macro 2:

Active	Ins #	Label	Size	Type	Description	Comment
<input checked="" type="checkbox"/>	0		1	Set Variable	Index: 0x607f; SubIndex: 0x00; Operation: Cor	LIMIT: max prof. vel. (max permissible)
<input checked="" type="checkbox"/>	1		1	Set Variable	Index: 0x60c5; SubIndex: 0x00; Operation: Cor	LIMIT: max profiler acceleration (<= 2
<input checked="" type="checkbox"/>	2		1	Set Variable	Index: 0x60c6; SubIndex: 0x00; Operation: Cor	LIMIT: max profiler deceleration (<= 2
<input checked="" type="checkbox"/>	3		1	Set Variable	Index: 0x6067; SubIndex: 0x00; Operation: Cor	ERROR: position window threshold (in
<input checked="" type="checkbox"/>	4		1	Set Variable	Index: 0x6068; SubIndex: 0x00; Operation: Cor	ERROR: position window time (in ms)
<input checked="" type="checkbox"/>	5		1	Set Variable	Index: 0x2503; SubIndex: 0x01; Operation: Cor	TORQUE: P constant
<input checked="" type="checkbox"/>	6		1	Set Variable	Index: 0x2503; SubIndex: 0x02; Operation: Cor	TORQUE: I constant
<input checked="" type="checkbox"/>	7		1	Set Variable	Index: 0x2503; SubIndex: 0x03; Operation: Cor	TORQUE: scaling factor
<input checked="" type="checkbox"/>	8		1	Set Variable	Index: 0x2500; SubIndex: 0x01; Operation: Cor	POSITION: P constant
<input checked="" type="checkbox"/>	9		1	Set Variable	Index: 0x2500; SubIndex: 0x02; Operation: Cor	POSITION: I constant
<input checked="" type="checkbox"/>	10		1	Set Variable	Index: 0x2500; SubIndex: 0x03; Operation: Cor	POSITION: D constant
<input checked="" type="checkbox"/>	11		1	Set Variable	Index: 0x2500; SubIndex: 0x05; Operation: Cor	POSITION: Velocity FF constant
<input checked="" type="checkbox"/>	12		1	Set Variable	Index: 0x2500; SubIndex: 0x06; Operation: Cor	POSITION: Acceleration FF constant
<input checked="" type="checkbox"/>	13		1	Set Variable	Index: 0x2500; SubIndex: 0x07; Operation: Cor	POSITION: I limit
<input type="checkbox"/>	0		1	Set Variable	Index: 0x6075; SubIndex: 0x00; Operation: Cor	MOTOR: continuous current (motor rat
<input type="checkbox"/>	0		1	Set Variable	Index: 0x6073; SubIndex: 0x00; Operation: Cor	MOTOR: max system current (%)
<input type="checkbox"/>	0		1	Set Variable	Index: 0x6076; SubIndex: 0x00; Operation: Cor	MOTOR: continuous force (motor ratec
<input checked="" type="checkbox"/>	14		1	Macro	Action: Return	Return to macro that called this macro

Fig. 64: Screenshot of a sample Macro 2 to set the default VCA parameters.

This macro is used to set the following:

- VCA limits for maximum profile velocity, acceleration, and deceleration,
- error position window threshold and time,
- torque (or current) control P and I gains, as well as scaling constant,
- position control P, I, and D gains, and
- position control velocity feedforward, acceleration feedforward, and integral limit values

- continuous current, max system current, continuous force ...
- Note:** These three instructions/commands are only enabled for MEASSuRE-Mini systems as the actuator current settings need to be changed depending on which motion modality is being used to move the VCA (i.e., Profile Position vs Oscillations).

This macro is called by all stretch macros.

8.3.5 Static tests macros – Macros 6 through 11:

These six macros work together (i.e., Macro 6 calls Macro 7, Macro 7 calls Macro 8, and so on) to apply **static** stretch on the sMEA. Only Macro 6 needs to be run, and the other macros are called upon.



IMPORTANT: These macros make movements based on absolute positions. Thus, if the homing (or reference) position is changed, all positions must be correspondingly updated.

Table 2: List of instructions (or commands) in Macro 6 through Macro 11.

Ins #	Macro Type	Description	User Input Req'd?
Macro 6			
0	Motor	Enable the VCA.	No
1	Macro	Call Macro 2 to set the default VCA-specific parameters.	No
2	Homing	Home to the negative mechanical limit. Use the homing block as the home or reference point. This will become our new reference or 0- μ m position point.	No
3	Profile Position	Raise the platform 100 counts above home (i.e., reference position). The user must now remove the homing block underneath the platform. NOTE: Regardless of the VCA conversion factor between μ m and counts, this distance should provide enough clearance to remove the homing block.	No
4	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
5	Profile Position	Lower the platform to the "flush" position , which is the position where the indenter is just making contact with the sMEA. NOTE: When using the homing blocks, the flush position will also be provided by BMSEED, which might vary between MEASSuRE systems. Due to minor manufacturing variabilities in sMEAs, we strongly recommend using the camera to verify the flush position and make any necessary adjustments.	YES
6	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
7	Profile Position	Lower the platform to 0.5% strain .	YES
8	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
9	Profile Position	Lower the platform to 1.0% strain .	YES
10	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
11	Profile Position	Lower the platform to 1.5% strain .	YES
12	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No

13	Profile Position	Lower the platform to 2% strain.	YES
14	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
15	Macro	Jump to Macro 7.	No
Macro 7			
0	Profile Position	Lower the platform to 3% strain.	YES
1	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
2	Profile Position	Lower the platform to 4% strain.	YES
3	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
4	Profile Position	Lower the platform to 5% strain.	YES
5	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
6	Profile Position	Lower the platform to 6% strain.	YES
7	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
8	Profile Position	Lower the platform to 7% strain.	YES
9	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
10	Profile Position	Lower the platform to 8% strain.	YES
11	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
12	Profile Position	Lower the platform to 9% strain.	YES
13	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
14	Profile Position	Lower the platform to 10% strain.	YES
15	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
16	Macro	Jump to Macro 8.	No
Macro 8			
0	Profile Position	Lower the platform to 11% strain.	YES
1	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
2	Profile Position	Lower the platform to 12% strain.	YES
3	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
4	Profile Position	Lower the platform to 13% strain.	YES
5	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
6	Profile Position	Lower the platform to 14% strain.	YES
7	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
8	Profile Position	Lower the platform to 15% strain.	YES
9	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
10	Macro	Jump to Macro 9.	No
Macro 9			
0	Profile Position	Raise the platform to 14% strain.	YES

1	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
2	Profile Position	Raise the platform to 13% strain.	YES
3	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
4	Profile Position	Raise the platform to 12% strain.	YES
5	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
6	Profile Position	Raise the platform to 11% strain.	YES
7	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
8	Profile Position	Raise the platform to 10% strain.	YES
9	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
10	Macro	Jump to Macro 10.	No
Macro 10			
0	Profile Position	Raise the platform to 9% strain.	YES
1	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
2	Profile Position	Raise the platform to 8% strain.	YES
3	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
4	Profile Position	Raise the platform to 7% strain.	YES
5	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
6	Profile Position	Raise the platform to 6% strain.	YES
7	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
8	Profile Position	Raise the platform to 5% strain.	YES
9	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
10	Profile Position	Raise the platform to 4% strain.	YES
11	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
12	Profile Position	Raise the platform to 3% strain.	YES
13	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
14	Profile Position	Raise the platform to 2% strain.	YES
15	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
16	Macro	Jump to Macro 11.	No
Macro 11			
0	Profile Position	Raise the platform to 1.5% strain.	YES
1	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
2	Profile Position	Raise the platform to 1.0% strain.	YES
3	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
4	Profile Position	Raise the platform to 0.5% strain.	YES
5	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No

6	Profile Position	Raise the platform to 0% strain , or the flush position .	YES
7	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
8	Profile Position	Raise the platform 100 counts above home (i.e., reference position). The user must now place the homing block underneath the platform. NOTE: Regardless of the VCA conversion factor between μm and counts, this distance should provide enough clearance to place the homing block.	No
9	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
10	Profile Position	Lower the platform to the home position .	No
11	Motor	Disable the VCA.	No

8.3.6 Impulse tests macros – Macros 18 to 30:

Active	Ins #	Label	Size	Type	Description	Comment
✓	0		3	Motor	Motor: On	MOTOR: Turn ON
✓	1		1	Macro	Action: Call; Macro Number: 2	SETTINGS - VCA parameters
✓	2		10	Homing	Method: Endstop	HOMING: neg. mech. limit
✓	3		1	Wait	Time (ms): 1000	WAIT: 1sec, to allow VCA to go to 0um
✓	4		9	Profile Position	Mode: Absolute; Target Position: 100	MOVE: above home (by 100 counts)
✓	5		1	Macro	Action: Call; Macro Number: 1	PUSH-BUTTON - remove homing block
✓	6		9	Profile Position	Mode: Absolute; Target Position: -25	*** MOVE: slow, to Starting Position ***
✓	7		1	Set Variable	Index: 0x6081; SubIndex: 0x00; Operation: Cor	*** SET: profile velocity ***
✓	8		1	Set Variable	Index: 0x6083; SubIndex: 0x00; Operation: Cor	*** SET: profile acceleration ***
✓	9		1	Set Variable	Index: 0x6084; SubIndex: 0x00; Operation: Cor	*** SET: profile deceleration ***
✓	10		1	Set Variable	Index: 0x6067; SubIndex: 0x00; Operation: Cor	* ERROR: position window threshold (in ms)
✓	11		1	Set Variable	Index: 0x6068; SubIndex: 0x00; Operation: Cor	* ERROR: position window time (in ms)
✓	12		1	Macro	Action: Call; Macro Number: 1	PUSH-BUTTON - Impulse start
☐	0		1	Set Variable	Index: 0x60f2; SubIndex: 0x00; Operation: Con	[N/A as of now] SET: relative pos
✓	13		1	Set Variable	Index: 0x2503; SubIndex: 0x03; Operation: Cor	* SET: change torque ctrl scaling const
✓	14		1	Set Variable	Index: 0x2500; SubIndex: 0x01; Operation: Cor	*** SET: position control P gain prior to
✓	15		1	Set Variable	Index: 0x2500; SubIndex: 0x02; Operation: Cor	* SET: position control I gain prior to ir
✓	16		1	Set Variable	Index: 0x2500; SubIndex: 0x03; Operation: Cor	*** SET: position control D gain prior to
✓	17		1	Set Variable	Index: 0x607a; SubIndex: 0x00; Operation: Cor	*** SET: target strain position ***
✓	18		1	Set Variable	Index: 0x6040; SubIndex: 0x00; Operation: Cor	MOVE: to new setpoint, immediately, a
✓	19		1	Set Variable	Index: 0x6040; SubIndex: 0x00; Operation: Cor	RESET: new setpoint
✓	20		1	Set Variable	Index: 0x6081; SubIndex: 0x00; Operation: Cor	*** SET: profile velocity for upwards m
✓	21		1	Set Variable	Index: 0x6083; SubIndex: 0x00; Operation: Cor	*** SET: profile acceleration for upwar
✓	22		1	Set Variable	Index: 0x6084; SubIndex: 0x00; Operation: Cor	*** SET: profile deceleration for upwar
✓	23		1	Set Variable	Index: 0x607a; SubIndex: 0x00; Operation: Cor	* SET: end position
✓	24		1	Set Variable	Index: 0x6040; SubIndex: 0x00; Operation: Cor	MOVE: to new setpoint, immediately, a
✓	25		1	Set Variable	Index: 0x6040; SubIndex: 0x00; Operation: Cor	RESET: new setpoint
✓	26		1	Wait	Time (ms): 0	* WAIT: Delay to update position contr
✓	27		1	Set Variable	Index: 0x2500; SubIndex: 0x01; Operation: Cor	*** SET: updated position control P gai
✓	28		1	Set Variable	Index: 0x2500; SubIndex: 0x03; Operation: Cor	*** SET: updated position control D ga
✓	29		1	Wait	Time (ms): 200	WAIT: wait time, 200ms, to reset positi
✓	30		1	Macro	Action: Call; Macro Number: 2	RESETTING Setting values (especially P
✓	31		1	Macro	Action: Call; Macro Number: 1	PUSH-BUTTON
✓	32		9	Profile Position	Mode: Absolute; Target Position: 100	MOVE: above home (by 100 counts)
✓	33		1	Macro	Action: Call; Macro Number: 1	PUSH-BUTTON - place homing block
✓	34		9	Profile Position	Mode: Absolute; Target Position: 0	MOVE: home position
✓	35		3	Motor	Motor: Off	MOTOR: Turn OFF

Fig. 65: Screenshot of a sample Macro 24 to run a 20% impulse stretch.

These seven macros (every even macro between Macro 18 and Macro 30) are independent from each other. Thus, when performing an impulse stretch to a specific strain, only one of these macros is run.



IMPORTANT: These macros make movements based on absolute positions. Thus, if the homing (or reference) position is changed, all positions must be correspondingly updated.

Table 3: List of instructions (or commands) in an impulse stretch macro.

Ins #	Macro Type	Description	User Input Req'd?
0	Motor	Enable the VCA.	No
1	Macro	Call Macro 2 to set the default VCA-specific parameters.	No
2	Homing	Home to the negative mechanical limit. Use the homing block as the home or reference point. This will become our new reference or 0- μm position point.	No
3	Wait	Wait 1000 ms to resume the program. This delay allows the VCA to smoothly transition from homing to profile position.	No
4	Profile Position	Raise the platform 100 counts above home (i.e., reference position). The user must now remove the homing block underneath the platform. NOTE: Regardless of the VCA conversion factor between μm and counts, this distance should provide enough clearance to remove the homing block.	No
5	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
6	Profile Position	Lower the platform to the starting position of the impulse stretch. Typically, this is the " flush " position, or the position where the indenter is just making contact with the sMEA. NOTE: When using the homing blocks, the flush position will also be provided by BMSEED, which might vary between MEASSuRE systems. Due to minor manufacturing variabilities in sMEAs, we strongly recommend using the camera to verify the flush position and make any necessary adjustments. For faster strain rates, the starting position for the impulse could be above the flush position. For instance, 3mm or 6mm above depending on the target strain rate.	YES
7	Set Variable	Set the profile velocity (c/s) based on target strain and strain rate for the impulse downwards motion (i.e., increasing the applied strain).	YES
8	Set Variable	Set the profile acceleration (c/s ²) based on target strain and strain rate for the impulse downwards motion (i.e., increasing the applied strain).	YES
9	Set Variable	Set the profile deceleration (c/s ²) based on target strain and strain rate for the impulse downwards motion (i.e., increasing the applied strain).	YES
10	Set Variable	Set the error position window threshold (c). By default, this value is set to 200 μm and typically remains unchanged.	Rarely
11	Set Variable	Set the error position window time (ms). By default, this value is set to 2 ms and typically remains unchanged. It is only increased for slower rates.	Rarely
12	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed. This allows the user to make all preparations prior to applying the impulse stretch, such as arming the camera and the Scope window in MotionLab. Once pressed, the impulse stretch will be performed.	No
13	Set Variable	Set the torque control scaling constant . This parameter is set to a value larger than the default value (set in Macro 2) as more power is required for impulse stretches.	Rarely
14	Set Variable	Set the position control P gain to achieve the target strain and strain rate. The P gain is used to achieve the target position quickly. Increase it when a faster VCA response is desired.	YES
15	Set Variable	Set the position control I gain to achieve the target strain and strain rate. The I gain is used to remove steady state error, which is not very predominant during impulse stretches.	Rarely

16	Set Variable	Set the position control D gain to achieve the target strain and strain rate. The D gain is used to control the overshoot during the impulse. Increase it when the profile must be slowed down and the overshoot is significant.	YES
17	Set Variable	Set the target position (c) to achieve the target strain.	YES
18	Set Variable	Set the controlword to 31. This command moves the platform to the target position set in Ins #17. Using this control word, the motion is executed immediately, using "absolute position", until target is reached. Setting the controlword to 95 results in a "relative position" displacement. NOTE: The controlword is used to check the controller status. Using Ingenia servo drives, combination of controlword bits generate device control commands.	No
19	Set Variable	Set the controlword to 15. This command resets the controlword to have it ready for the next motion and is required after a motion command.	No
20	Set Variable	Set the profile velocity (c/s) based on target strain and strain rate for the impulse upwards motion (i.e., decreasing the applied strain). NOTE: This command should only be enabled when applying impulse stretches with asymmetric profiles (i.e., different strain rates for the downwards and upwards motion).	YES
21	Set Variable	Set the profile acceleration (c/s ²) based on target strain and strain rate for the impulse upwards motion (i.e., decreasing the applied strain). NOTE: In most situations, this command should be disabled as it could introduce unwanted dwell time at the target strain position. This command should ONLY be enabled when applying impulse stretches with asymmetric profiles (i.e., different strain rates for the downwards and upwards motion) AND if the short delay introduced by this command is not negatively affecting VCA performance.	YES
22	Set Variable	Set the profile deceleration (c/s ²) based on target strain and strain rate for the impulse upwards motion (i.e., decreasing the applied strain). NOTE: In most situations, this command should be disabled as it could introduce unwanted dwell time at the target strain position. This command should ONLY be enabled when applying impulse stretches with asymmetric profiles (i.e., different strain rates for the downwards and upwards motion) AND if the short delay introduced by this command is not negatively affecting VCA performance.	YES
23	Set Variable	Raise the platform to the ending position after the impulse stretch. By default, this value is set to the home position since this is higher than the flush position to ensure no additional strain is applied to the sMEA after the impulse stretch.	Rarely
24	Set Variable	Set the controlword to 31. This command moves the platform to the previously set target position. Using this control word, the motion is executed immediately, using absolute positions, until target is reached.	No
25	Set Variable	Set the controlword to 15. This command resets the controlword to have it ready for the next motion and is required after a motion command.	No

26	Wait	Wait a few milliseconds, if any, to resume the program. By default, the wait time is set to 0ms. NOTE: When optimizing VCA performance, adding a short delay (e.g., 10ms) prior to updating the position control gains could result in smoother position profiles. NOTE: In addition, slow impulse stretches (i.e., those that take 50ms or longer from flush to target position) will benefit from adding a delay since the controller will ensure that the target is reached prior to moving to the next command. If there is no wait time, the impulse is slow, and the position threshold is too large, the VCA will think it reached the target position when it did not, resulting in an undershoot. A non-zero wait time can be used to address this behavior.	Rarely
27	Set Variable	Update the position control P gain to help the VCA move faster to the ending position. For symmetric impulses, a value larger than the one set for the downward motion is typically required since the VCA must move the platform against gravity, which is more physically demanding. NOTE: This P gain update occurs as the upwards motion is occurring.	YES
28	Set variable	Update the position control D gain to stabilize the position profile as the VCA rises to the ending position. NOTE: This P gain update occurs as the upwards motion is occurring.	YES
29	Wait	Wait 200 ms to resume the program. This delay allows the motion to stabilize prior to returning the parameters to the pre-impulse stretch values.	No
30	Macro	Call Macro 2 to set the VCA parameters back to their default values.	No
31	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
32	Profile Position	Raise the platform 100 counts above home (i.e., reference position). The user must now place the homing block underneath the platform. NOTE: Regardless of the VCA conversion factor between μm and counts, this distance should provide enough clearance to place the homing block.	No
33	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
34	Profile Position	Lower the platform to the home position .	No
35	Motor	Disable the VCA. At this moment electrophysiology signals could be recorded post-impulse stretch.	No

Each macro is independent and applies an impulse stretch to one specific strain value. The default impulse stretch macros provided by BMSEED are:

- Macro 18 → 2% strain
- Macro 20 → 5% strain
- Macro 22 → 10% strain
- Macro 24 → 20% strain
- Macro 26 → 30% strain
- Macro 28 → 40% strain
- Macro 30 → 50% strain

8.3.7 Cyclic tests macros – Macros 34 to 40:

Active	Ins #	Label	Size	Type	Description	Comment
✓	0		1	Set Variable	Index: 0x2430; SubIndex: 0x00; Operation: Cor	SET: command ref. source = Network
✓	1		1	Set Variable	Index: 0x6060; SubIndex: 0x00; Operation: Cor	SET: operation mode = Profile Position
✓	2		3	Motor	Motor: On	MOTOR: Turn ON
✓	3		1	Macro	Action: Call; Macro Number: 2	SETTINGS - VCA parameters
✓	4		10	Homing	Method: Endstop	HOMING: neg. mech. limit
✓	5		1	Wait	Time (ms): 1000	WAIT: 1sec, to allow VCA to go to 0um
✓	6		9	Profile Position	Mode: Absolute; Target Position: 100	MOVE: above home (by 100 counts)
✓	7		1	Macro	Action: Call; Macro Number: 1	PUSH-BUTTON - remove homing bloc
✓	8		9	Profile Position	Mode: Absolute; Target Position: -397	*** MOVE: slow, to FLUSH ***
✓	9		1	Macro	Action: Call; Macro Number: 1	PUSH-BUTTON - Move to baseline
✓	10		9	Profile Position	Mode: Absolute; Target Position: -600	*** MOVE: slow, to BASELINE ***
✓	11		1	Wait	Time (ms): 500	WAIT: wait time, 500ms, to allow VCA t
✓	12		1	Set Variable	Index: 0x6075; SubIndex: 0x00; Operation: Cor	SET: continuous current (motor rated c
✓	13		1	Set Variable	Index: 0x6073; SubIndex: 0x00; Operation: Cor	SET: max system current (in %)
✓	14		1	Set Variable	Index: 0x6076; SubIndex: 0x00; Operation: Cor	SET: continuous force (motor rated tor
✓	15		1	Set Variable	Index: 0x2503; SubIndex: 0x03; Operation: Cor	* SET: change torque ctrl scaling const
✓	16		1	Set Variable	Index: 0x2500; SubIndex: 0x01; Operation: Cor	*** SET: position control P gain ***
✓	17		1	Set Variable	Index: 0x2500; SubIndex: 0x02; Operation: Cor	*** SET: position control I gain ***
✓	18		1	Set Variable	Index: 0x2500; SubIndex: 0x03; Operation: Cor	*** SET: position control D gain ***
✓	19		1	Set Variable	Index: 0x2500; SubIndex: 0x07; Operation: Cor	*** SET: position control I limit ***
✓	20		1	Set Variable	Index: 0x2430; SubIndex: 0x00; Operation: Cor	SET: command ref. source = Internal Si
✓	21		1	Set Variable	Index: 0x6060; SubIndex: 0x00; Operation: Cor	SET: operation mode = Cyclic Synchroni
✓	22		1	Set Variable	Index: 0x2436; SubIndex: 1; Operation: Consta	SET: function type = sine wave
✓	23		1	Set Variable	Index: 0x2436; SubIndex: 2; Operation: Consta	*** SET: amplitude of oscillations ***
✓	24		1	Set Variable	Index: 0x2436; SubIndex: 3; Operation: Consta	*** SET: frequency of oscillations in 10i
✓	25		1	Macro	Action: Call; Macro Number: 1	PUSH-BUTTON - End oscillations
✓	26		1	Set Variable	Index: 0x2430; SubIndex: 0x00; Operation: Cor	SET: command ref. source = Network
✓	27		1	Wait	Time (ms): 500	WAIT: wait time, 500ms, to avoid overs
✓	28		1	Set Variable	Index: 0x6060; SubIndex: 0x00; Operation: Cor	SET: operation mode = Profile Position
✓	29		1	Macro	Action: Call; Macro Number: 2	SETTINGS - VCA parameters
✓	30		9	Profile Position	Mode: Absolute; Target Position: -397	*** MOVE: slow, to FLUSH ***
✓	31		1	Macro	Action: Call; Macro Number: 1	PUSH-BUTTON
✓	32		9	Profile Position	Mode: Absolute; Target Position: 100	MOVE: above home (by 100 counts)
✓	33		1	Macro	Action: Call; Macro Number: 1	PUSH-BUTTON - place homing block
✓	34		9	Profile Position	Mode: Absolute; Target Position: 0	MOVE: home position
✓	35		3	Motor	Motor: Off	MOTOR: Turn OFF

Fig. 66: Screenshot of a sample Macro 38 to run a 10% cyclic stretch.

These four macros (every even macro between Macro 34 and Macro 40) are independent from each other. Thus, when performing a cyclic stretch to a specific strain, only one of these macros needs to be run.



IMPORTANT: These macros make movements based on absolute positions. Thus, if the homing (or reference) position is changed, all positions must be correspondingly updated.

Table 4: List of instructions (or commands) in a cyclic stretch macro.

Ins #	Macro Type	Description	User Input Req'd?
0	Set Variable	Set the command reference source to 0, which corresponds to Network. This command ensures that the VCA will initiate in the correct reference source for profile position movements (i.e., non-oscillatory motions).	No
1	Set Variable	Set the operation mode to 1, which corresponds to Profile Position. This command ensures that the VCA will initiate in the correct operation for profile position movements (i.e., non-oscillatory motions).	No
2	Motor	Enable the VCA.	No
3	Macro	Call Macro 2 to set the default VCA-specific parameters.	No
4	Homing	Home to the negative mechanical limit. Use the homing block as the home or reference point. This will become our new reference or 0- μm position point.	No
5	Wait	Wait 1000 ms to resume the program. This delay allows the VCA to smoothly transition from homing to profile position.	No
6	Profile Position	Raise the platform 100 counts above home (i.e., reference position). The user must now remove the homing block underneath the platform. NOTE: Regardless of the VCA conversion factor between μm and counts, this distance should provide enough clearance to remove the homing block.	No
7	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
8	Profile Position	Lower the platform to the "flush" position , or the position where the indenter is just making contact with the sMEA. NOTE: When using the homing blocks, the flush position will also be provided by BMSEED, which might vary between MEASSuRE systems. Due to minor manufacturing variabilities in sMEAs, we strongly recommend using the camera to verify the flush position and make any necessary adjustments.	YES
9	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed. This allows the user to make all preparations prior to starting the cyclic stretch. Once pressed, the platform will move to the baseline position and start the oscillations.	No
10	Profile Position	Lower the platform slowly to the baseline position of the specified oscillatory profile based on the target strain. The baseline of oscillation is set so that the high position corresponds to the flush position (i.e., 0% strain) and the low position corresponds to the target strain.	YES
11	Wait	Wait 500 ms to resume the program. This delay allows platform to smoothly transition from profile position mode to internal signal generator (i.e., oscillatory) mode prior to initiating the sinusoidal motion.	No
12	Set Variable	Set the continuous current (in mA) for the oscillatory motion. NOTE: This command is typically enabled only when running MEASSuRE-Mini systems as the 'motor current' parameters for the VCA vary when running oscillatory and non-oscillatory motions. The oscillatory values are smaller, which is critical since the VCA can be left running for long periods of times (i.e., days to weeks).	No

13	Set Variable	Set the max system current (in % of the continuous current) for the oscillatory motion. NOTE: This command is typically enabled only when running MEASSuRE-Mini systems as the 'motor current' parameters for the VCA vary when running oscillatory and non-oscillatory motions. The oscillatory values are smaller, which is critical since the VCA can be left running for long periods of times (i.e., days to weeks).	No
14	Set Variable	Set the continuous force (in mN) for the oscillatory motion. NOTE: This command is typically enabled only when running MEASSuRE-Mini systems as the 'motor current' parameters for the VCA vary when running oscillatory and non-oscillatory motions. The oscillatory values are smaller, which is critical since the VCA can be left running for long periods of times (i.e., days to weeks).	No
15	Set Variable	Set the torque control scaling constant . This parameter value typically remains unchanged from the set default value (from Macro 2).	Rarely
16	Set Variable	Set the position control P gain to achieve the target strain and frequency. Increase it when a faster VCA response is desired.	YES
17	Set Variable	Set the position control I gain to achieve the target strain and frequency. The I gain is used to remove steady state error. Increase it to achieve a faster VCA response.	YES
18	Set Variable	Set the position control D gain to achieve the target strain and frequency. Increase it when the profile must be slowed down and the overshoot is significant.	YES
19	Set Variable	Set the position control I limit to achieve the target strain and frequency. The I limit must be larger than the I gain.	YES
20	Set Variable	Set the command reference source to 6, which corresponds to Internal Signal Generator. This command is necessary for applying oscillatory motions with the VCA.	No
21	Set Variable	Set the operation mode to 8, which corresponds to Cyclic Synchronous Position. This command is necessary for applying oscillatory motions with the VCA.	No
22	Set Variable	Set the function type to 0, which corresponds to sinusoidal. NOTE: Oscillations will now start.	No
23	Set Variable	Set the amplitude of oscillations based on the target strain.	YES
24	Set Variable	Set the frequency of oscillations based on the target frequency. NOTE: The value corresponds to a multiple of 10 mHz. For instance, if a frequency of 1 Hz is desired, set the value to 100 (set frequency = 10 mHz × 100 = 1 Hz). By default, this value is set to 100.	YES
25	Macro	When you want to stop the oscillations, call Macro 1 to stop oscillations and move to the next command. Oscillations will only stop when the "VCA go" button is pressed.	No
26	Set Variable	Set the command reference source to 0, which corresponds to Network. This command is required to return to the VCA performing profile position movements (i.e., non-oscillatory motions).	No
27	Wait	Wait 500 ms to resume the program. This delay allows the VCA to smoothly transition from internal signal generator (i.e., oscillatory) mode to position profile mode, and it prevents overshoots during the transition.	No

28	Set Variable	Set the operation mode to 1, which corresponds to Profile Position. This command is required to return to the VCA performing profile position movements (i.e., non-oscillatory motions).	No
29	Macro	Call Macro 2 to set the VCA parameters back to their default values.	No
30	Profile Position	Raise the platform to the flush position .	YES
31	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
32	Profile Position	Raise the platform 100 counts above home (i.e., reference position). The user must now place the homing block underneath the platform. NOTE: Regardless of the VCA conversion factor between μm and counts, this distance should provide enough clearance to place the homing block.	No
33	Macro	Call Macro 1 to hold position until the "VCA go" push button is pressed.	No
34	Profile Position	Lower the platform to the home position .	No
35	Motor	Disable the VCA. At this moment electrophysiology signals could be recorded post-impulse stretch.	No

Each macro is independent and applies a cyclic stretch to one specific strain value (set parameters include oscillation baseline, amplitude, and frequency). The default cyclic stretch macros provided by BMSEED are:

- Macro 34 \rightarrow 2% strain
- Macro 36 \rightarrow 5% strain
- Macro 38 \rightarrow 10% strain
- Macro 40 \rightarrow 20% strain

8.3.8 Remarks on macros

Some important remarks regarding the operation of macros:

- Any changes to the home position, flush position, or the counts conversion factor will require updating all macro instructions where VCA positions are defined.
- **Macros use "counts" (NOT "mm" or " μm ") as units for distance.** Thus, it is important to perform all corresponding conversions when creating the macros. In the MotionLab main window, you can click on "Units" to see the conversions or use the converter tool. Typical values for the conversion factor are:
 - **MEASSuRE-X:** **1 count = $\sim 6.5 \pm 0.5 \mu\text{m}$**
 - **MEASSuRE-Premium:** **1 count = $\sim 5.9 \pm 0.5 \mu\text{m}$**
 - **MEASSuRE-Mini:** **1 count = $\sim 1.8 \pm 0.1 \mu\text{m}$**
- The different models of MEASSuRE have different homing block heights:
 - **MEASSuRE-X:** 25.4 mm tall homing blocks
 - **MEASSuRE-Premium:** 25.4 mm tall homing blocks
 - **MEASSuRE-Mini:** 22 mm tall homing blocks
- Using a "Profile position" command allows the user to specify more parameters than using a "Position" command. The former allows the user to change the profile velocity, profile acceleration, and profile deceleration.

9 Execution of Experiments – Impulse Stretch Macro

- 1) Before you start, make sure to:
 - a. have the sMEA with your tissue/cell culture ready;
 - b. if using a MEASSuRE X, set the power supplies' output to the correct voltage, enable their output enabled ("Output" LED must be lit), and **enable the power supplies' foldback protection** ("Fold" LED must be lit);
 - c. ensure the hardware is set up correctly (see **Section 5**);
 - d. ensure the high-speed camera is set up correctly;
 - e. find the flush position, i.e., the position at which the PDMS membrane of the sMEA just touches the surface of the indenter (see **Section 4.B.c** of the Imaging Module User Manual);
 - f. **have run tests with a 'setup' sMEA (or stretchwell) to ensure optimal performance of the VCA when running the macro you plan to use on the actual sample.**
- 2) Lubricate the top surface of the indenter with corn or canola oil to minimize friction.
- 3) Make sure the homing block is placed under the Y-adaptor to ensure the sMEA is positioned above the indenter prior to loading the sample.
- 4) Place the sample (sMEA or stretchwell with the cells to be stretched) on the movable platform of the MEASSuRE system.
 - If electrophysiological measurements are planned with the sample on the MEASSuRE system, the sMEA is placed in the Electrophysiology Interface Board (**Fig. 67**).

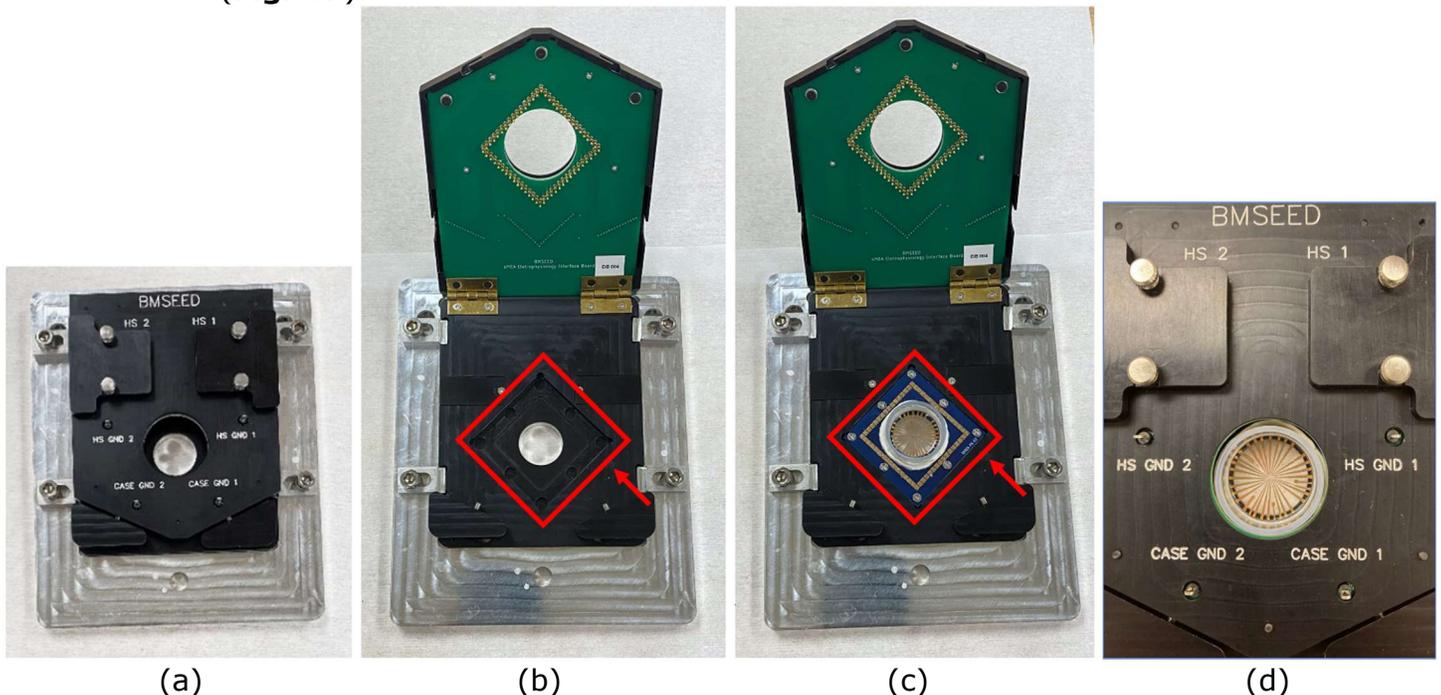


Fig. 67: Interface board (a) closed on a MEASSuRE system movable platform, (b) opened to place an sMEA or MEA, (c) opened up with an sMEA placed with the correct orientation, and (d) closed with an sMEA loaded and ready for stretching.

To load the sample in the EIB, open the clamshell board (**Fig. 67a**) and place the sMEA in the recess on the board (**Fig. 67b**). It is important that the arrays are placed in the correct orientation (**Fig. 67c**) so that the electrode channel on the software matches the electrode location on the array.

- If electrophysiological measurements are **not** planned, the sMEA or stretchwell is placed in the mechanical holder as an alternative to the interface board (**Fig. 68**).

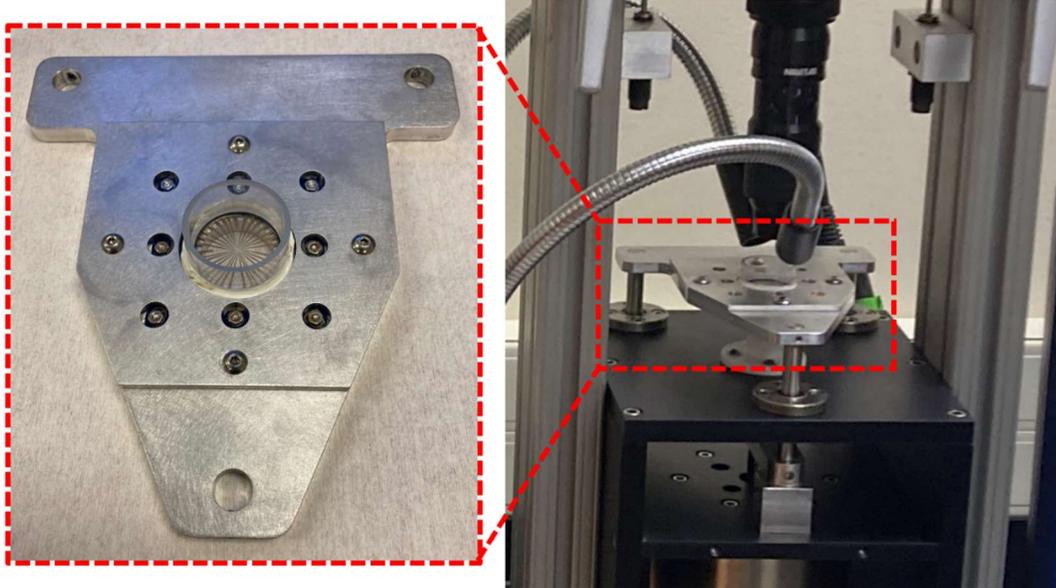


Fig. 68: Mechanical holder with an sMEA on the bench and on the MEASSuRE frame.

When using the mechanical holder, the orientation of the sMEA on the mechanical holder is not important.



Make sure to place the sMEA is in the correct orientation into the interface board: the side of the sMEA with the white label "BMSEED sMEA" should be along the EIB indentation edge with the placement arrow (highlighted by the red arrows in **Fig. 67b** and **Fig. 67c**).

- 5) Follow the instructions in the Electrophysiology Module User Manual if you plan to carry out electrophysiological measurements immediately before and/or after stretching the sample.
- 6) Home the VCA with the homing block supporting the Y-adapter.
- 7) Load the macros and write them to the drive per instructions in **Section 8**.
- 8) Select the macro you want to execute, ensuring all parameters have been properly set. As mentioned in **step 1) f** above, ALWAYS test run a macro prior to running the macro with a sample.
- 9) Click "RUN" in MotionLab's Composer window to start macro execution.
- 10) The VCA movable platform will rise above the homing block.
- 11) Remove the homing block.

- 12) Press the “VCA go” button on the front panel of the electronics enclosure.

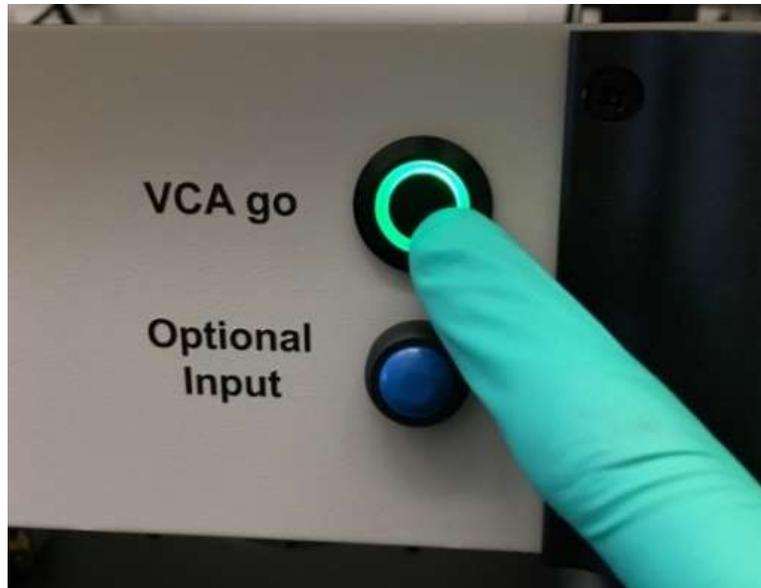


Fig. 69: Pressing the “VCA go” button on the front panel of the enclosure.



If the VCA does not behave as expected, shut it down immediately by pressing an “Emergency Stop” button (either on the electronics enclosure front panel or the stand-alone button near the MEASSuRe system).



NEVER put your fingers or any body part between the movable sections of the VCA. This is very dangerous and can cause permanent harm. The VCA is very powerful and will crush bones.



ALWAYS use a pen, screwdriver, or a similar tool to move the homing block underneath the Y-adapter. DO NOT reach underneath the Y-adapter using your fingers or any body part to move the homing block.

- 13) The VCA will move to the starting position for the target impulse stretch.
- 14) Press the “Start” button in the MotionLab Scope window. Use the monitoring mode and set Motion as the trigger to start data collection.
- 15) Press the “Record” button in the Motion Studio software to arm the camera (i.e., the camera will start the recording once triggered). Use Motion Detect as trigger with the sensitivity slider towards the left to increase the camera’s sensitivity to motions.
- 16) Press the “VCA go” button on the front panel of the electronics enclosure.
- 17) The VCA will move downwards to stretch the sample (i.e., sMEA or stretchwell with the cells/tissue) and immediately back up to the home position complete impulse stretch.
- 18) Press the “VCA go” button on the front panel of the electronics enclosure.
- 19) The VCA movable platform will rise above the home position (determined in **step 6** above).

- 20) Place the homing block back underneath the Y-adapter.
- 21) Press the "VCA go" button on the front panel of the electronics enclosure.
- 22) The VCA will be disabled, and the movable platform will rest on the homing block.
- 23) The VCA data (e.g., actual position and demand position) will be displayed in the MotionLab Scope window. It is recommended to export and save the VCA data as a csv. In addition, a screenshot of the Scope window can be saved.
- 24) The camera video/frames will be stored in the camera's internal DRAM memory. It is recommended to save the camera acquisition (i.e., video frames) for image strain analysis later.
- 25) The user can immediately record post-stretch electrophysiological measurements. See the Electrophysiology Module User Manual for details.



Electrophysiological measurements during stretching are only recommended when slowly stretching sMEAs at velocities of 200 to 500 $\mu\text{m/s}$. At higher velocities motion artifacts due to movement of the medium (i.e., solution) will distort the measurements.

Troubleshooting of potential issues that may be encountered when running the VCA can be found in **Appendix J**.

10 Completion Instructions

After completion of an experiment, make sure to complete the following:

- 1) If using a MEASSuRE-X, turn off the outputs on each power supply (LED should not be lit).
- 2) If using a MEASSuRE-X, turn off each power supply using the black power switch on the left side of their front panel.
- 3) Turn off the power switch on the back panel of the MEASSuRE system electronics enclosure.
- 4) If using an Intan data acquisition controller, turn off its power switch on its rear panel.
- 5) Unplug the camera's power cord to power it off.
- 6) Close the MotionLab (VCA), Intan (electrophysiology), and Motion Studio (camera) software.

Appendix A: Alternative High Voltage Power Supplies for MEASSuRE-X

An alternative to a pair of TDK-Lambda Gen 100-15 power supplies, a pair of **Instek PSU-60-25** power supplies may be used to power the VCA used in MEASSuRE-X systems.

Similar to the Gen 100-15 power supplies, the PSU-60-25 power supplies are located outside the electronics enclosure because they are too large to fit inside. Each of the two Instek PSU-60-25 can provide up to 60V at 25A. The two power supplies are wired in series, for a total output voltage of 120V and 25A current that can be provided to the VCA.

Follow the instructions below.

- 1) Connect the cable from the power supplies (with a red and black sheath) to the Supply & Shunt Connector on the back panel of the enclosure.
- 2) Plug the power cord of each power supply into electrical outlets that use separate fuses.
- 3) Turn on the power supplies by pushing the switch at the front panel.

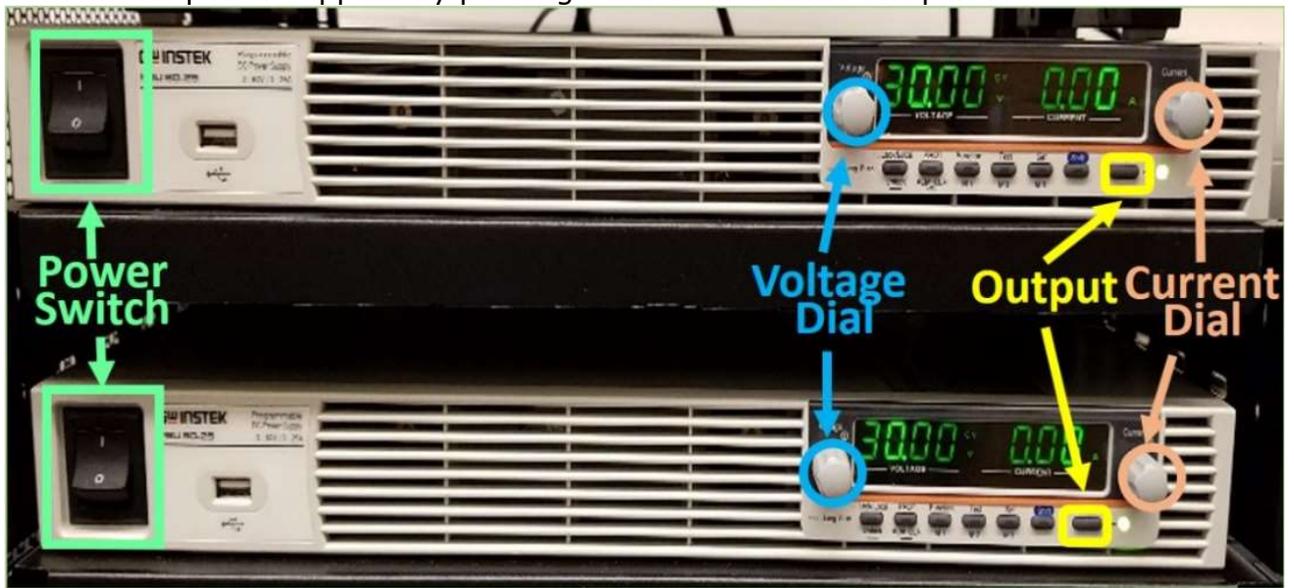


Fig. 70: Two Instek PSU-60-25 power supplies connected in series.

- 4) The power supply will show the Power On settings ("Pon") at start up. If no Power On settings are configured, the PSU will recover the state right before the power was last turned OFF.



The power supply takes approximately 8 seconds to fully turn on or shutdown. Do not turn the power on and off quickly.

- 5) The standard operating mode for MEASSuRE-X is constant voltage. Each of the two power supplies can be set up to 60V, for a total voltage of 120V for the VCA. The current limit is set to 20A as this is the limit of the VCA. The power supplies can provide up to 25A.
- 6) If a different operating procedure is desired, follow the instructions below.



When changing the voltage or any other setpoint on the power supply, make sure that the "Output" is turned OFF, i.e., the green LED next to the "Output" button is NOT lit.

- i. Change the voltage setpoint:
 - Make sure output off (i.e., LED next to "Output" button is not lit).
 - Press the "Set" button on the power supply; the green LED should have lit up.
 - Turn the voltage dial until the desired voltage is reached. Turning clockwise increases the voltage; turning counterclockwise decreases the voltage.
 - Pressing the knob changes the step size of changes in voltage. The step size can be changed between 0.01V, 0.1V, and 1V.
- ii. Set the different protections: Over-Voltage-Protection (OVP), Under-Voltage-Limit (UVL), and Over-Current-Protection (OCP)

The OVP is an important setpoint, particularly for very fast VCA motions. The default **OVP setpoint is 63V** on each power supply, i.e., 126V total voltage. The power supply will show an "OVP" error when the voltage on either power supply exceeds 63V. An alarm will sound. The voltage on the power supply can exceed the output voltage when the mechanical energy of the VCA is converted to electrical energy during deceleration ("breaking"). A shunting resistor and transistor inside of the electronics enclosure prevents an OVP from occurring by "shunting" the extra energy during deceleration away from the power supply. The shunting circuit must be enabled in the software. The voltage when the shunting circuit gets activated is typically 122V, i.e., when the voltage sensed on the controller exceeds 122V, the shunting transistor opens the shunting circuit so that the mechanical energy from the VCA deceleration is converted to heat (the current flows through a large resistor).

It is recommended to keep the **OCP and UVL** at the default **setpoints of 20A and 10V, respectively**.



NEVER set the shunting voltage in MotionLab to a value below the output voltage of the power supplies (both combined); this will result in the shunting circuit being permanently activated, i.e., a current of several amps will flow through the shunting resistor, creating excessive heat and potentially damaging the electronics.

- Press the "PROT" key (Protection key) below the display, which is the second key from the left. The green LED should have lit up.
 - The protection function will be displayed on the voltage display, and the value of the setpoint will be displayed on the current display. In addition to over-voltage protection (OVP), Under-Voltage-Limit (UVL) and Over-Current-Protection (OCP) can be adjusted as well.
 - Turn the Voltage dial to choose the protection function: OVP, UVL, or OCP.
 - Use the Current dial to set the setpoint of the different protection functions.
 - Press the PROT key again. The green LED will turn off.
 - Press the PROT key again and check that your changes were accepted.
 - After verifying the setpoints, press the PROT key one more time.
- iii. Clear an alarm:
 - To clear an OVP, UVL, or OCP alarm, press and hold the "ALM_CLR" key for 3 seconds to clear the alarm.



If you see the current increasing without using the VCA, turn off the output on the supplies immediately as some incorrect usage/connection likely occurred. This action will prevent damage to the equipment and prevent injury or death. Contact BMSEED.

Appendix B: Manually Updating the Servo Drive Firmware

The firmware can also be manually updated by **first connecting to the control drive using USB communication** (USB connector in the rear of the enclosure) and following these steps.

- 1) For firmware download, go to: <https://drives.novantamotion.com/emcl/downloads>

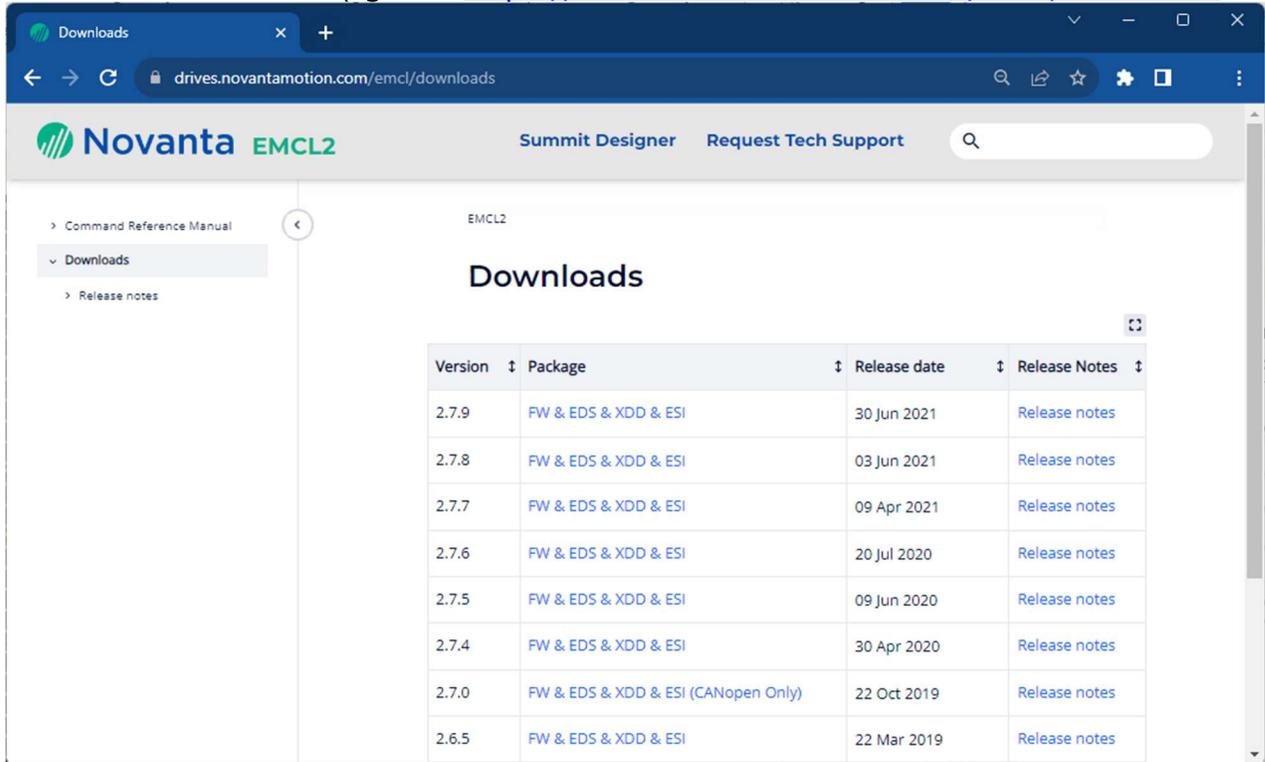


Fig. 71: Ingenia's Downloads website for the firmware and device drive files.

- 2) Click on the newest firmware version.

Remarks:

- You may scroll down the list to find older versions of the firmware.
- Our current MEASSuRE system uses CANopen communication protocol, so make sure to download an appropriate firmware version.

- 3) Once the download has completed, locate the EMCL zip file (which should contain the firmware ".hexenc" file). The zip file might have been saved in the computer's "Downloads" folder.

- 4) Open the MotionLab software. Click on the Gear icon on the top right of the window and click "Recovery."

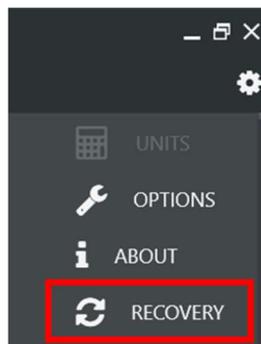


Fig. 72: Settings button (gear icon) on the top right of the MotionLab window.

- 5) Select "USB"; find the COM Port where the USB cable is connected; select "Update Manually"; click the "Browse" button; find the downloaded firmware file; and click "Update Firmware."

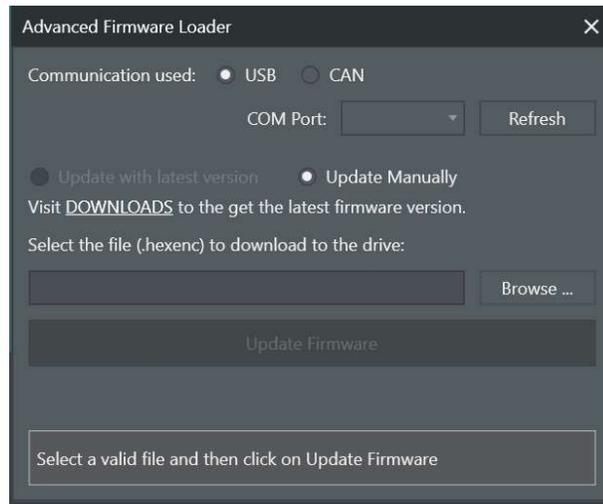


Fig. 73: Advanced Firmware Loader window to manually load a firmware.

- 6) A warning message will appear. Click "Ok." The firmware update should take less than a minute. Once the driver has updated successfully, close the window.

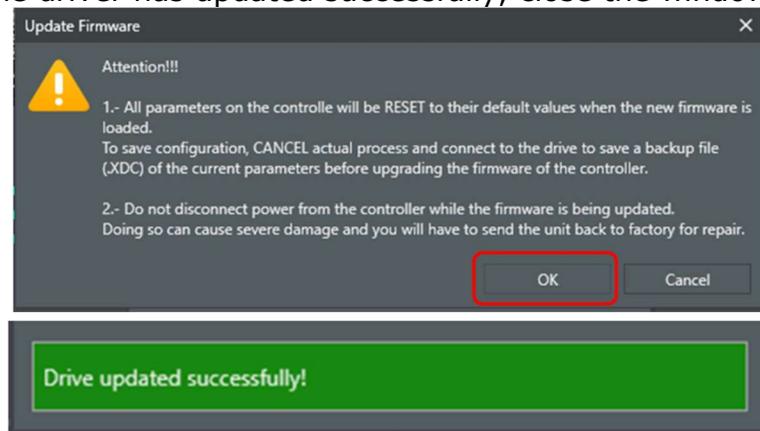


Fig. 74: Warning message and progress bar when updating the firmware.

- 7) On the main window of the MotionLab software, click on "Scan again" at the top right corner. The control drive with updated firmware should be detected.

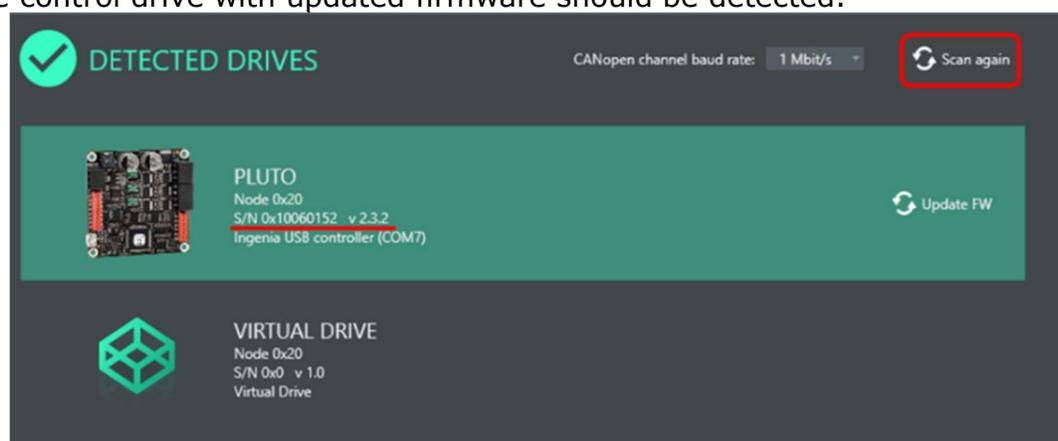


Fig. 75: Detected drives window showing the drive with the updated firmware.

Appendix C: Manually Updating the XML Device Drive (XDD) File

If a manual update of the XDD file is required (for example, due to the recommended and used XDD files not matching) follow these steps:

- 1) Go to the Ingenia website (<https://drives.novantamotion.com/emcl/downloads>) and download the most recent versions of the firmware and XDD file.

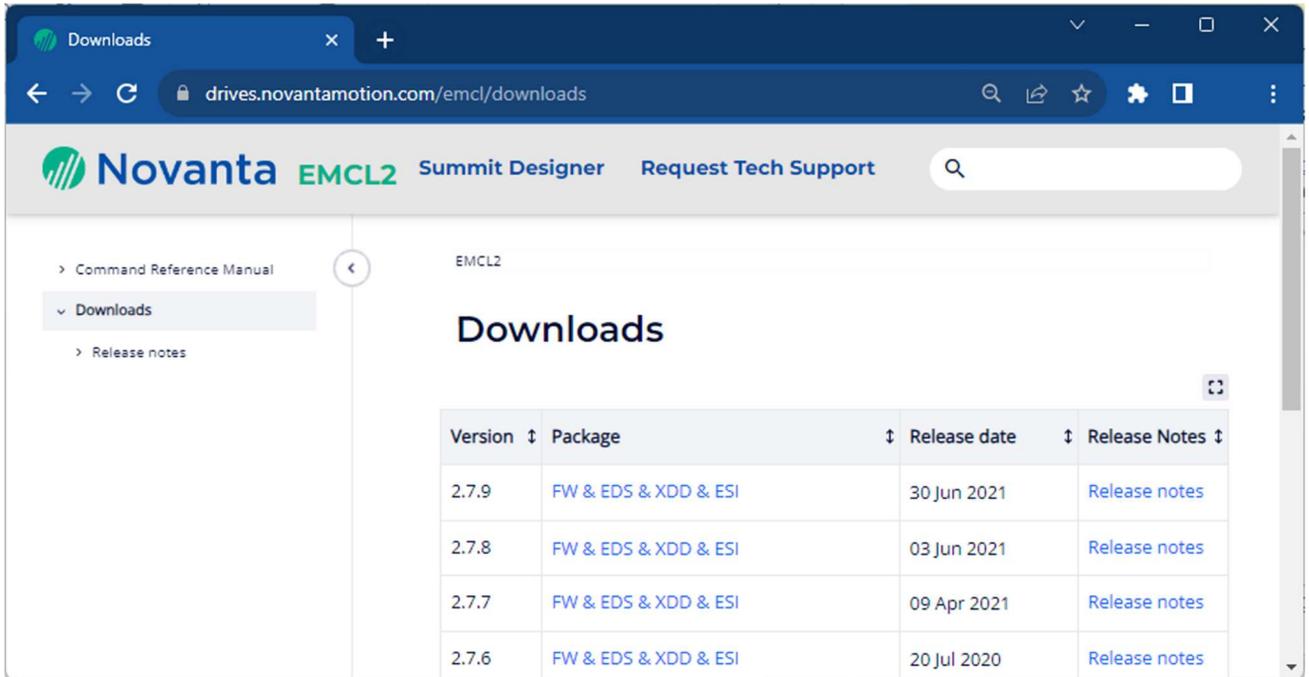


Fig. 76: Screenshot of the Ingenia website where the firmware and XDD files can be downloaded.

- 2) Locate the downloaded XDD files within the computer.

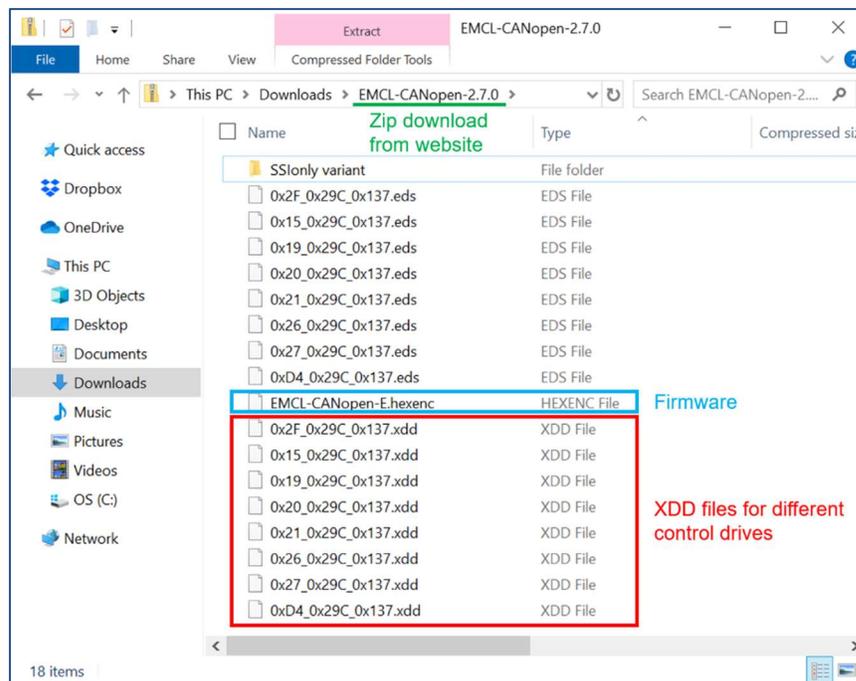


Fig. 77: A list of device drive (XDD) files.

- 3) Connect to the control drive (Jupiter or Pluto) you want to verify or configure.

- 4) In the Drive Overview section, click "Additional drive information."
- 5) The pop-up window will list the recommended XDD and used XDD. In the example shown in **Fig. 78**, the listed XDDs do not match which requires a manual update of the XDD.

Note: The recommended XDD is determined by both the control drive (i.e., Jupiter vs. Pluto) and firmware version being used.

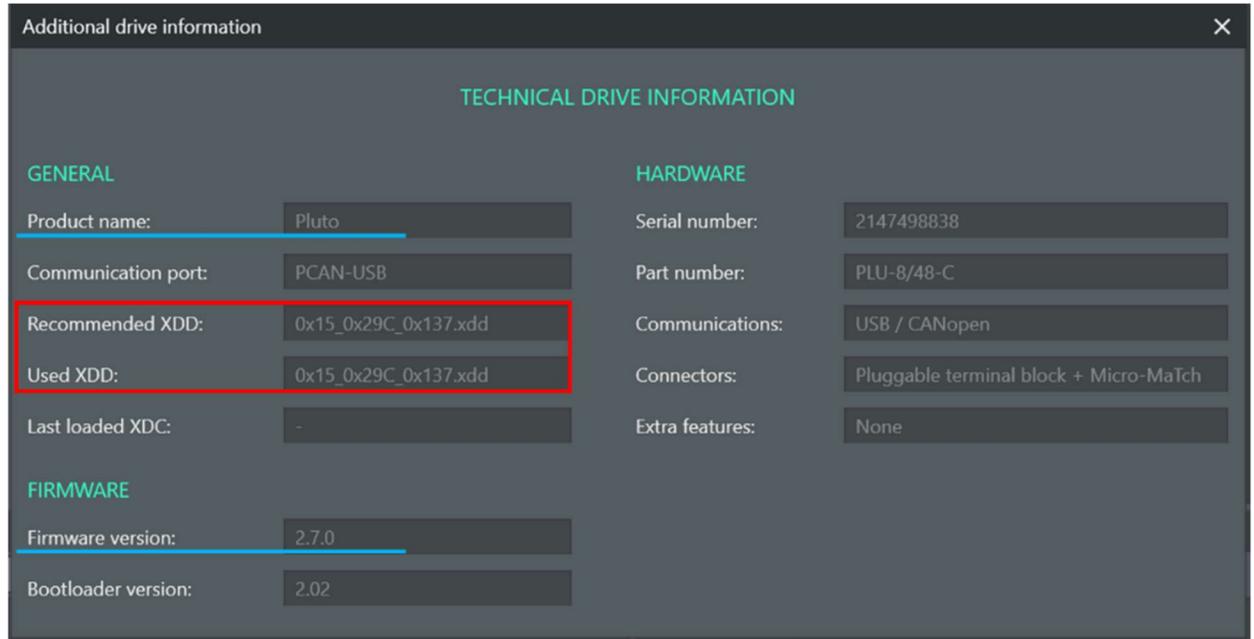


Fig. 78: Additional Drive Information window.

- 6) Since a manual update of the XDD is required, click on "Options" in the main menu.
- 7) In the Options window, uncheck "Automatically detect XDD" and click "Ok."

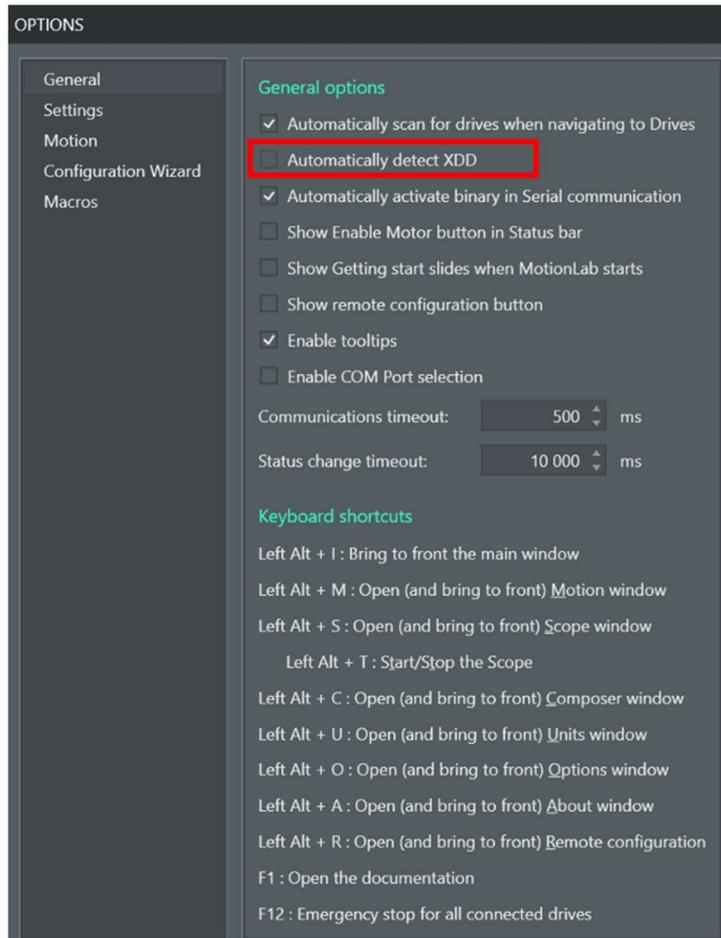


Fig. 79: Options window after clicking the Gear icon and “Options.”

- 8) On the Drives column in the main window, right-click on the drive’s name and select “Disconnect.”

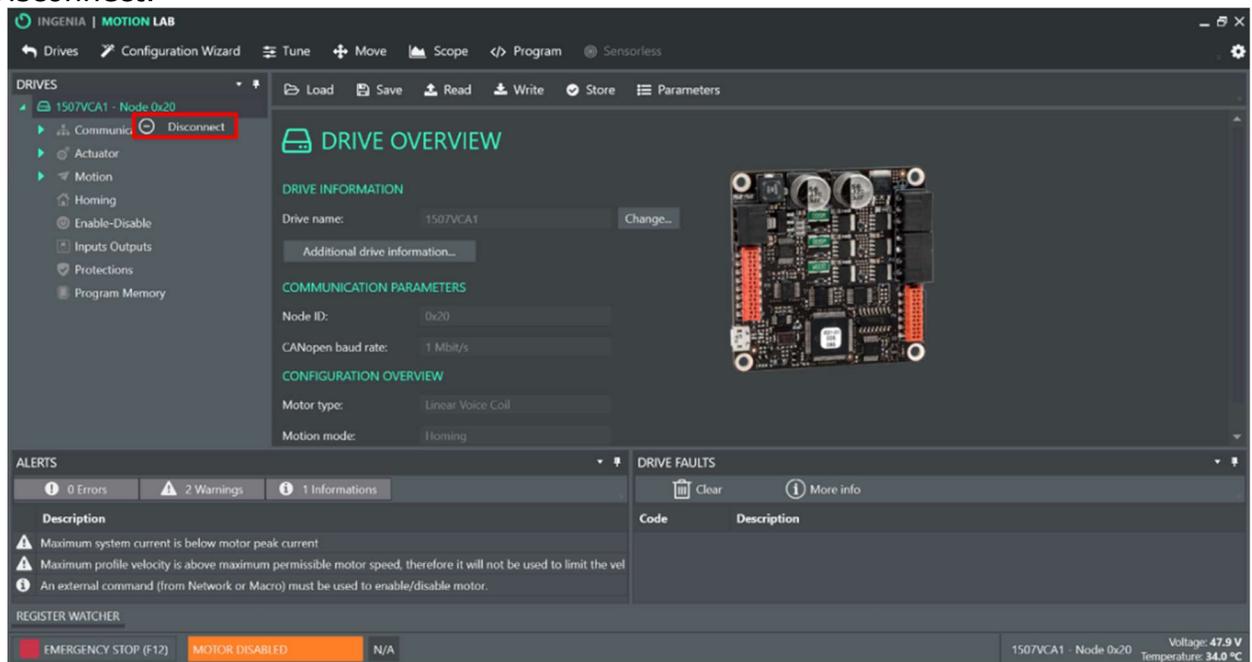


Fig. 80: Disconnecting from the currently connected control drive.

- 9) Back in Detected Drives menu, click on the Jupiter or Pluto drive you want to connect to.

- 10) In the popup window search for and select the recommended XDD (cyan underline in **Fig. 81**). Click "Ok."

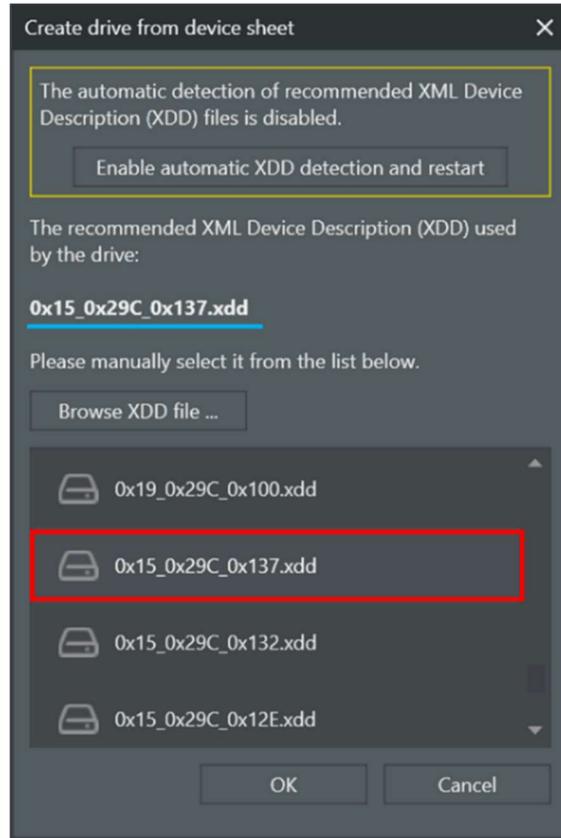


Fig. 81: Manually selecting an XDD file.

Appendix D: “Tune” Menu

When running MotionLab macros, the user **MUST use native units** for the torque control PI gains and position control PID gains. In the MotionLab GUI, the user can toggle between native units and non-native units. BMSEED recommends working with native units to avoid confusion when switching between the MotionLab GUI and its macros.

D.1 Changing to native units in the control loop

Follow these steps to enable the use of native units in the GUI.

- 1) Go to “Settings” (gear icon on the upper right of the main MotionLab window).

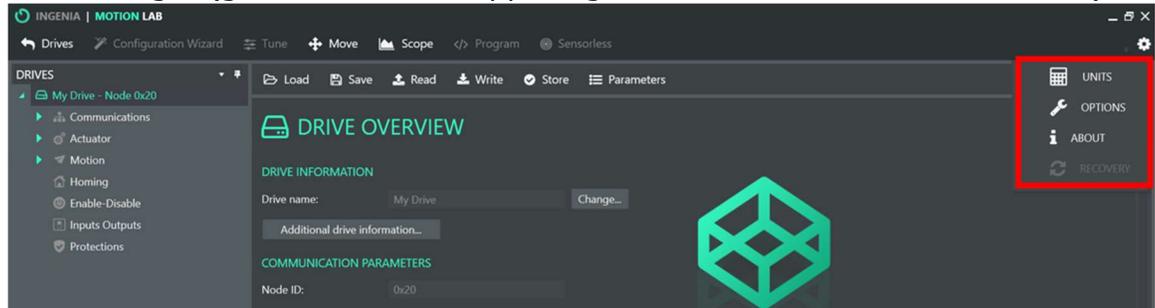


Fig. 82: Settings menu in the MotionLab window.

- 2) Click on “Options.” The following menu will appear.

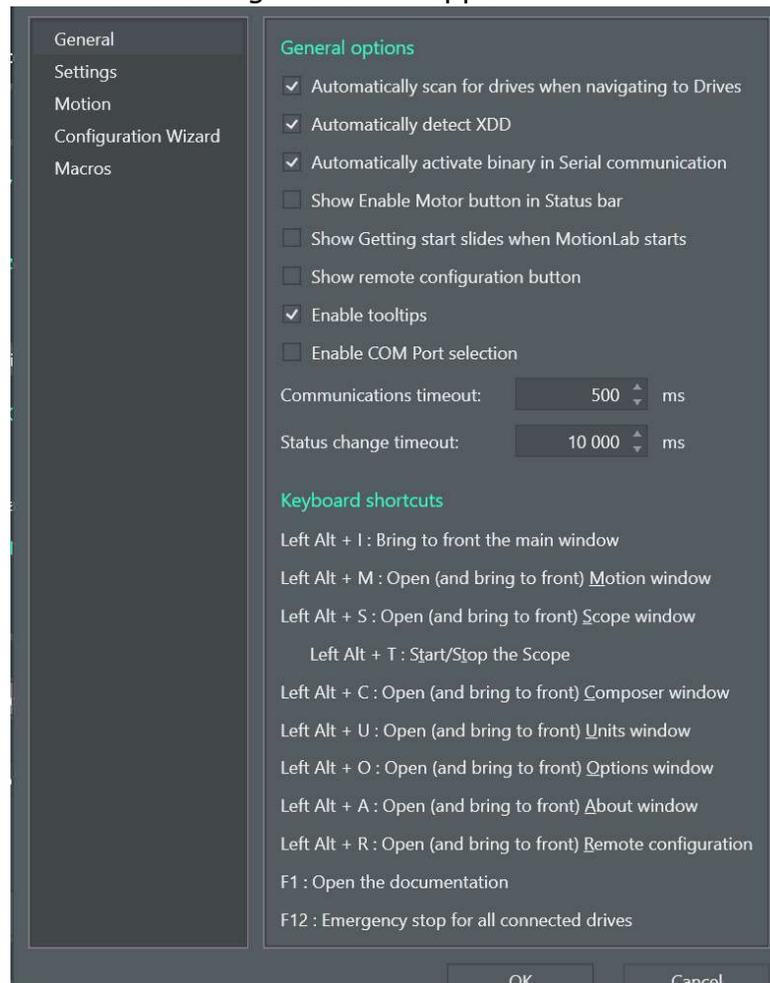


Fig. 83: Options window.

- 3) Click on “Motion” in the left panel and check the “Use drive native units in control loop parameters” box.

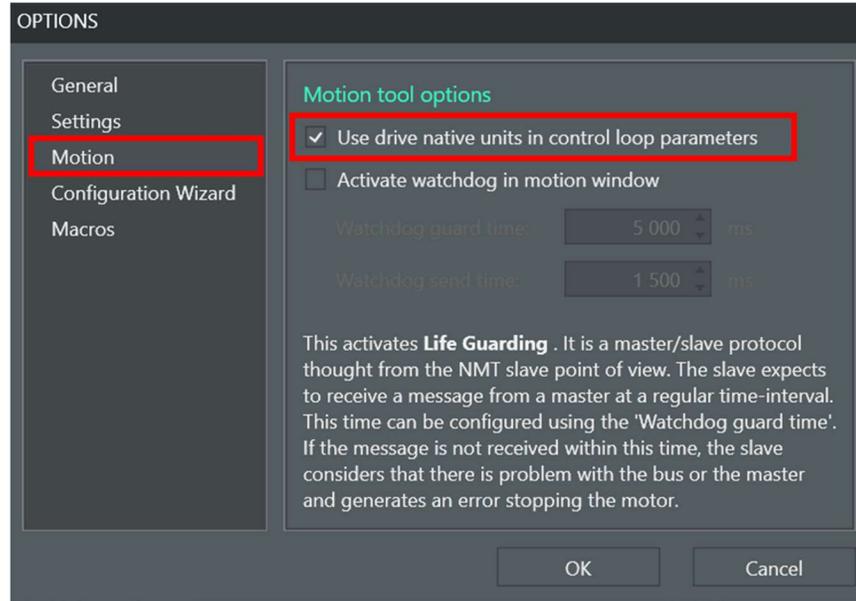


Fig. 84: Motions sub-menu in the Options window.

D.2 Tuning the torque control PI gains and position control PID gains

Before using the VCA, you need to tune the parameters of the PID controller. This will be done by BMSEED prior to tool delivery. Periodic re-tuning, particularly after changes to frame setup (e.g., movable platform), may be necessary.

The parameters P, I, and D of the controller have the following purpose:

- **“P”**: Proportional component or gain
 - Depends only on the difference between the setpoint for the VCA position (i.e., demand position) and the actual/measured value of the VCA position (i.e., actual position).
 - The error_term = demand_position – actual_position
 - The Proportional Gain = $K_p = \text{actual_position} / \text{error_term}$.
 - **The higher the value of the P gain (or K_p), the faster the VCA will move to the setpoint position for the same error term. If the P gain is too large, the VCA could become unstable.**
- **“I”**: Integral component or gain
 - The I gain is used to reduce the steady-state error of the system.
 - Increasing its value, increases the magnitude of the “corrections” made by the controller to the VCA actual position.
 - **The higher the value for the I gain, the faster the VCA will reach its steady state value. If the I gain is too large, the overshoot could be large, and the VCA could become unstable.**
- **“D”**: Derivative component or gain
 - The D gain is used to control or dampen the system’s response based on the rate of change of the error.
 - Increasing its value reduces the overshoot of the VCA actual position.

- **The higher the value for the D gain, the lower the overshoot of the system. If the D gain is too large, the VCA's response could be slowed down, and the VCA could become unstable.**

To tune the controller, follow these steps:

- 1) Click the "Tune" tab in the MotionLab top menu bar.

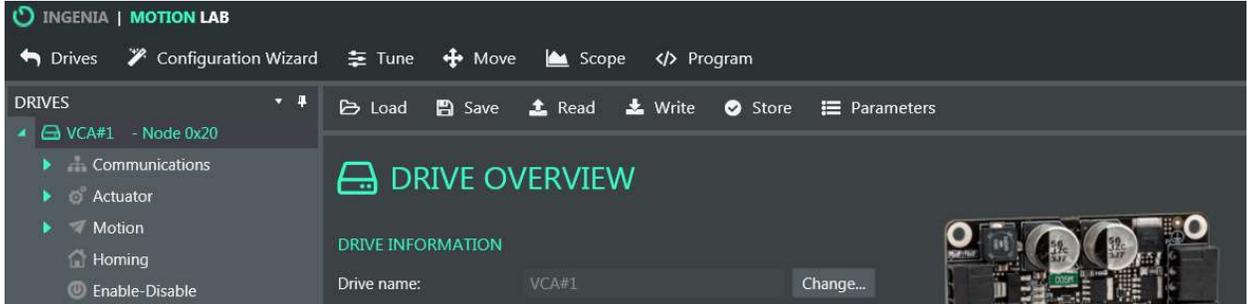


Fig. 85: Top menu bar of the MotionLab window.

- 2) The "Tune" window will pop up.

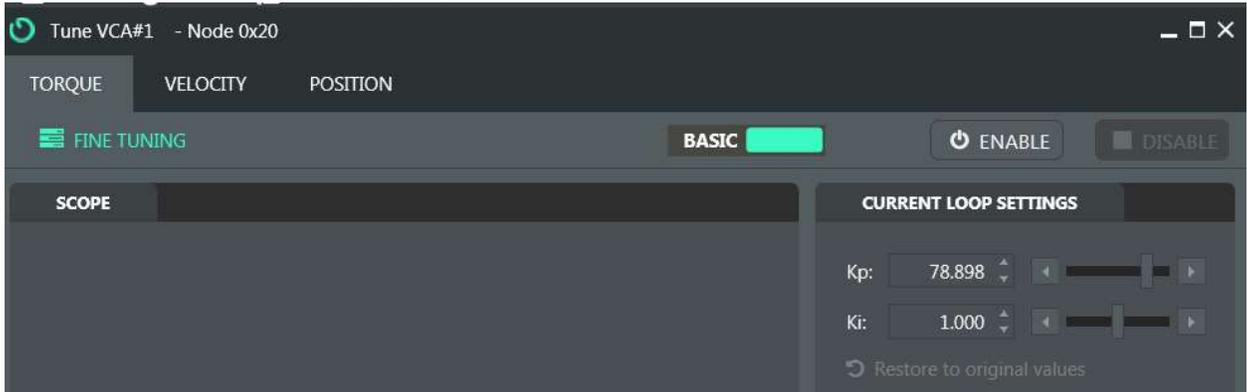


Fig. 86: Tune window.



IMPORTANT: The user can tune "Torque," "Velocity," and "Position." "Torque" needs to always be tuned, followed by "Position" tuning. "Velocity" tuning NOT required for MEASSuRE because the system operates in Position mode.

- 3) **Torque tuning:**
 - i. Click on "BASIC" in the Torque window. The "PRO" settings will be displayed.

- ii. Click “ENABLE” to engage the VCA. You will likely hear a humming noise from the VCA.

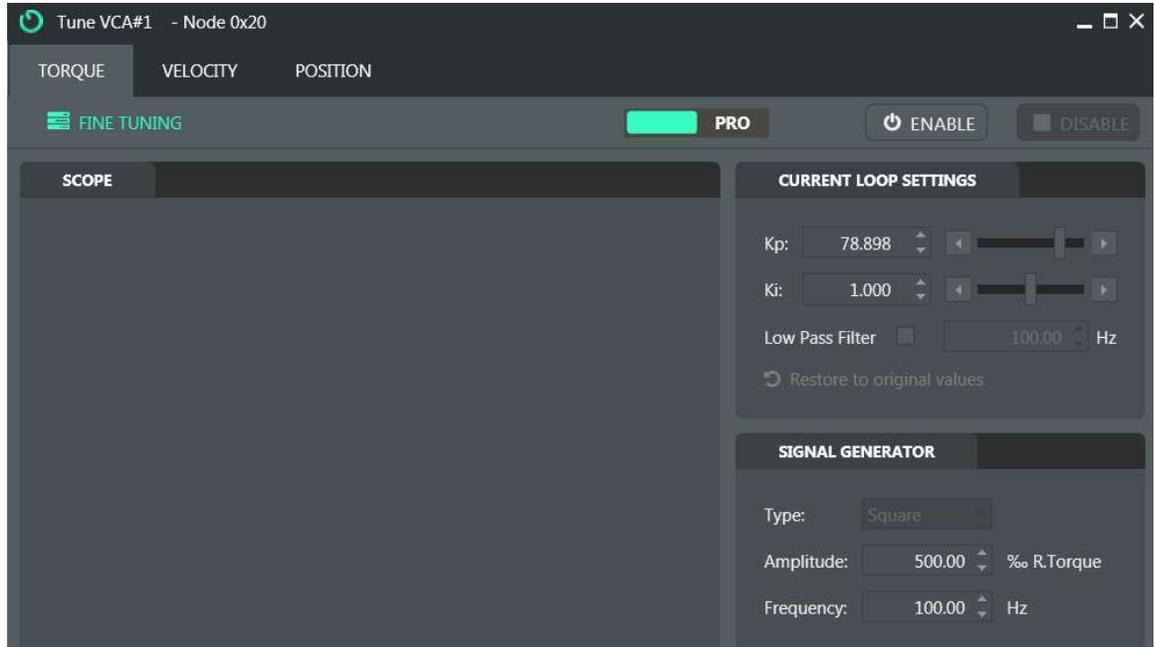


Fig. 87: “Pro” settings under the Torque tab in the Tune window.

- iii. In general, decrease the “Signal Generator” amplitude to 250%, and start increasing first the proportional gain K_p , and then the integral gain K_i until the “Demand” values (blue line) and “Current” values (yellow line) match.
- iv. Once good values for K_p and K_i have been determined, increase the amplitude back to 500%. The resulting actual torque (yellow) should closely match the demand torque (blue) as shown below.

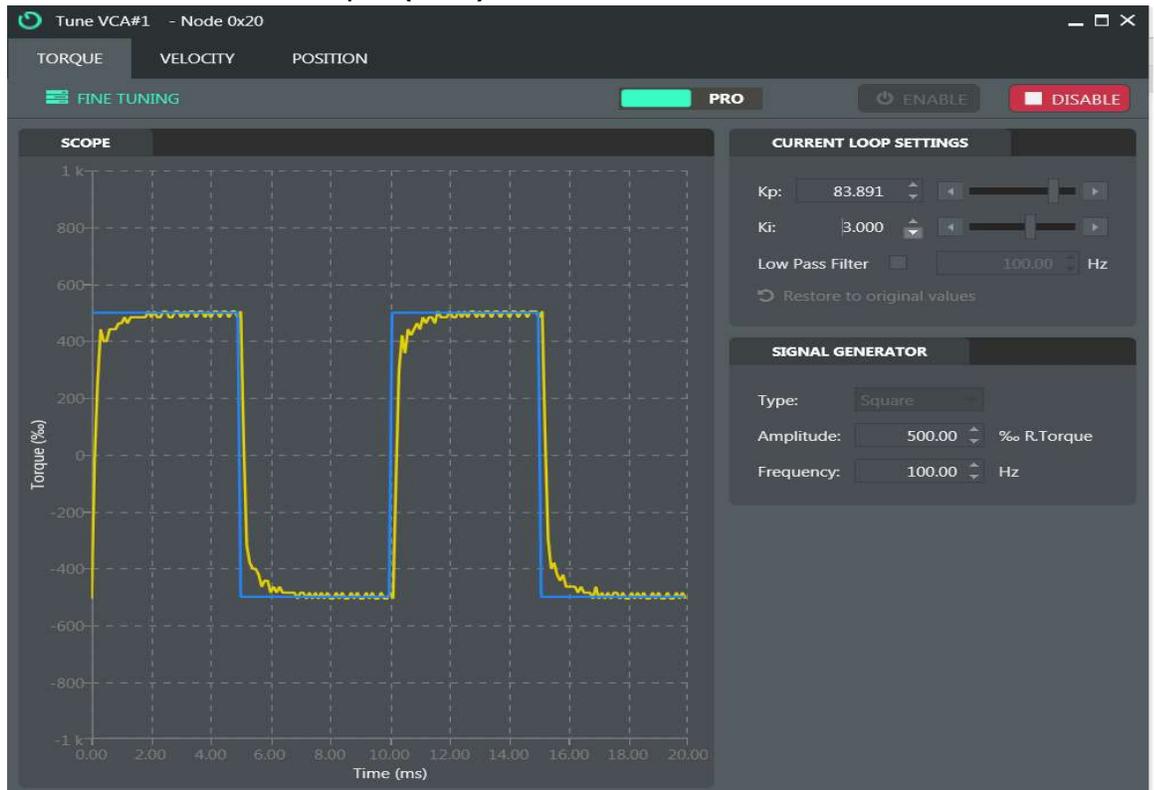


Fig. 88: Torque tuning in the Torque tab.

- v. If this is achieved, you can move to “Position” tuning after disabling the VCA first.

4) **Position tuning:**

There are several methods to Position tune your controller. The preferred method described here is the Ziegler-Nichols method.

- i. Click on the “Position” tab on the top menu bar.

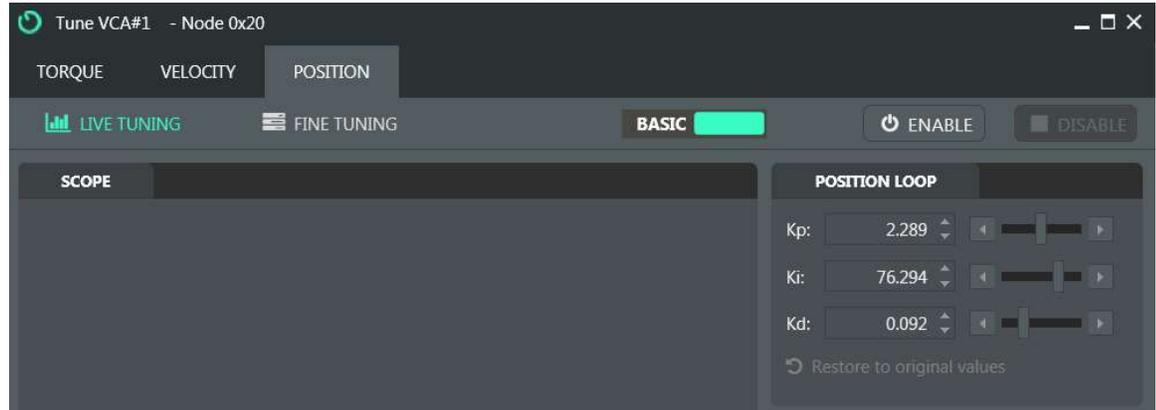


Fig. 89: Position tab in the Tune window.

- ii. Click on “BASIC” in the Position window. The “PRO” settings will be displayed.

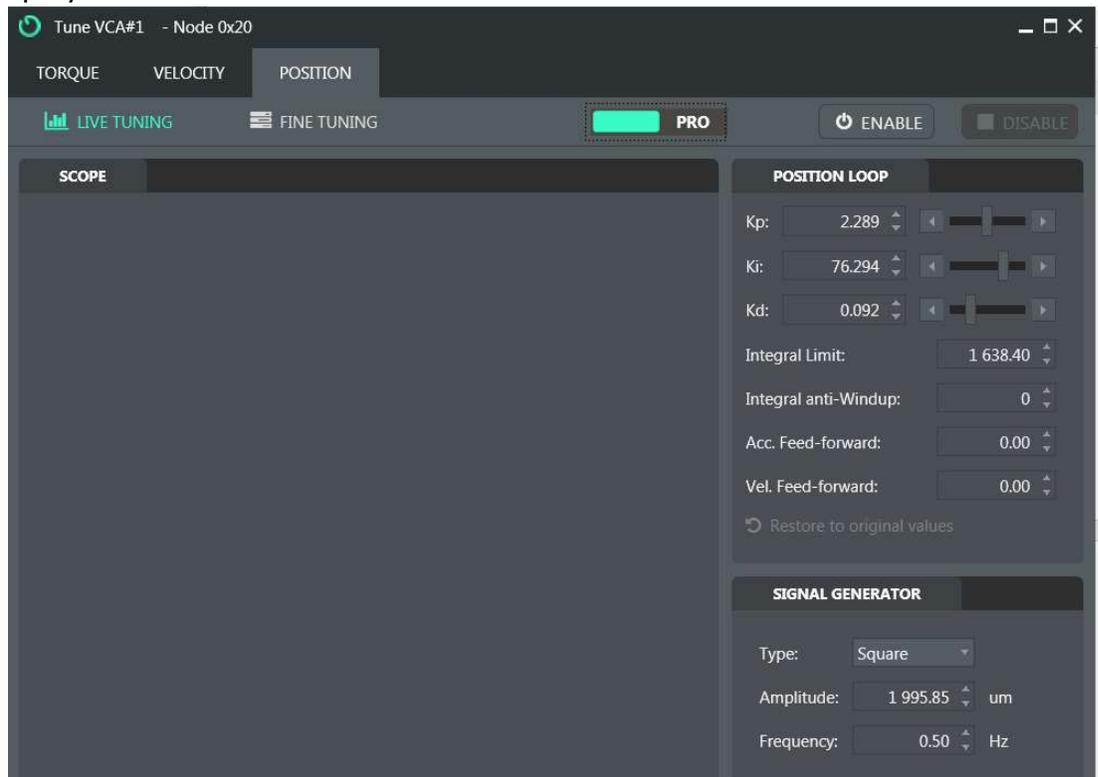


Fig. 90: “Pro” settings under the Position tab in the Tune window.

- iii. Set the “Frequency” in the “Signal Generator” menu (bottom right) to 0.25 Hz. This will result in a 4-second period for each VCA square cycle.

- iv. Set the position control proportion gain K_p , integral gain K_i , and derivative gain K_d to 0.

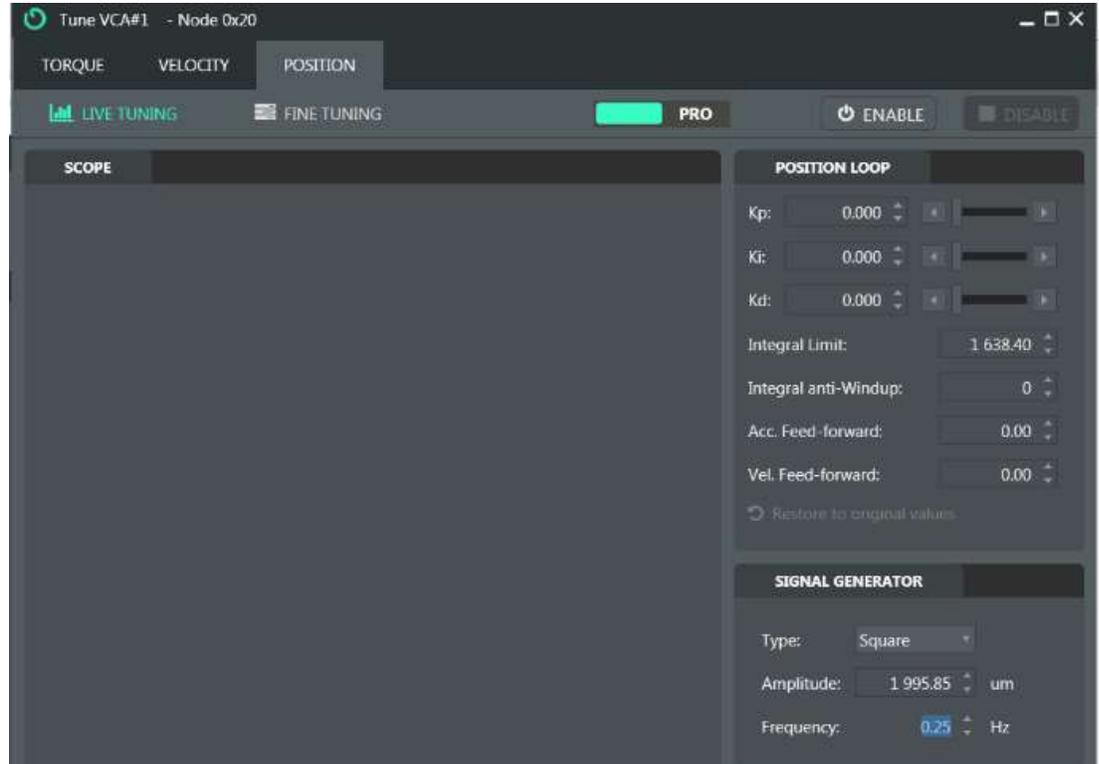


Fig. 91: Setting the position control PID gains to 0.

- v. Click “ENABLE” to engage the VCA.
- vi. Set K_i and K_d to 0 and increase K_p until the VCA oscillates with a constant amplitude. The constant K_c is defined as the K_p value in which the VCA oscillates with constant amplitude. The full period of the oscillation is defined as P_u .



Fig. 92: Starting the position tuning in the Position tab.

- vii. K_c in the example above is 12, and P_u is 0.4s. The values for the K_p , K_i , and K_d for the VCA operation are then calculated in the following manner:
- $$K_p = 0.6(K_u) = 0.6(12) = 7.2$$
- $$K_i = 0.5(P_u) = 0.5(0.4) = 0.2$$
- $$K_d = 0.125(P_u) = 0.125(0.4) = 0.05$$
- viii. Running the VCA with these settings should provide a plot akin to the one shown below.



Fig. 93: Successful position tuning of the VCA.

- 5) Click "SAVE" in the main MotionLab window to save these settings as a new drive configuration file (.xdc) and apply them to the VCA motion.



IMPORTANT: While position control PID gains can be tuned this way, these values should be used as 'default' values when not running the Impulse or Cyclic stretch macros. When running these macros, the position control PID gains might need to be re-optimized for each strain/strain rate combination for impulse stretches and strain/frequency combination for cyclic stretches.

Appendix E: Typical MotionLab Parameter Values for the Different Models of MEASSuRE

Table 5: Typical motor parameters for the different models of MEASSuRE.

Motor Parameters	X	Premium	Mini
Wiring inductance (mH)	3.825 – 5.175	2.200 – 4.100	0.875 – 1.620
Terminal resistance (mΩ)	3,410 – 4,380	2,100 – 2,700	4,110 – 5,280
Stroke (mm)	31 – 37	24 – 28	6.8 – 7.6
Continuous force (mN)	1,020,855 – 1,247,730	182,500 – 223,000	12,677 – 15,487
Force sensitivity (mN/A)	68,057 – 83,182	18,250 – 22,300	11,410 – 13,940
Continuous current (mA)	15,000	10,000	1,111
Current at peak force (mA)	15,000	10,400	1,111
Peak time (ms)	10,000	10,000	10,000
Max permissible speed (μm/s)	3,000,000	61,035,154	650,000
Cycle time (ms)	2,000	2,000	2,000

Table 6: Typical protections parameters for the different models of MEASSuRE.

Protections	X	Premium	Mini
Max system current (mA)	15,100	10,450	1,504
Under voltage warning level (V)	12.0	12.0	12.0
Over voltage warning level (V)	133.0	50.0	50.0
Under temperature fault level (°C)	-20.0	-20.0	-20.0
Over temperature fault level (°C)	45.0	45.0	45.0

Table 7: Typical torque control parameters for the different models of MEASSuRE when running basic, simple motions through the MotionLab GUI and cyclic stretches via macros.

Torque Control Parameters	X	Premium	Mini
Proportional (P) gain, K_p	24,192	20,480	20,480
Integral (I) gain, K_i	2,304	1,280	6,144
Scaling	3	4	2

Table 8: Typical position controls parameters for the different models of MEASSuRE when running basic, simple motions through the MotionLab GUI.

Position Control Parameters	X	Premium	Mini
Proportional (P) gain, K_p	20,000	25,000	300,000
Integral (I) gain, K_i	20	50	200
Derivative (D) gain, K_d	60,000	325,000	450,000
Integral anti-windup	0	0	0
Vel. feed-forward	0	0	0
Acc. feed-forward	0	0	0
Integral limit	200	1,000	16,000

Table 9: Typical position controls parameters for the different models of MEASSuRE when running cyclic stretches via macros.

Position Control Parameters	X	Premium	Mini
Proportional (P) gain, K_p	80,000	50,000	360,000
Integral (I) gain, K_i	20	700	16,000
Derivative (D) gain, K_d	140,000	600,000	720,072
Integral anti-windup	0	0	0
Vel. feed-forward	0	0	0
Acc. feed-forward	0	0	0
Integral limit	200	1,000	16,000

Appendix F: Applied Strain to sMEAs

The most important parameters are the strain and the strain rate. The displacement of the PDMS membrane over the circular indenter determines the strain that the sMEA, and thus the cells/tissue that are grown on it, experience. The velocity with which the VCA moves the sMEA over the indenter determines the strain rate. See below for a schematic.

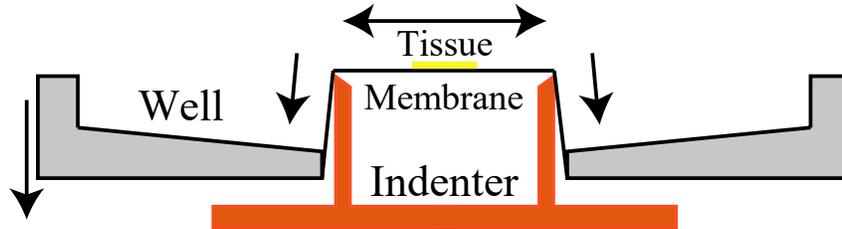
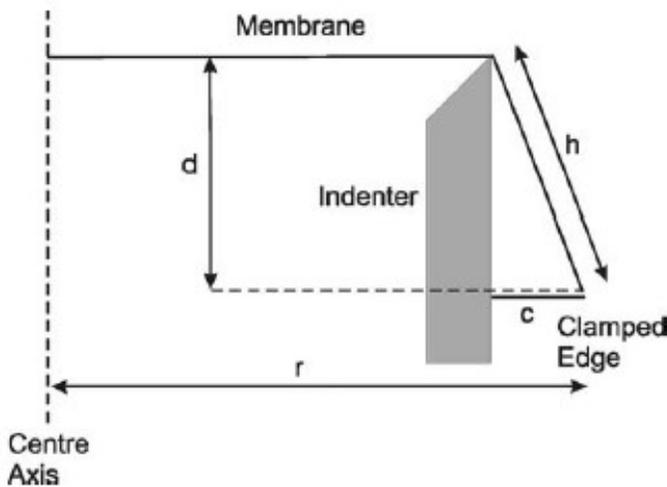


Fig. 94: Schematic of a stretched sMEA (from Morrison et al., *J. Neurosci. Meth.*, 2006).

The Lagrangian biaxial strain that on the sMEA can be calculated using the following equation:



$$d = \sqrt{[r * (\sqrt{2\varepsilon + 1} - 1) + c]^2 - c^2}$$

d: vertical displacement of indenter, i.e., stroke
 r: radius of clamped membrane [12.5 mm]
 c: gap between indenter and clamped edge [3.5 mm]
 ε: applied strain

Fig. 95: Theoretical calculations of the stretchable membrane biaxial strain (from Morrison et al., *J Neurosci. Meth.*, 2006).

Fig. 96 below shows graphically the relationship between the applied strain (experimentally determined) and the displacement below the indenter required to achieve such strain. The table below the plot (**Table 10**) shows the numerical values for the theoretical and experimental displacement over the indenter for a given strain.



BMSEED will provide this mapping in the MEASSuRE system-specific mechanics Excel workbook (explained in **Section 8.1** above). Use those values in your experiments as they correspond to your system.

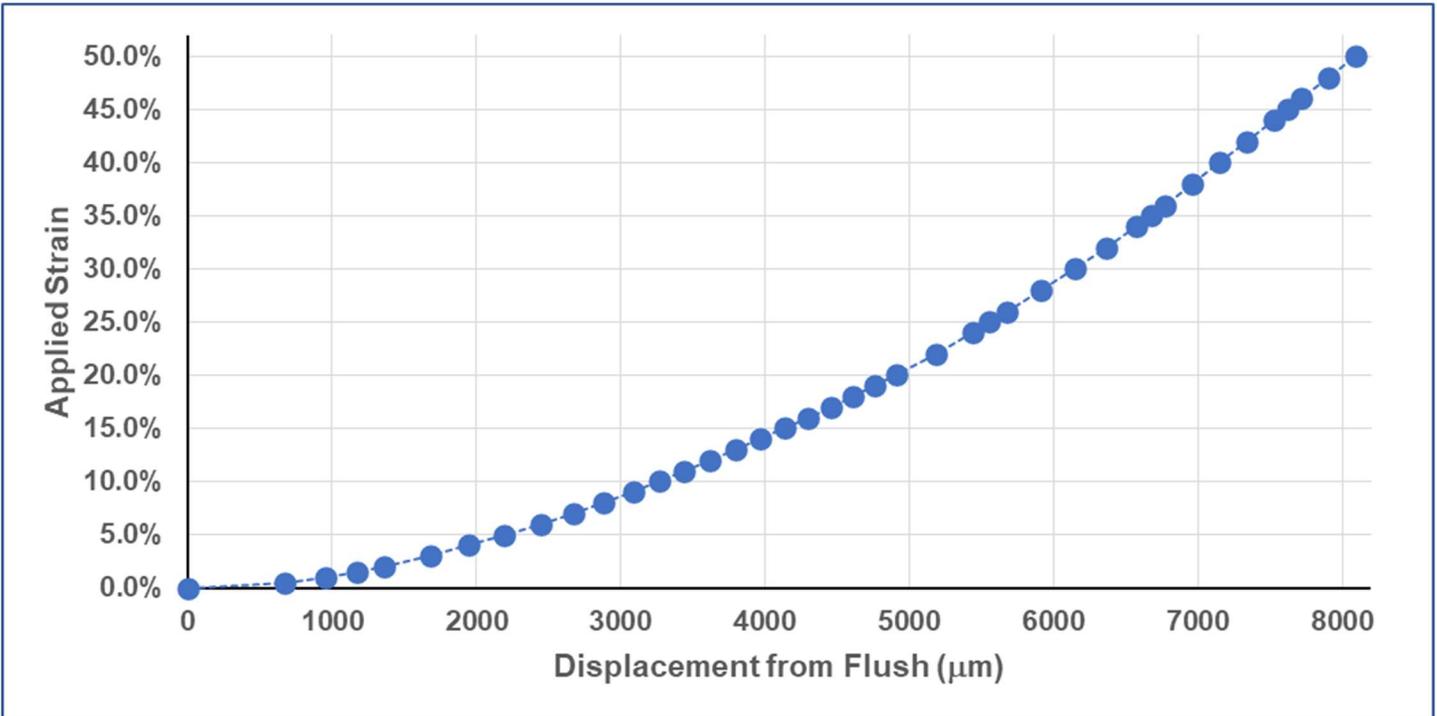


Fig. 96: Applied biaxial strain on the sMEA membrane as a function of displacement below flush.

Table 10: Vertical displacement from flush for various target strains.

Strain (ϵ)	Relative displacement from flush [μm]	Strain (ϵ)	Relative displacement from flush [μm]
0%	0	22%	5187
0.50%	675	24%	5436
1%	957	25%	5558
2%	1361	26%	5679
3%	1677	28%	5916
4%	1947	30%	6151
5%	2195	32%	6368
6%	2442	34%	6577
7%	2671	35%	6678
8%	2885	36%	6774
9%	3085	38%	6963
10%	3269	40%	7152
12%	3619	42%	7335
14%	3971	44%	7529
15%	4140	45%	7625
16%	4300	46%	7721
18%	4610	48%	7910
20%	4907	50%	8098

Appendix G: Impulse Stretch - Strain Rate and Applied Velocity Profiles

Calculated velocity (*v*) and acceleration (*a*) values for different strain and strain rate pairs for a trapezoidal velocity profile for moving from flush position to the target position (Δd).

Table 11: Example of kinematics parameters for different strain/strain rate combinations when using a MEASSuRE-X system and an 'aggressive' trapezoidal velocity profile.

Strain (%)	Strain Rate (1/s)	Δd (μm)	Δd (c)	Δt (ms)	<i>v</i> (c/s)	<i>a</i> (c/s ²)
2	1	1361	169	0.020	8,662	17,324,495
2	5	1361	169	0.004	43,311	433,112,365
2	10	1361	169	0.002	86,622	1,732,449,459
5	1	2195	272	0.050	5,587	4,469,549
5	5	2195	272	0.010	27,935	111,738,713
5	10	2195	272	0.005	55,869	446,954,851
5	20	2195	272	0.0025	111,739	1,787,819,402
10	1	3269	406	0.100	4,159	1,663,726
10	5	3269	406	0.020	20,797	41,593,138
10	10	3269	406	0.010	41,593	166,372,552
10	20	3269	406	0.005	83,186	665,490,208
10	25	3269	406	0.004	103,983	1,039,828,449
10	35	3269	406	0.00286	145,576	2,038,063,761
15	1	4140	514	0.150	3,512	936,653
15	5	4140	514	0.030	17,562	23,416,332
15	10	4140	514	0.015	35,124	93,665,326
15	20	4140	514	0.0075	70,249	374,661,305
15	25	4140	514	0.006	87,811	585,408,290
15	45	4140	514	0.003333	158,060	1,896,722,858
20	1	4907	609	0.200	3,122	624,417
20	5	4907	609	0.040	15,610	15,610,423
20	10	4907	609	0.020	31,221	62,441,690
20	20	4907	609	0.010	62,442	249,766,761
20	25	4907	609	0.008	78,052	390,260,564
20	50	4907	609	0.004	156,104	1,561,042,255
20	55	4907	609	0.003636	171,715	1,888,861,128
30	1	6151	763	0.300	2,609	347,870
30	5	6151	763	0.060	13,045	8,696,741
30	10	6151	763	0.030	26,090	34,786,963
30	20	6151	763	0.015	52,180	139,147,853
30	25	6151	763	0.012	65,226	217,418,520
30	50	6151	763	0.006	130,451	869,674,082
30	70	6151	763	0.004	195,677	1,956,766,684
40	1	7152	887	0.400	2,275	227,539
40	5	7152	887	0.080	11,377	5,688,479
40	10	7152	887	0.040	22,754	22,753,916
40	20	7152	887	0.020	45,508	91,015,664
40	25	7152	887	0.016	56,885	142,211,975
40	50	7152	887	0.008	113,770	568,847,898
40	75	7152	887	0.005333	170,654	1,279,907,771
40	80	7152	887	0.004444	204,785	1,843,067,190
50	1	8098	1005	0.500	2,061	,164,871
50	5	8098	1005	0.100	10,304	4,121,765
50	10	8098	1005	0.050	20,609	16,487,058
50	20	8098	1005	0.025	41,218	65,948,232
50	25	8098	1005	0.020	51,522	103,044,113
50	50	8098	1005	0.010	103,044	412,176,450
50	75	8098	1005	0.006667	154,566	927,397,014
50	90	8098	1005	0.005	206,088	1,648,705,802

Upon MEASSuRE system installation and training, BMSEED will provide a spreadsheet with the calculated velocity and acceleration values for each strain/strain rate combination specific to your system. The μm -to-counts conversion factor for the system will also be provided.



Always check the motion profile in the Scope window before executing an experiment

Table 11 above is an **example** of the spreadsheet provided for a MEASSuRE-X system with a LAS43-88-000A-10I VCA with a conversion factor of $8.06 \mu\text{m}/\text{c}$. This is a **sample table**.

Sample calculations to determine velocity and acceleration:

Here we show how the velocity and acceleration values were calculated for the previous table. The user can follow this procedure to achieve their target position profile.

- 1) Identify your target strain (%) and strain rate (s^{-1}).
For instance, **40% strain** at a rate of **50 s^{-1}** .
- 2) Use **Table 10**, to determine the experimental displacement (in μm) that corresponds to the target strain.
For instance, for our target strain of 40% strain, the experimental displacement was determined to be to **$7152 \mu\text{m}$** .

- 3) Divide the desired strain (unitless) by the desired strain rate (s^{-1}) to determine the time for the VCA to execute this displacement.

For this example,
$$\frac{\text{strain}}{\text{strain_rate}} = \frac{40\%}{50 \text{ s}^{-1}} = \frac{0.40 \text{ s}}{50} = \mathbf{0.008 \text{ s}}$$

- 4) Derive the equations for calculating velocity and acceleration.
For the provided trapezoidal profile, we have set the following:
 - Velocity is 0 mm/s at 0% of the target time.
 - Target Velocity is reached at 2.5% of the target time (here: 0.2ms).
 - Velocity is maintained between 2.5% and 97.5% of the target time (here: 0.2-7.8ms).
 - Velocity starts decreasing at 97.5% of the target time (here: 7.8ms).
 - Velocity is 0 mm/s at 100% of the target time (here: 8ms).

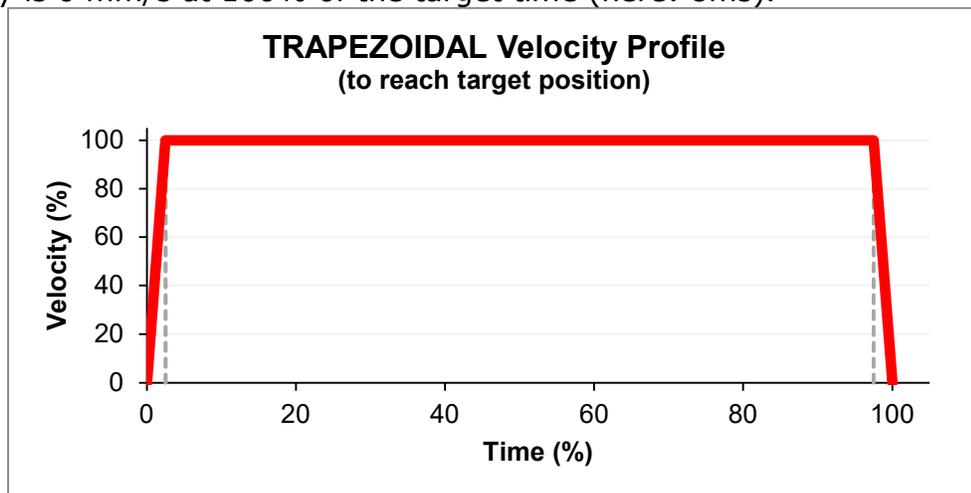


Fig. 97: Trapezoidal velocity profile to calculate the velocity and acceleration parameters.

The formula to calculate distance traveled is derived by adding the areas under the velocity profile curve.

For this example,

$$d = 0.5(0.025t)(v) + (0.95t)(v) + 0.5(0.025t)(v)$$

$$d = 0.0125vt + 0.95vt + 0.0125vt$$

$$d = 0.975vt$$

The formula is then rearranged to solve for velocity,

$$v = \frac{d}{0.975t}$$

Acceleration can now be calculated dividing velocity by time to reach said velocity. For this example, we have set that velocity is reached at 2.5% of the target time. Thus, acceleration can be calculated using the formula

$$a = \frac{v}{0.025t}$$

- 5) Use the derived equations and known distance and time values to calculate velocity and acceleration.

In our example, for the trapezoidal profile,

$$v = \frac{d}{0.8t} = \frac{7152\mu\text{m}}{0.975(0.008)} = 916982\mu\text{m/s}$$

$$a = \frac{v}{0.2t} = \frac{916982\mu\text{m/s}}{0.025(0.008)} = 4584910256\mu\text{m/s}^2$$

- 6) Divide the velocity and acceleration by the conversion factor (specific to the system's VCA) to transform units from μm to counts. The conversion factor **specific to the system in this example (and Table 11 above)** is **8.06 $\mu\text{m}/\text{c}$** .

In our example, for the trapezoidal velocity profile, velocity and acceleration are **113,770 c/s** and **568,847,898 c/s²**, respectively.

Determining the velocity and acceleration for other trapezoidal velocity profiles:

If interested in other trapezoidal velocity profiles, you would need to modify the equations in **step 4** above.

- For instance, another approach would be using a **more conservative trapezoidal profile** (i.e., reaches the max velocity more slowly). If the max velocity is to be reached at 20% of the target time, maintained between 20% and 80% of the target time, and decreased to zero velocity starting at 80% of the target time, the velocity and acceleration equations would change to:

$$v = \frac{d}{0.80t} \qquad a = \frac{v}{0.20t}$$

- A **triangular profile** (i.e., reaches the max velocity midway through the motion) could also be attempted. If the max velocity is to be reached at 50% of the target time and decreased to zero velocity immediately after, the velocity and acceleration equations would change to:

$$v = \frac{d}{0.50t} \qquad a = \frac{v}{0.50t}$$

Once the new velocity and acceleration equations have been defined, **repeat steps 5 and 6 above** to calculate the velocity and acceleration values to be used in the macros.



Note that in all macros, the position, velocity and acceleration/deceleration values must be provided in c, c/s and c/s² respectively.

Appendix H: Impulse Stretch - Position Control PID Gains and Motion Start Position

Upon MEASSuRE system installation and training, BMSEED will provide a spreadsheet with the suggested sets of parameters to use as **starting points** for different strain/strain rate combinations specific to your MEASSuRE system.

Table 12 is an **example** of some information provided for a MEASSuRE-X system with a LAS43-88-000A-10I VCA. This is a **sample table**. Note that the actual spreadsheet will be formatted differently and will contain all the relevant information for each strain/strain rate pair.

For each strain/strain rate combination shown in **Table 12**, position control gains (proportional "P", integral "I", and derivative "D") and motion start position (i.e., at flush position or distance above flush) are provided. Most of the other parameters not listed here typically remain the same (e.g., torque control PI gains and input voltage) or change very slightly (e.g., error position threshold and error position time) in a few cases.

Table 12: Sample position control PID gains and impulse starting positions for different strain/strain rate combinations for a MEASSuRE-X system.

strain rate (s ⁻¹)	strain (%)						
	2	5	10	20	30	40	50
1	P: 2 000 I: 40 D: 300 000						
	Flush						
5	P: 15 000 I: 40 D: 300 000	P: 16 000 I: 40 D: 300 000	P: 12 000 I: 40 D: 300 000	P: 10 000 I: 40 D: 300 000	P: 10 000 I: 40 D: 300 000	P: 8 000 I: 40 D: 300 000	P: 16 000 I: 40 D: 300 000
	+3mm	Flush	Flush	Flush	Flush	Flush	Flush
10	P: 8 500 I: 40 D: 300 000	P: 16 000 I: 40 D: 300 000	P: 20 000 I: 40 D: 300 000	P: 12 000 I: 40 D: 300 000	P: 15 000 I: 40 D: 300 000	P: 14 000 I: 40 D: 300 000	P: 22 000 I: 40 D: 300 000
	+3mm	+3mm	Flush	Flush	Flush	Flush	Flush
25	n/a	n/a	P: 8 000 I: 40 D: 300 000	P: 21 000 I: 40 D: 300 000	P: 28 000 I: 40 D: 300 000	P: 28 000 I: 40 D: 300 000	P: 17 000 I: 40 D: 300 000
			+3mm	+3mm	Flush	Flush	Flush
50	n/a	n/a	n/a	P: 24 000 I: 40 D: 300 000	P: 20 500 I: 40 D: 325 000	P: 30 000 I: 40 D: 300 000	P: 21 300 I: 40 D: 300 000
				+3mm	+3mm	+3mm	+3mm
75	n/a	n/a	n/a	n/a	n/a	P: 40 000 I: 40 D: 300 000	P: 40 000 I: 40 D: 300 000
						+3mm	+3mm
90	n/a	n/a	n/a	n/a	n/a	n/a	P: 98 000 I: 40 D: 300 000
							+4mm

Note: Strain/strain rate pairs listed as "n/a" are currently unattainable due to hardware limitations (i.e., acceleration/deceleration values are too large to be used as servo drive input).



****Disclaimer:** The sets of parameter values provided by BMSEED upon tool installation and training should **ONLY** be used as starting points. It is the user's responsibility to identify values that will produce the desired motions and profiles for their experiments.

Appendix I: Impulse Stretch - MEASSuRE Systems Strain Rate Limits

The models of MEASSuRE are built with different components to suit a wide range of applications. Thus, each model has different capabilities and limitations. **Table 13** shows max strains that can be achieved when running symmetric impulse stretches (i.e., same target rates for the downwards and upwards motions) with a MEASSuRE-X system. **Fig. 98** illustrates the max strain rates with a MEASSuRE-X. For downwards motions of impulse stretches, the user may start the impulse above the flush position to achieve the faster, more demanding impulses. This is not the case for the upwards motions since the starting position for this movement is restricted to the target impulse strain position. Otherwise, unwanted additional strain will be applied to the sample.

Table 13: Max achievable strain rates when running symmetric impulse stretches.

strain (%)	Max strain rate (s ⁻¹)			
	MEASSuRE-X VCA (LAS43-88-000A-P01-10I)		MEASSuRE-Premium VCA (LAS28-53-000A-P01-12I)	
	Downwards motion	Upwards motion	Downwards motion	Upwards motion
2	10.00	10.00	8.51	7.15
5	20.00	16.99	16.69	11.78
10	35.71	29.44	25.00	19.42
15	45.45	38.97	-	-
20	55.56	50.03	37.39	30.78
30	70.60	64.52	45.45	38.23
40	82.48	71.43	52.98	45.98
50	90.10	74.27	62.50	53.20

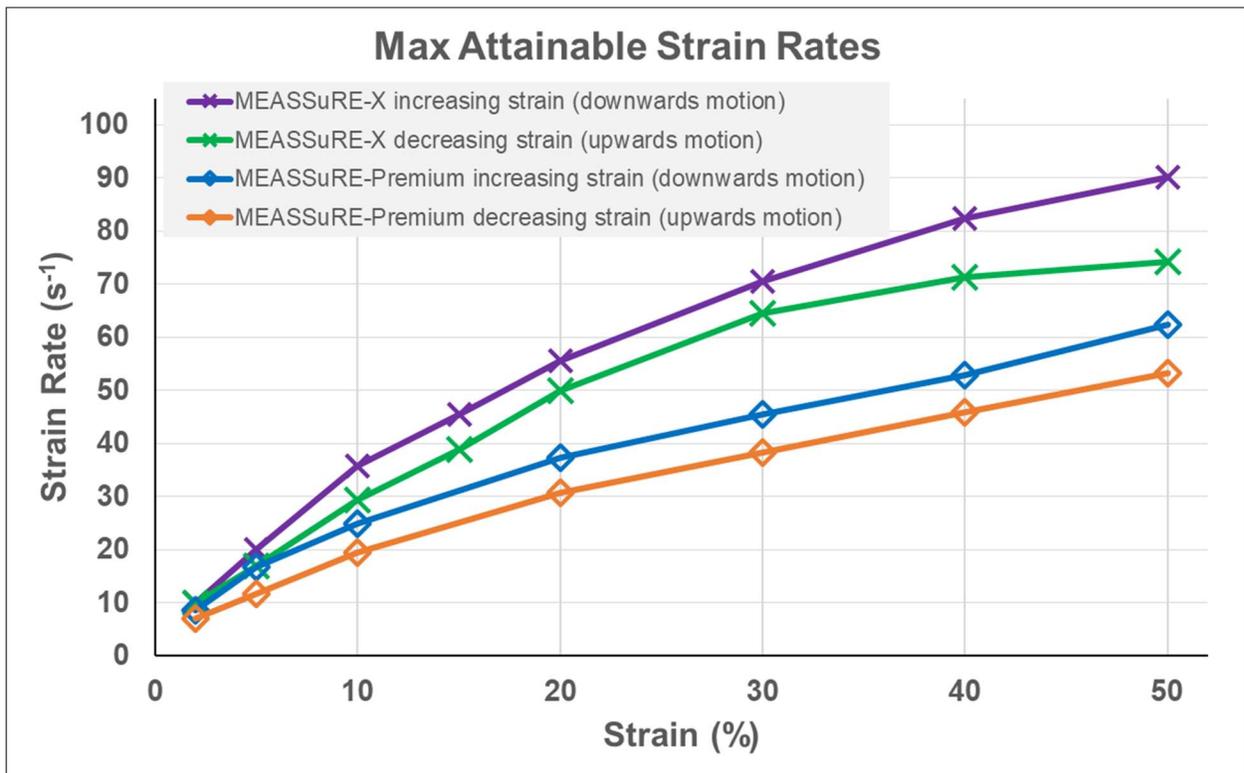


Fig. 98: Max strain rates when running symmetric impulses.

Appendix J: Troubleshooting

Here is a list of issues that may be encountered while running the VCA.

Issue #1: VCA is not moving.

- a. Is the VCA enabled?
- b. Are the voltage output LEDs on the power supplies green?
- c. Is the voltage on the power supplies set to a non-zero value?
- d. Are you trying to move the VCA down with the homing blocks in place?
- e. Check for a warning on MotionLab that might need to be cleared.
- f. Has the emergency stop button been pressed, but not released?
- g. Check that the VCA motor and feedback (I/O) cables are properly connected to the back panel of the electronics enclosure.

Issue #2: Error code: 0x5430 " Input stage problem detected. Voltage not stable or not available."

- a. Is the power cord of both power supplies plugged in?
- b. Is the "output" button on both power supplies lit?
- c. Has the emergency stop button been pressed, but not released?

Issue #3: The VCA is enabled but is behaving erratically.

- a. Check the torque PI control tuning.
- b. Check the position PID control tuning.
- c. Download the most recent firmware and corresponding XDD file.
- d. Verify that the analog input signal 1 (i.e., Hall effect position sensor within the VCA) is responding properly when raising and lowering the movable platform. If this is not the case, the VCA is damaged and might need to be replaced. Contact BMSEED immediately.

Issue #4: After running a macro and completing the macro or stopping it while executing the macro, the VCA is not following the target position or behavior when enabled the next time.

- a. The VCA might be trying to finish executing the previous macros. Remove the sample and homing block from the frame and keep pressing the "VCA go" button until the VCA is disabled or starts behaving as expected.

Appendix K: Glossary

sMEA:	stretchable microelectrode array
SW:	stretchwell
VCA:	voice coil actuator
PBS:	phosphate buffered solution
GUI:	graphical user interface