INSTEC

FOCUS ON EXCELLENCE

User's Manual

mK2000B

Precision Temperature Controller

INSTEC, Inc.
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Version 3.10

INSTEC, Inc.

Warranty

April 30, 2025

INSTEC, Inc. guarantees the product will conform to the specifications outlined in this manual and will remain free of defects in workmanship and materials for one year from the date of delivery. Should a product, in *INSTEC'*s opinion, malfunction during the warranty period because of a defect in workmanship or material, *INSTEC* will repair or replace it at no charge to the buyer, provided the product has not been subject to accidental damage, misuse, abuse, or unauthorized alteration, modification, and/or repair.

Examples of actions that will make this warranty null and void include, but are not limited to, the following:

- Storing or operating the device at any temperature outside the operating and storage temperature range.
- Performing or attempting to perform unauthorized service or repair.
- Resale -- except through an authorized dealer.

Products requiring service under this WARRANTY should be delivered to *INSTEC*, Inc. All portions of such systems, hardware, and software should be sent, along with proof of purchase if obtained from an authorized dealer. The buyer must ensure the product or assume the risk of damage or loss in transit. If unable to repair or replace the product, *INSTEC* will refund the purchase price paid by the original buyer.

DISCLAIMER

THE FOREGOING WARRANTY IS IN LIEU OF AND TO THE EXCLUSION OF ALL OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING WITHOUT LIMITATION, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. *INSTEC*, INC.'S LIABILITY AND THE BUYER'S EXCLUSIVE REMEDY FOR BREACH OF THE FOREGOING WARRANTY SHALL BE LIMITED TO THE REPAIR OR REPLACEMENT OF THE PRODUCT OR REFUND OF THE PURCHASE PRICE. UNDER NO CIRCUMSTANCES WILL *INSTEC* BE LIABLE TO THE BUYER IN ANY WAY FOR DAMAGES, INCLUDING ANY LOST PROFITS, LOST SAVINGS, OR OTHER INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF THE USE OR MISUSE OF THE PRODUCT, OR *INSTEC*'S BREACH OF THE FOREGOING WARRANTY

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Chapter 0. Safety Information

WARNING

Always follow the safety guidelines outlined in this User Manual. Improper use may result in personal injury or death

Within this manual, a set of symbols are used to call attention to Safety Warnings, Caution Notices, and Notes. The symbols are defined in

Figure 1:

Warning Symbol Indicates a safety guideline that should be followed at all times	**Caution Symbol** Indicates a caution notice that calls attention to a potential safety risk	**Note Symbol** Indicates an important notice which should be given careful consideration.

Figure 1: *Symbol Legend*

Documentation: The mK2000 Precision temperature controller is just one component of your *INSTEC* temperature control system. Be sure to carefully read, and follow the safety guidelines outlined for each component device in the system.

Electrical Connections: Always use the correct Input voltage and frequency according to the end-user's region. 110VAC 60Hz AC for North America, 220VAC 50Hz in Europe, etc. *INSTEC* will configure each element of the *INSTEC* temperature control system with an appropriate receptacle before delivery. NEVER use power plug adapters when using the mK2000, or any other part of your *INSTEC* System.

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Ventilation Saftey: XP1 units rely on ventilation holes and electrical fans to provide airflow to the internal components. Be sure to install the equipment in such a manner that the vents are not blocked.

Cleaning: Do not submerge any INSTEC instrument. Clean only with a microfiber cloth and either a mild detergent, or Isopropyl Alcohol.

Improper Use: If any part of the Instec system is used In manner not specified by Instec Inc. the Saftey protections provided by the instrument are no longer guaranteed, and may be impaired. While this documentation includes installation and setup instructions, responsibility for safe installation and operating of this system is ultimately up to the assembler/ installer of the system.

Child Saftey: Instec XP1 units, and temperature control systems, are not suitable for use in locations where children are likely to be present.

Current Limiting Devices: Most devices used in your *INSTEC* System contain a replaceable fuse rated appropriately for each device. The fuse for the mK2000 is located within the AC power receptacle (or in a standalone fuse holder) and can be accessed using a flathead screwdriver. **The fuse should only be accessed when the device is unplugged from the AC power supply.** Never replace the fuse with a fuse of a different current rating than what is indicated on the back panel of the controller.

Extreme Temperatures: While the MK2000B case should never exceed ambient temperatures, special care should be taken concerning the Stage/Plate/Chuck/ probe station being controlled. Both the chassis and sample temperature can exceed 60 C, or drop below -20 C depending on the configuration. Always be aware of the operating temperature of your stage and avoid physical contact accordingly. Contact with extreme temperatures, hot or cold, may cause bodily harm.

Power Button: Power is supplied or interrupted on the mK2000 temperature controller via an illuminated push-button switch located on the front panel of the controller. This button can be identified by the power symbol below in **Figure 2**.

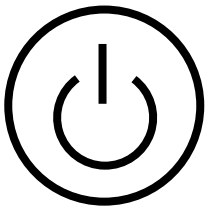

Figure 2. *Primary power switch indicator*

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Chapter 1. Introduction

1.1 Product Description

The mK2000B series temperature controller offers precision, accuracy, and stability for temperature measurement and control. When coupled with heating/cooling equipment from *INSTEC*, the mK2000B can provide temperature control that is accurate to 0.001°C (1 milli-Kelvin) and stability at the set temperature of 0.05 °C. Instec stages/plates/chucks cannot be used on any other mK2000B, as each controller is uniquely calibrated and configured for a single stage/plate/chuck.

The mK2000B is a modular platform that can be configured and customized for nearly any application, including virtually any Process Control. By default, the majority of mK2000B controllers are configured for temperature control, but in order to support non-temperature control applications, most terminology in the user interface and documentation is expressed in abstract process Control terminology. This manual will assume that the mK2000B is being used for precision temperature control.

1.2 Features

- User-friendly touchscreen LCD display.
- Standalone operation via front panel, or software control through a PC (Windows 10/11).
- User-adjustable temperature ramp rate.
- Tunable PID control algorithm.
- Precisely controls temperature with up to 0.001°C accuracy with 0.05°C stability.
- Data logging/ exportation (requires PC connection).
- Command reference guide and sample code for custom software solutions.
- Customizable to include Analog Input/Output, multiple loops, GPIO outputs, and more.

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1.3 Specifications

Table 1: *Table of General Specifications*

General Specifications	
Specification	Value
Supply Voltage	*Supply voltage depends on the region and stage/plate/chuck. Always consult the nameplate/ label on the back of the mK2000B before connecting it to external AC/DC power.*
Temperature Range	-200°C to 1500°C (functional range is model dependent)
LCD Dimensions	70mm x 55mm
Chassis Dimensions	Type A: 25.5cm x 34.5cm x 17cm, Type B: 36cm x 39cm x 17cm
Sensor Type	Platinum 100Ohm RTD, S/K type thermocouple, Thermistor (application dependent, must be configured before delivery)
Environmental requirements	Ambient Temperature 0°C ~ 50°C, indoor use only Humidity < 85%RH Altitude to 2000 m, Pollution Degree 2

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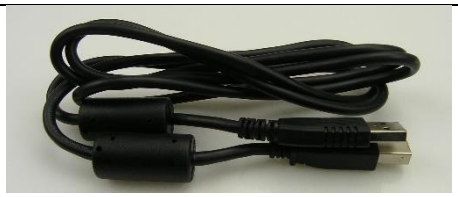
Chapter 2. System Installation

2.1 Unpacking and Equipment List for mK2000B

Please inspect the shipping carton for any signs of damage that may have occurred during shipment. If the shipping carton shows any signs of damage, please retain the shipping carton for insurance purposes. Open the shipping carton and remove and inspect the contents. Please report any occurrences of shipping damage to *INSTEC* immediately.

Shipping Carton: It is highly recommended to retain the shipping carton for the duration of the 1-year factory warranty. Using the original packaging for manufacturer-approved return shipping greatly reduces instances of shipping damage.

Table 2: Standard Parts for the mk2000B

Standard Parts for the mK2000B	
One (1) mK2000B standalone controller	
One (1) Power cord (Region Specific)	
One (1) USB cable	

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2.2 mk2000B Rear panel

Figure 3. *A sample The rear panel of the mK2000B controller (Nearly every mK2000B has a different rear-panel configuration). The serial number is unique for each controller, and the replacement fuse specifications are labeled under the fuse holder or on the nameplate/label.*

2.3 Setting up the mk2000B

Place the mk20000B controller on a level, clean surface with ample ventilation. Because the mk2000B controller is equipped with a cooling fan on the rear panel, make sure the airflow is unobstructed by nearby walls or objects. The rear panel of a standard mk2000B is shown in **Figure 3**. All connections to the mk2000B use different types of ports to eliminate the possibility of an incorrect connection. A minimum configuration uses only the Sensor/Heater port for connecting the *INSTEC* Stage/Plate/Chuck, and the AC Input input port for connecting the AC power cable. Additional connections for communications and cooling accessories are available upon request.

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Installation Safety: Do not connect the power cable and turn on the mK2000B until all other connections being used have been made.

- **Sensor/Heater** (DB15_M/F for most stages, 8-pin aviation connector for large chucks/plates, or a custom connector)

  The stage/plate/chuck is connected to the Sensor/Heater port using the connector at the end of the gray service cable from the Stage/Plate/Chuck. Secure the connector using the integrated screws/ nut to ensure a reliable connection.

High-Power Controllers: Some mK2000B controllers used for high-power applications (ie. 1000W or above), may use a DB-20 or Bayonet connector for a dedicated power supply cable. When present, the stage/plate/chuck heating element is connected to the DB-20/ Bayonet connector, while the Sensor connections remain in the DB-15 connector.

- **USB (USB Type B)**

  The USB port is connected to the Type-A port on the end user's PC using the USB cable provided with the mk2000B.

- **Ethernet**

  The "Ethernet" port is used to connect the mK2000B to a local network via one RJ-45 cable. Once connected, the mK2000B can be configured to use a static IP, or dynamically assigned IP, and can then be connected to and controlled by any PC on the network using the InstecApp software.

- **Cooling I/O:**

  The Cooling/IO port is used to connect a variety of *INSTEC* cooling accessories to the mK2000B (ie. liquid nitrogen pump or water flow controller). This port accepts standard Male PS-2 cables.

- **AC Input**

  The AC power cable is connected to the receptacle located in the lower left corner of the rear panel. Once connected to AC power, the device is energized using the push-button switch located on the front panel (marked with the power symbol described in **Figure 2.**)

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Chapter 3. Setup and Operations

3.1 Power-On and Home Page

After the mk2000B is powered on, the *INSTEC* logo is displayed on the LCD panel (**Figure 4**).

***Figure 4**. Power-On screen*

Once booted, the system will automatically enter Idle mode, and the home screen will be displayed (**Figure 5**). The current temperature as detected by the instrument is denoted **PV** (Process Variable).

Press the  button from the LCD to return to the Home Page at any time.

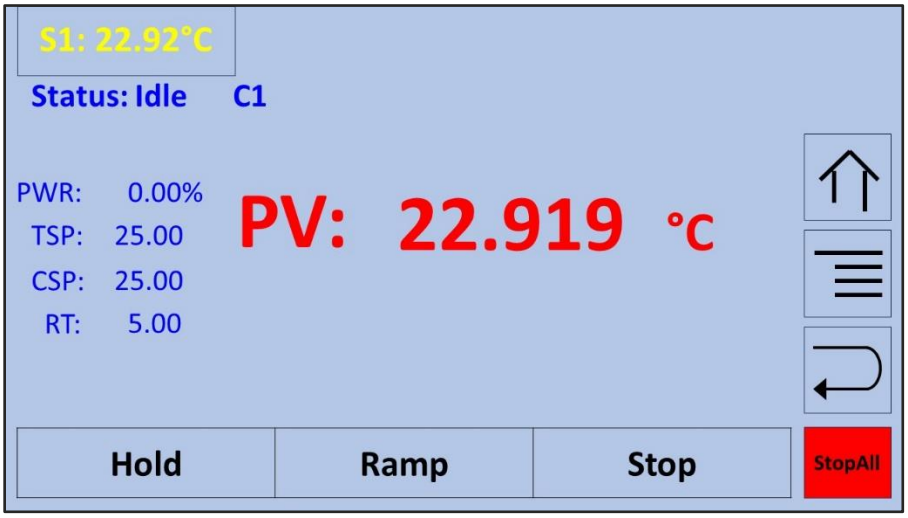

***Figure 5**. Initial Idle Mode from the Home Page.*

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Display terminology :

Temperature units: By default, all temperatures displayed by the mK2000B temperature controller are expressed in units of degrees Celsius (°C). The display unit can be set to °F or °K through the "Setup → Unit" Menu. Contact **support@instec.com** for information about alternate display units for non-temperature control applications.

- **PV**: Process Variable, e.g. current temperature of the Stage/Plate/Chuck (°C/°F/°K).
- **MV**: Monitor Value, e.g. monitor temperature (°C/°F/°K) used to measure monitor temperature (available as an option in select models only).
- **TSP**: Target Set Point, e.g. final target temperature (°C/°F/°K) set by the user for the Hold or Ramp command.
- **CSP**: Current Set Point, e.g. current target temperature (°C/°F/°K). While running a Hold command CSP will be equal to the final target temperature (TSP). During a Ramp command, the CSP is calculated using the TSP and the Ramp Rate (RT). When the controller is Paused, CSP stores the temperature of the Stage/Plate/Chuck when the Pause button was pressed.
- **RT**: Rate of PV change (°C/°F/°K per minute) when using the Ramp command (i.e. the ramp rate of heating or cooling).
- **PWR**: Percent Power (%) is the percentage of total output power being applied to the Stage/Plate/Chuck. PP is positive when the stage is heating and negative when the stage is cooling.
- **Hold**: Hold is a method of rapidly controlling the temperature. Once a Hold command is issued, the controller will attempt to reach and maintain the target temperature (TSP) as fast as possible. The rate of temperature increase is limited internally to prevent excessive overshoot and maintain thermal uniformity. The performance of this function is highly dependent on the PID parameters used by the controller.
- **Ramp**: The ramp function is used to change the PV temperature at a constant rate set by the user. The system will perform temperature control, bringing the temperature of the hot stage, at a rate determined by the user, to the final target temperature and then main that final target temperature.
- **RunPP**: Run Power Percentage (RunPP) is a method for applying constant heating or cooling power to the sample. The range of values that may be entered into RunPP is -100% to 100%. By default, the RunPP button is not displayed on the home screen. The user can choose to display the RunPP button by modifying the settings inside the Setup->"User Interface" menu. This function may be useful for Open-loop control applications, or for determining PID parameters.

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3.2 Basic Operation

The Controller has 4 primary operational modes: **Idle**, **Hold**, **Ramp, and RunPP**. The system will automatically enter **Idle** mode after the mk2000B is powered on, and the current operating mode is always displayed in the top left of the LCD panel.

After pressing the **Hold** button, the Target Set Point (TSP) can be set using the on-screen digit keys and the decimal point key. Incorrect inputs can be deleted with the ← key. Press **Cancel** to exit this setup screen and return to the Home screen. Click **Clear** to completely erase the TSP field. Click **Enter** to start running a **Hold** command to the set temperature.

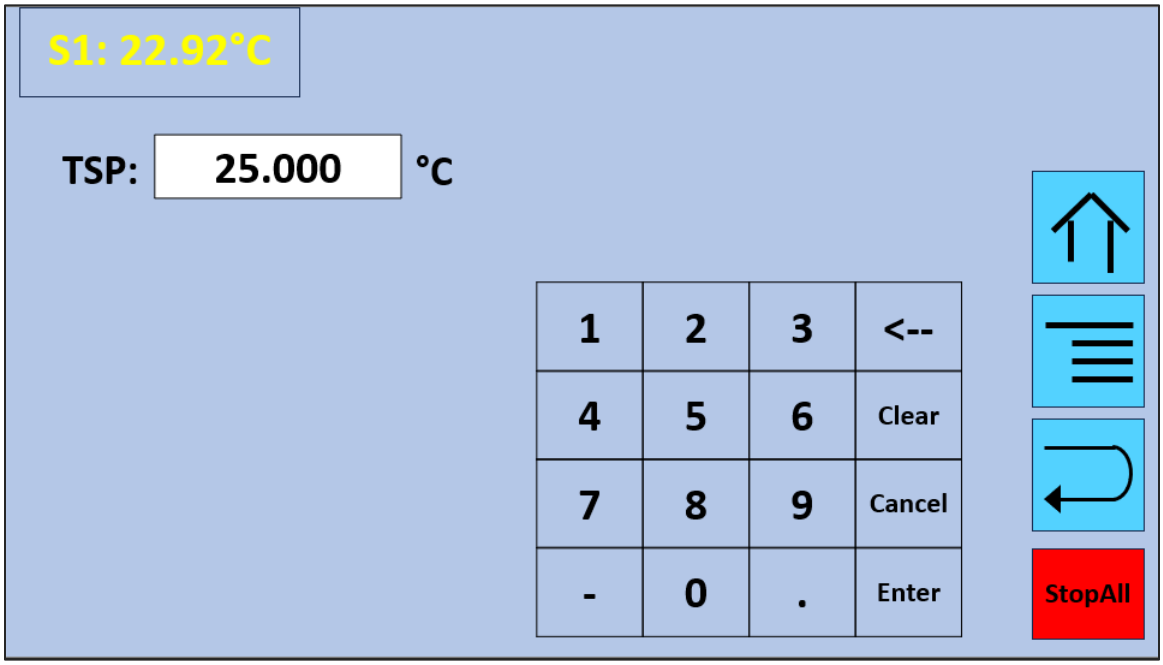

Figure 6. *Hold parameters input page*

Press the **Ramp** key from the Home Page and a popup window appears to input parameters. In addition to TSP, the user will also be prompted to enter the desired **Ramp** rate (RT). A similar screen is displayed when RunPP is utilized but instead asks the user to enter the desired output power. The default RT value is 5 (°C/°F/°K) per minute.

RunPP is useful for applications require non-closed loop control, or for troubleshooting. RunPP will output a constant PP% to the heating element or any connected accessories. By Default, the RunPP button is disabled, and can be re-enabled from the "Setup → UI" Menu.

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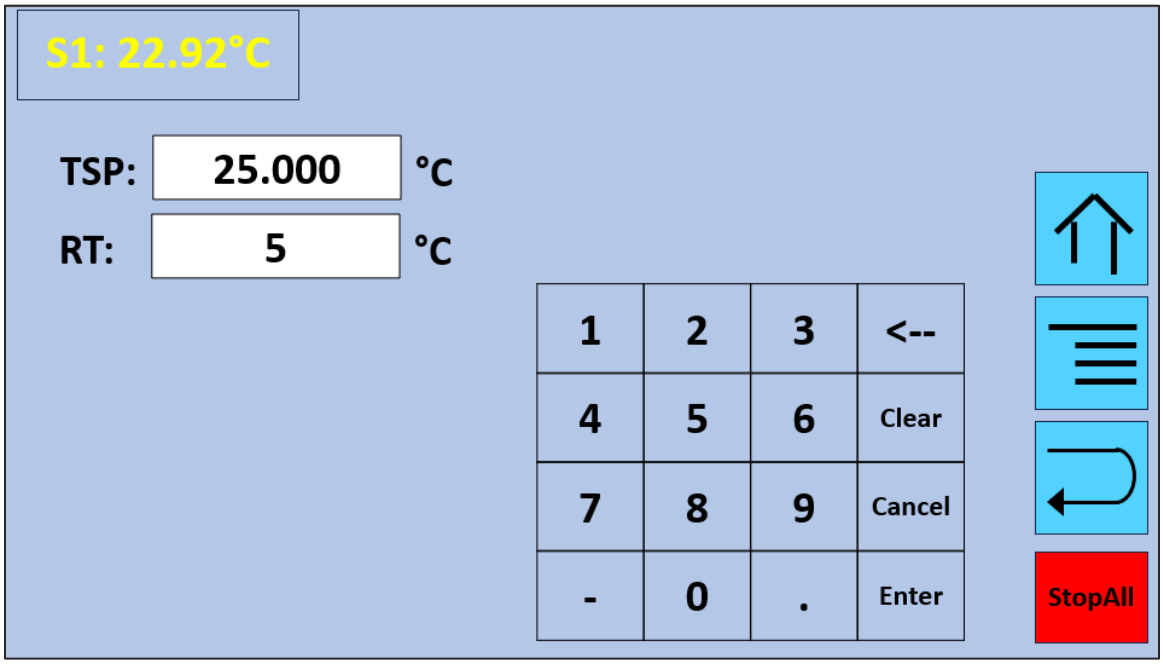

Figure 7. *Ramp parameters input page.*

3.3 The Menu Page

The Menu page can be used to change system settings, view system information, build custom temperature profiles, and reset the controller to the factory default settings.

To access the Menu page, press the  button at any time.

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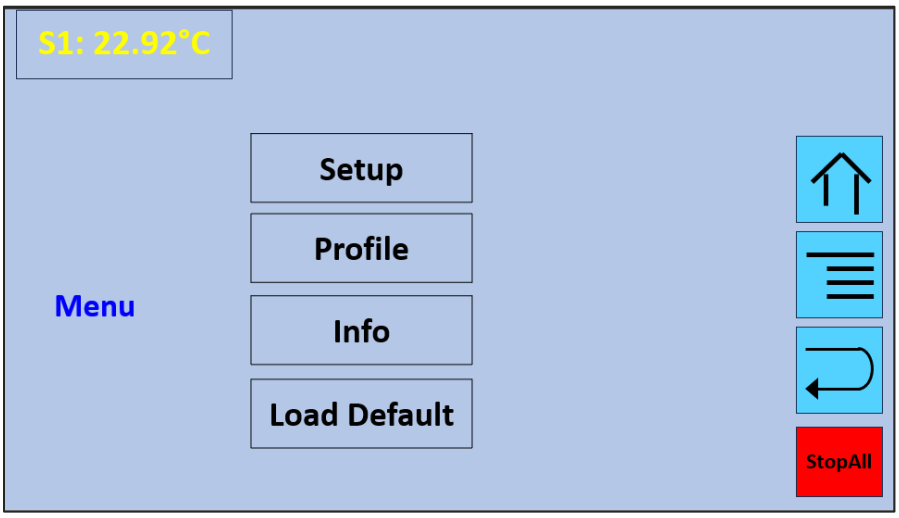

Figure 8. *The Menu Page.*

3.3.1 Setup Menu

The system will enter into the Setup Menu as shown in **Figure 9.** when the Setup key is pressed.

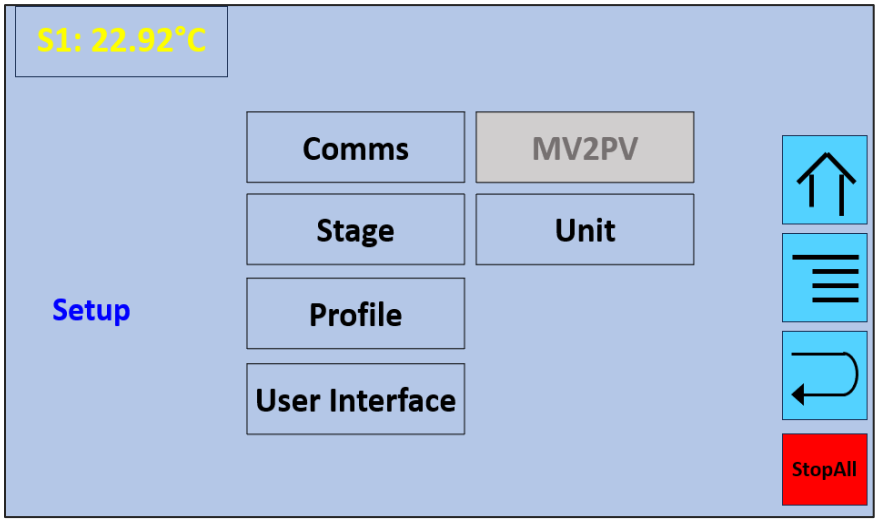

Figure 9. *The Setup Menu*

On the Setup screen, there are Six menu items: **Comms, Stage, Profile, User Interface, MV2PV and Unit**. These settings are used to configure the controller operating parameters, behavior, communication mode and units.

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3.3.2 Setup Menu - Communication

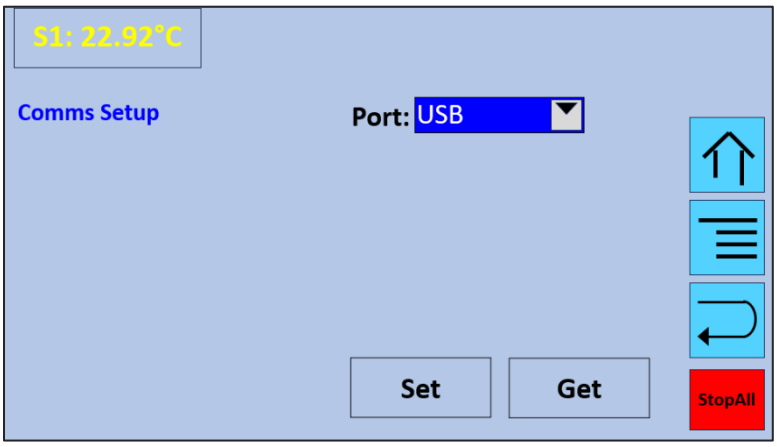

Figure 10. *The Communication Setup Page.*

For the mK2000B, there are two primary PC communication options: USB and Ethernet. Both Static IP and DHCP are supported for Ethernet communication. These settings are discussed in more detail within the InstecApp User's Manual / Quick start guide, as these settings are only relevant when connecting the controller to a PC for remote control. Click **Set** to confirm changes, and **Get** to retrieve the currently used settings.

3.3.3 Setup Menu - Control Mode

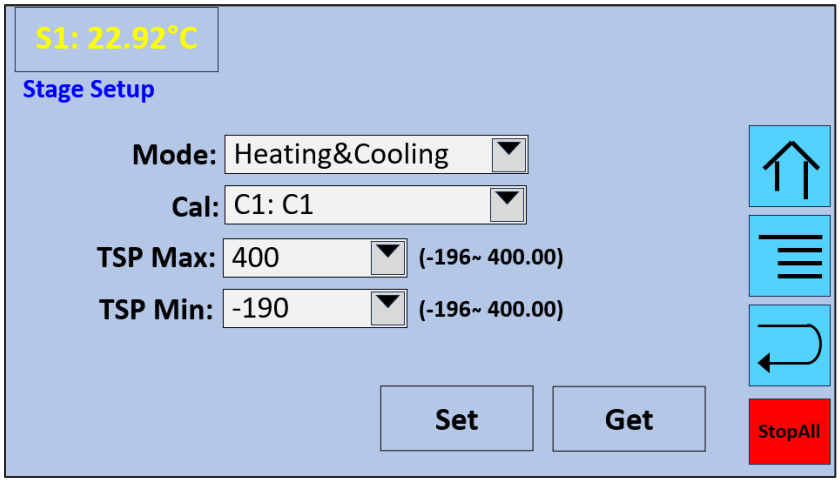

Figure 11. *The Control Mode Setup Page.*

The mK2000B supports 3 temperature control modes: HeatingAndCooling, Heating Only, and Cooling Only. The controller should be configured according to the system requirements, by *INSTEC*, before delivery. However, there may be times when the user might need to change the

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temperature control mode (i.e. The cooling system must be disabled). In the Heating Only and Cooling Only modes, the controller will use only heating or cooling outputs respectively. In HeatingAndCooling Mode, the controller is free to use both methods to control the target temperature as quickly as possible. To change the temperature control mode, select the desired temperature control mode from the dropdown box. Click **Set** to confirm changes, and **Get** to retrieve the currently used settings.

3.3.4 Setup Menu – Profile Setup

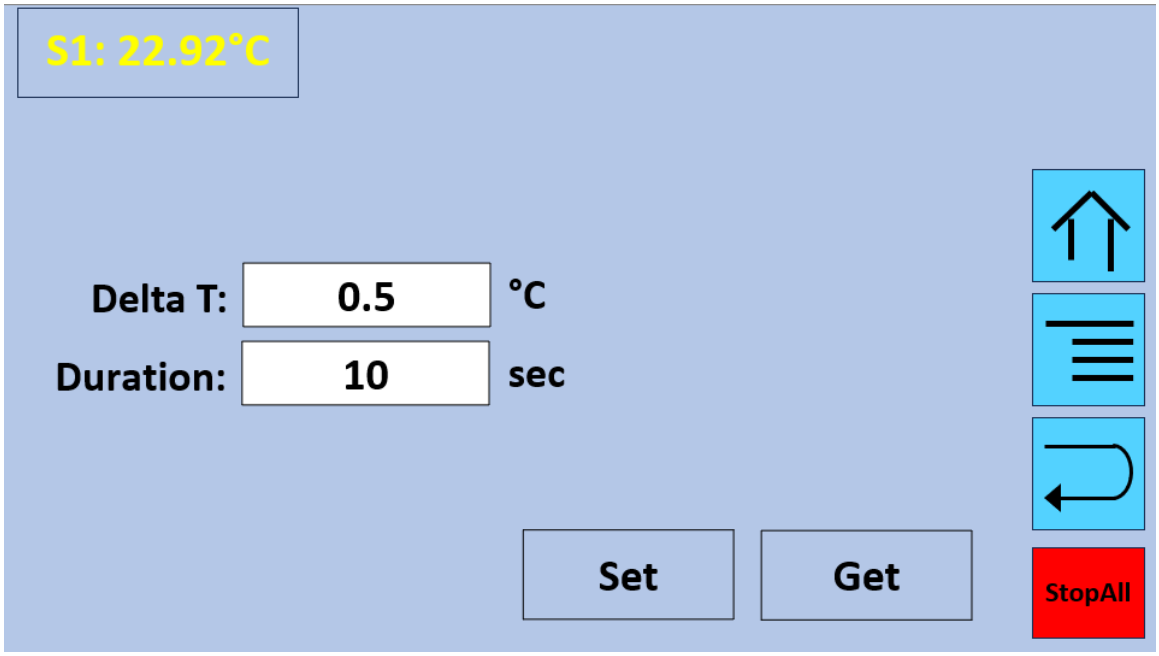

Figure 12. *The Profile setup page*

The Profile Setup screen is used to change the 'DeltaT' and 'Duration' parameters, which are used by the controller to determine when a profile command has been completed. For a command to be completed, the 'PV' temperature has to remain within 'DeltaT' (in degrees C) of the 'TSP' for the 'Duration'. An example of these parameters is **Figure 13**. In this example, the test profile consists of a "Hold" at 60C followed by a "Wait" for the 30s, and finally another "Hold" at 25C. We can see that once the temperature reaches 'TSP'-'DeltaT' (60C-.5C = 59.5 C), the controller starts a 10s timer. If this timer completes and the temperature is still within ± 'DeltaT', then the next profile command is executed.

By default, these parameters are set to DeltaT = .5C, and Duration = 10s.

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Improving Profile accuracy: Depending on the load, experimental parameters, and ambient conditions, the controller may require adjustment of the profile setup parameters to ensure proper execution of temperature profiles. In general, to improve profile accuracy, try decreasing the DeltaT parameter and increasing the Duration Parameter.

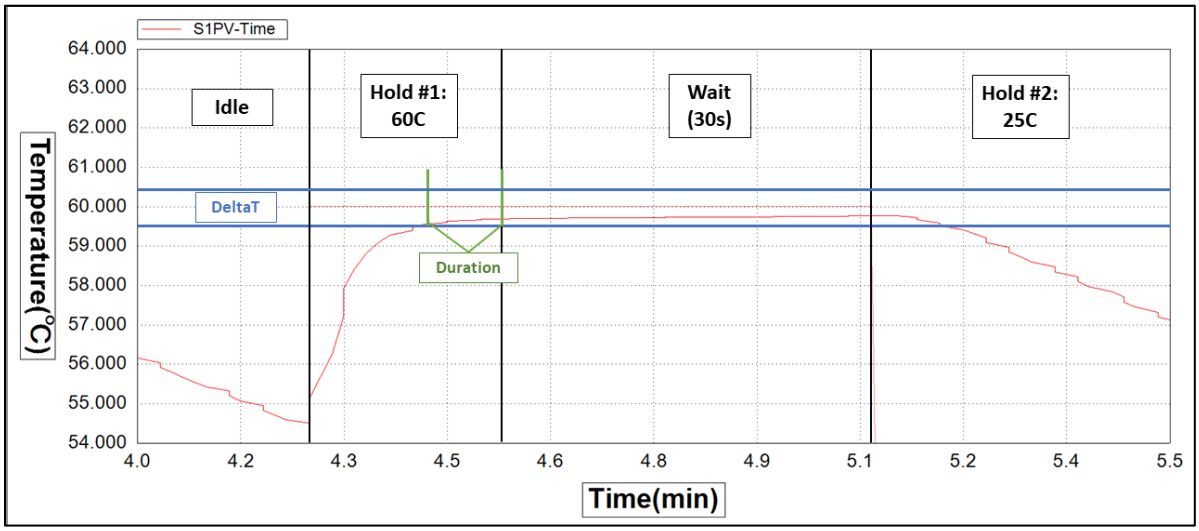

***Figure 13**: Visual Depiction of Profile Setup parameters.*

3.3.5 Setup Menu - User Interface (UI)

Tick the box to display the RunPP button on the Home Page. Click Set to confirm changes, and Get to retrieve the currently used settings. By default, the RunPP button is disabled, since this feature is not typically useful for general purpose temperature control. The “warning of no stage data” is intended to warn the user that the Instec stage/plate/chuck they have connected to the controller does not contain a digital ID chip, and will not be auto-configured for the mK2000B. By default, this warning is disabled.

3.3.6 Setup Menu – MV2PV

For very specific applications, the MV2PV feature can be utilized to allow an external temperature sensor to be used as the Process Variable, allowing for temperature control of arbitrary surfaces and bodies. This feature is disabled by default, and can only be enabled after consulting with **Support@instec.com**. MV2PV also requires that the mK2000B temperature controller be configured with at least 1 optional Monitoring Sensor.

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3.3.7 Setup Menu - Units

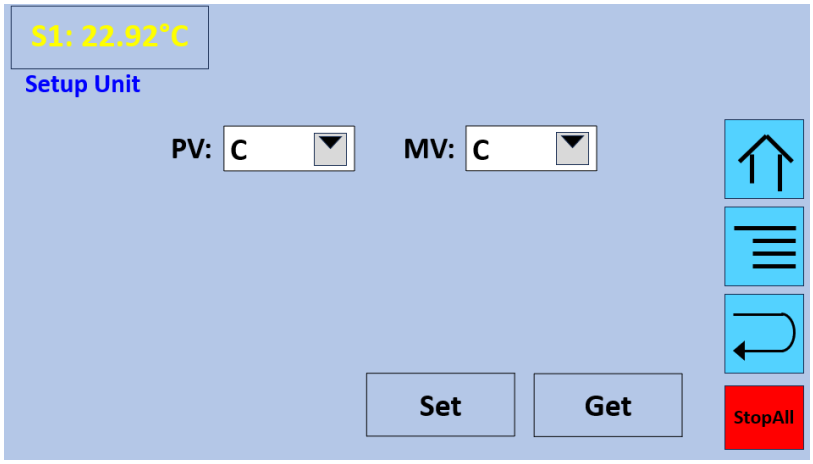

Figure 14. *User Interface Setup menu*

The Units menu can be used to change the unit used to display the PV and MV values. For temperature control applications, °C is the default, while °F and °K can be selected from the dropdown menu. Note that the dropdown menu contains units for general purpose ProcessControl applications – these units should not be selected unless they have been pre-configured by Instec.

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3.4 Profile Menu

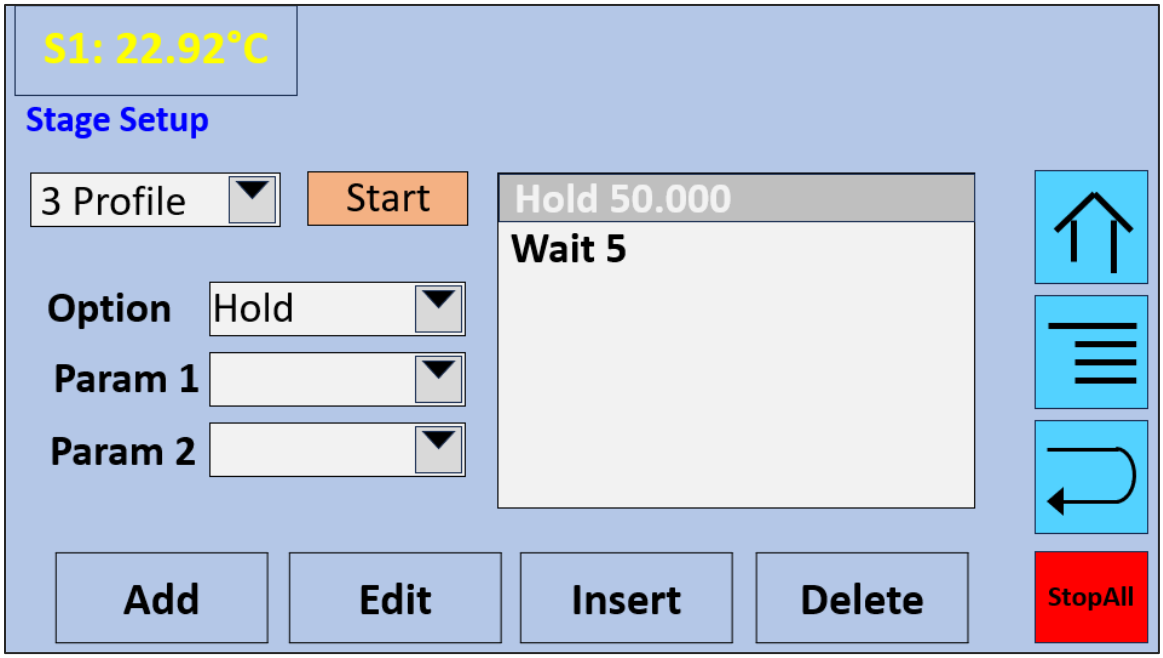

Figure 15. *The Profile Setup Page.*

The Profile menu allows the user to create and execute custom temperature control profiles. When the Profile button is pressed, the system will display the Profile Menu, as shown in **Figure 15**. There are 11 possible Profile commands which are described in **Table 3**.

Table 3: Command options for Profile Construction

Profile Command	Description	Parameters
Hold	Hold is a method of rapidly controlling the temperature. Once a Hold command is issued, the controller will attempt to reach and maintain the target temperature (TSP) as fast as possible. The performance of this function is highly dependent on the PID parameters used by the controller.	Param1: TSP in (°C/°F/°K)
Ramp	The ramp function is used to change the stage temperature at a rate set by the user. The system will perform temperature control, bringing the temperature of the PV, at a rate determined by the user, to the final target temperature and then maintaining that final target temperature.	Param1: TSP in (°C/°F/°K) Param2: Ramp Rate (RT) in ° / minute

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Wait	The Wait command is used to delay profile execution by a specified number of minutes.	Param1: Wait time in minutes
LoopBegin	LoopBegin is used to define the beginning of a Loop structure within a command profile. The user must enter the number of desired loop iterations as parameter1.	Param1: Number of loops (0-1000)
LoopEnd	LoopEnd is used to define the end of a loop structure within a command profile. This command must be used to terminate a loop structure, otherwise, the loop structure will be ignored.	Param1: NA
Purge	The purge command is used to activate the purging capability of compatible, connected *INSTEC* Equipment.	Param1: Purge delay time in seconds Param2: Purge Hold time in seconds
Stop	The Stop command will stop the currently executing command on a given Subsystem and return the Subsystem to Idle mode.	Param1: NA
Heat&Cool	The Heat&Cool command will set the temperature control mode to Heating&Cooling.	Param1: NA
HeatingOnly	The HeatingOnly command will set the temperature control mode to HeatingOnly.	Param1: NA
CoolingOnly	The CoolingOnly command will set the temperature control mode to CoolingOnly.	Param1: NA
RunPWR	The RunPWR command can be used to apply constant heating or cooling power to the sample.	Param1: Heating/Cooling power (-100% to 100%)

Select a profile number from the Profile dropdown box. Choose a command from the Option dropdown box and enter the parameters required in the textboxes ‘Param1’ and ‘Param2’. Click **Add** to input the command into the command queue.

Press the **Delete** button to erase a command, and press **Start** to run the profile.

To Insert a new command at any given point in the command queue, Select the command below the desired insertion point and press the **Insert** button.

To replace a command already inside the command queue with a new or modified command, select the command to be replaced. Next, choose a command from the option dropdown menu and input the desired parameters. Finally, press the **Edit** button to replace the selected command.

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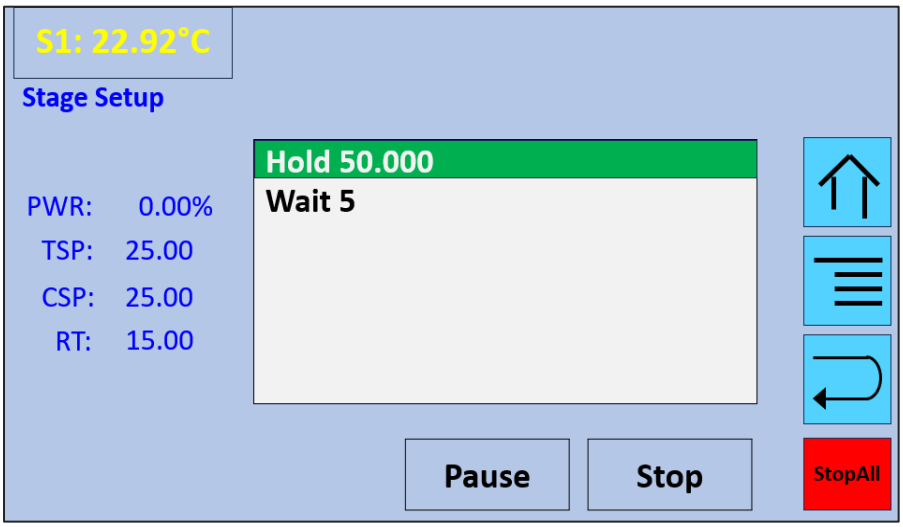

***Figure 16**. LCD panel depicting an executing command profile.*

After pressing the **Start** button as shown in **Figure 15**, the popup page shown in **Figure 16** displays. Select a subsystem to run the commands. Click **Pause** to pause the current state and suspend a Profile. Click **Stop** to stop running the commands.

Loop Commands: Each Loop command must subsequently include an "Endloop" command, otherwise the loop will be ignored.

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3.5 Information Page

When the Info button is pressed, the device information will be displayed. This information includes the Model number, serial number, firmware versions, and communication settings. Typically this screen will only need to be accessed when consulting with **Support@instec.com**.

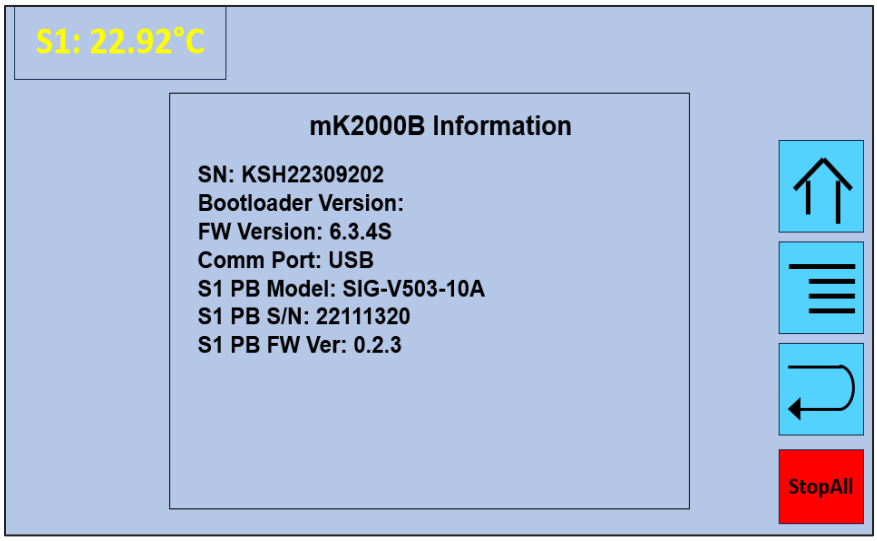

Figure 17. *The Information Page of the mK2000B.*

3.6 Load Default Settings Menu

This menu allows the user to restore the factory default settings stored internally on the mK2000B controller. This is a useful troubleshooting tool, and can often resolve issues with the controller, especially in cases where many system settings have been changed. The default parameters are always included on the USB flash drive shipped with the *INSTEC* system, or that are provided digitally; however, it is typically recommended to connect the controller to the InstecApp PC application and save the current system parameters before loading the factory default settings. Please contact **support@instec.com** for assistance before utilizing this feature.

3.7 Backup Button

Click the  button from the front panel to go back to the previous state or menu.

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Chapter 4. Advanced Features

4.1 PID Tuning

For advanced users, the temperature control response of the mK2000B can be customized to reduce overshoot, increase response time, or counteract external forces. This customization is done by altering the factory default PID tuning, but before doing that, it is important to establish a common understanding of what a PID algorithm is, and how it is implemented inside the mK2000B. Following the section on background information, a step-by-step example of PID tuning for the mK2000 will be presented.

PID Tuning: PID tuning can be a slow and challenging process. It is highly recommended by *INSTEC* to use the provided PID tuning unless absolutely necessary. Before creating a custom PID tuning be sure to save the factory PID parameters to a safe location so that they can be re-loaded at a later time if need be. If the mK2000B temperature control performance is not as expected, contact **support@instec.com** for assistance with troubleshooting. Poor thermal control is rarely due to the PID tuning, and instead an issue with thermal contact or sample preparation.

4.1.1 PID Algorithm Background information

The mK2000 Precision temperature controller regulates the sample temperature via a PID (Proportional, Integral, Derivative) algorithm. The theory of operation behind a standard PID controller is shown in **Figure 18**.

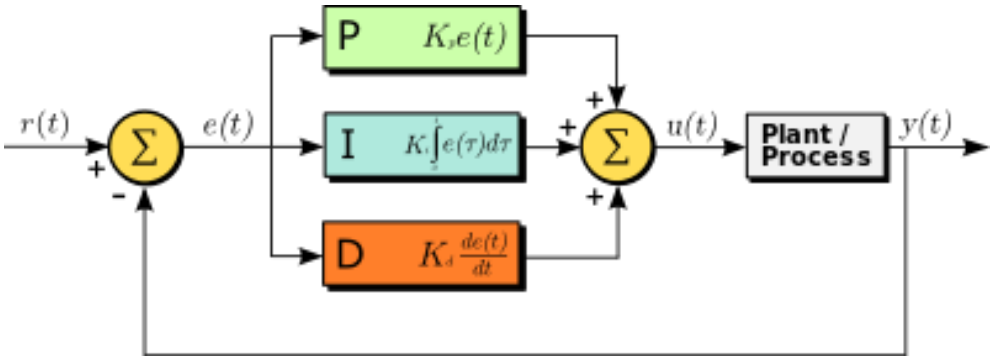

Figure 18. Generic PID algorithm block diagram where r(t) is the setpoint, e(t) is the error calculated by subtracting the setpoint from the measured value y(t), and u(t) is the calculated response based on the summation of the P, I and D terms.

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The PID algorithm control loop starts when the controller calculates an *error* signal e(t) by subtracting the desired temperature r(t) from the current measured temperature y(t). The controller then calculates a three-part response u(t) based on this *error* signal. Each of the three mathematical terms in the response calculation is tuned specifically to address specific response characteristics. For the mK2000B, the three terms P, I, and D used in our customized algorithm are defined as follows:

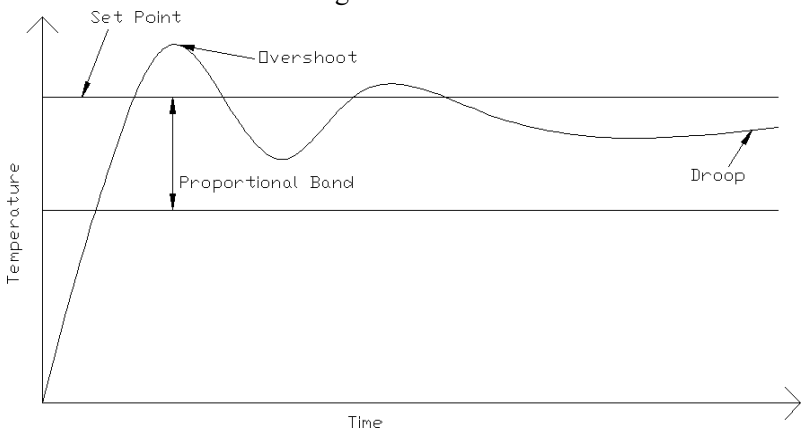

Figure 19. *Temperature response diagram*

P-Term (Proportional Band): The Proportional band is a fractional term that is divided against the *error* signal. The effect of the proportional band is to scale the output directly with the magnitude of the *error* signal. In simpler terms, the P-Term focuses on what the error is right now. The proportional band can also be conceptualized as the amount of change in the controller variable required to drive the loop output from 0 to 100%. What this means practically is that a smaller proportional band will lead to a faster temperature response with more overshoot, while a larger proportional band will lead to a slower response with less overshoot. The balance between response time and overshoot is the primary concern when tuning the P parameter. In General, an overshoot of 1 °C or less is acceptable and results in an acceptable response time. 5 is generally a good starting place for mK2000 P-term tuning.

I-Term (Integral time Constant): The Integral term, defined as a time constant in seconds for the mK2000B, is used to control steady-state error in the proportional response. The integral term looks at the sum of the error over time and impacts the process more as the error over time increases. As the time constant increases so too does the amount of time used for integration, and accordingly, the effect from the I term is diminished. If the Integral time constant is not used or is too large, then a steady state error will inevitably be present in the control response. To increase the effectiveness of the I term in the mK2000B PID algorithm, the I value should be incrementally decreased, with observations at each step determining whether the response has adequate steady-state accuracy with minimal added overshoot. 0.5 is generally a good starting place for mK2000 I-term tuning.

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D-Term (Derivative Gain): The Derivative term, defined as a gain (time constant * P-term) for the mK2000B, is used to act as a dampener on the PID response, resisting changes in the error signal. The faster the setpoint error changes, the larger the effect of the D term is to counteract that change. When used properly, this term can be used to greatly reduce overshoot and lead to a very nice PID response. However, when used improperly, this term can lead to the amplification of noise in the error signal and severe destabilization of the process control. The need for a D term in the mK2000 is reduced by the usage of temperature ramping limits, which prevent extremely rapid increases in temperature that the D term would typically counteract. As the D parameter increases, so too does the D-term response. 0.05 is generally a good starting place for mK2000B D-term tuning.

4.1.2 PID Tuning Procedure

To tune the mK2000B PID algorithm, the operating temperature range must be considered. A typical mK2000B has 8 zones, each with a unique set of PID parameters that are active for a certain temperature range, ie. Between 100 °C to 200 °C. These zones are used to account for differences in thermal characteristics over the operating temperature range. Furthermore, there are three sets of PID parameters for each zone that correspond to the operational mode; Heating Only, Cooling Only, and HeatingAndCooling. For the initial tuning, focus on the temperature range you are most interested in by choosing a value in the middle of that range, and then select the operational mode that most accurately represents the system. For example, if using a heating stage with an Instec LN2-P cooling system, choose HeatingAndCooling. If the Stage/Plate/Chuck does not have any active cooling accessories or capabilities, choose HeatingOnly.

When re-tuning the mK2000 PID algorithm, it is a good idea to start by eliminating the contribution from the I and D terms, instead of focusing on the P term. To do this, set I =99.9, and D = 0. Next, set the P value to a conservative starting value such as 30. Adjust the P parameter until a PID response similar to **Figure 20** is observed; small overshoot with fast response time. Inevitably, there will be a steady-state error observed by the response. If the P value is too large i.e. 100+, then an excessively slow response with a large steady-state error will be observed. If P is too small, there will be a large overshoot with subsequent oscillations around the setpoint. Both undesirable tuning scenarios are shown in **Figure 21**.

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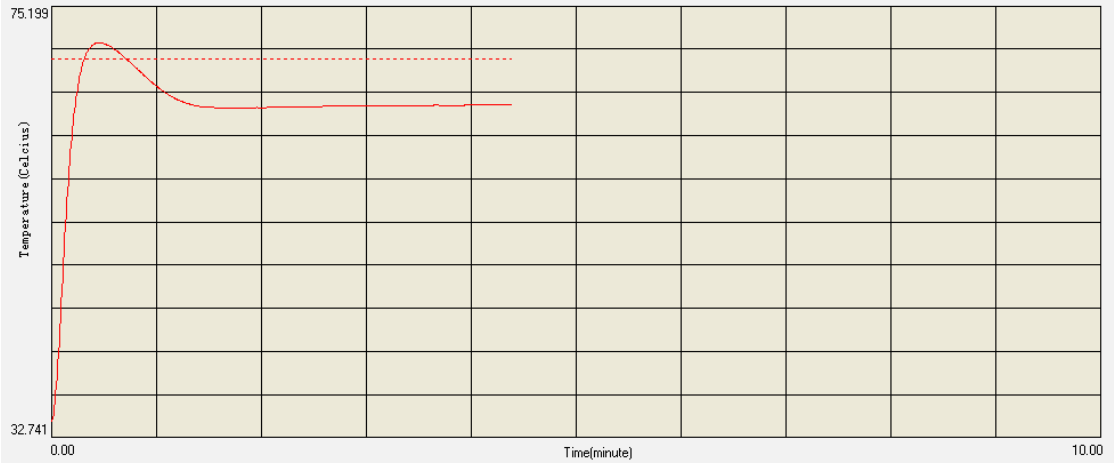

Figure 20: *Ideal P-only tuning response. P=30, I=99.9, D=0*

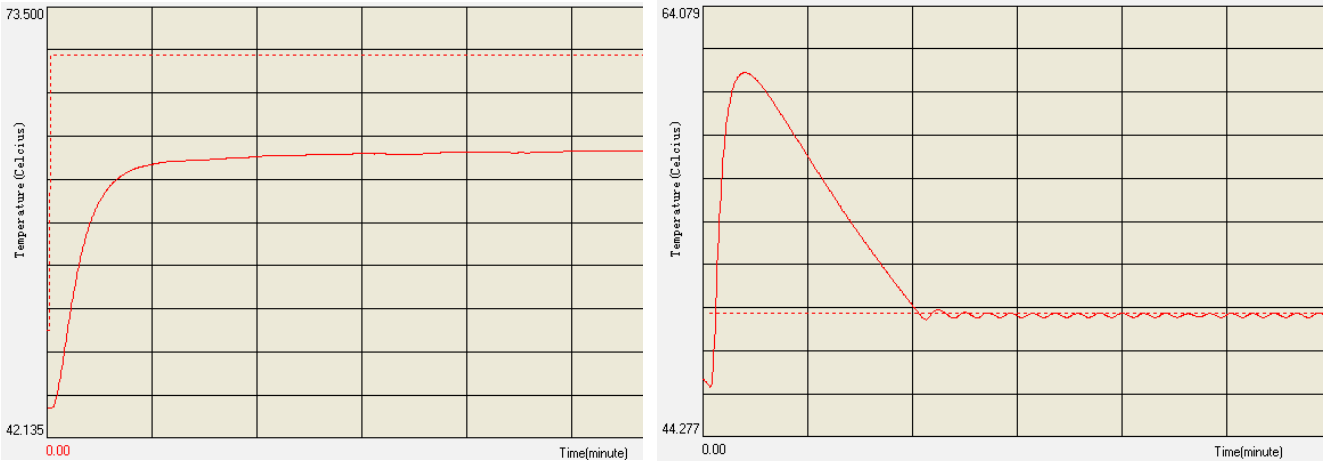

Figure 21: *Incorrect P-only tunings. Left side (P too high): P=100, I=99.9, D=0, Right side (P too small): P=1, I=99.9, D=0*

Next, we will adjust the I parameter to eliminate this steady-state error without adding excessive overshoot. Decrease the I term to about 1s and observe the result. Tune the I parameter until the response shows a fast response time with minimal steady-state error and minimal overshoot. **Figure 22** shows an example of good I-term tuning. If the I-term is too large, then the effect of the I-term is too small, and there will be some steady-state offset in the temperature. If the I-term is too small, then the effect of the I-term is too large, and there will be oscillations around the setpoint. Both undesirable tuning scenarios are shown in **Figure 23**. Once the I-term has been set, the controller is essentially tuned and ready for operation, however by setting the D-term we can further reduce the overshoot.

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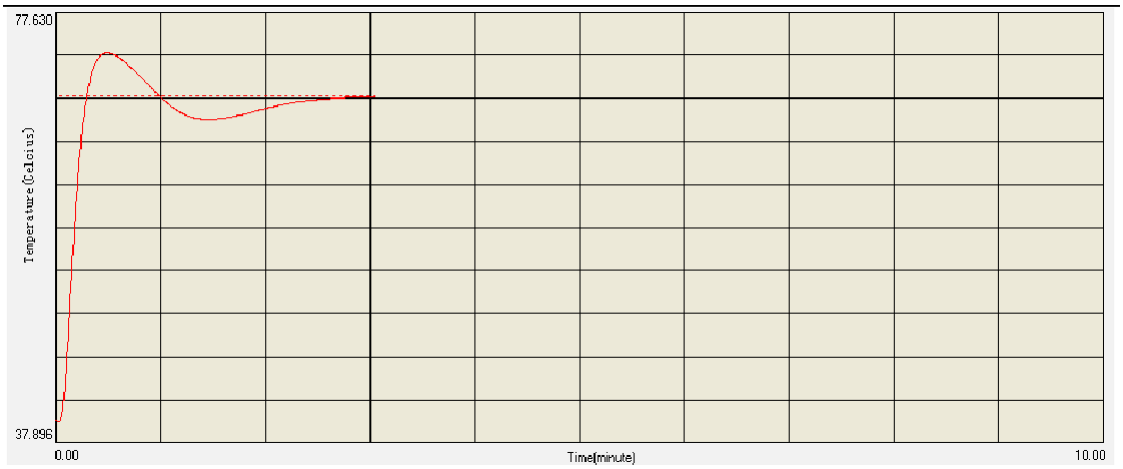

Figure 22: *Ideal I-term tuning, P=30, I=1, D=0*

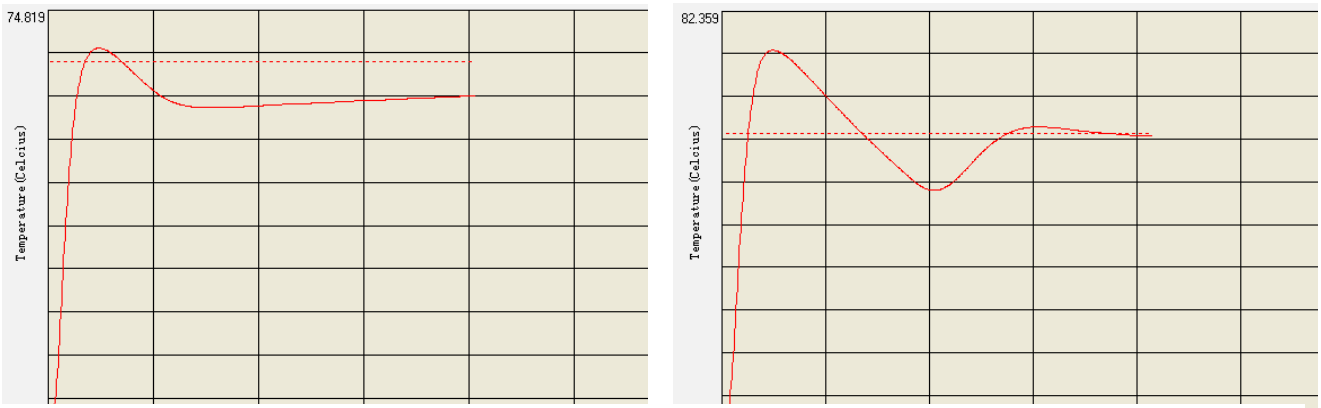

Figure 23*: Examples of incorrect I-term tuning. Left side: P=30, I=0.5, D=0, right side: P=30, I=10, D=0*

Finally, to tune the D-term, start by setting D to a small value such as 0.01. The objective is to minimize the overshoot without destabilizing the control algorithm. Once the D term has been approximately determined (typically between 0.01 and 0.05), it may be helpful to reduce the P and I terms slightly, increasing their contribution. With the D-term now active, the increased effect from P and I terms will be counteracted when close to the set point, resulting in a faster response without additional overshoot. An example of this ideal scenario is shown in **Figure 24.** If the D-term is too small, then the overshoot will remain significant. If the D-term is too large, then destabilization of the response may occur, resulting in slow oscillations or noise amplification. Both undesirable tuning scenarios are shown in **Figure 25**.

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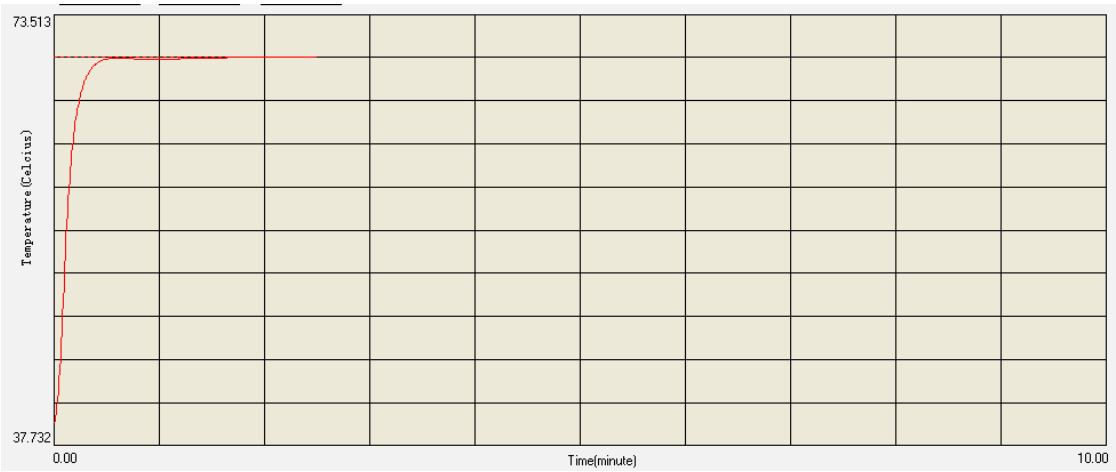

Figure 24: Ideal PID tuning. P=10, I=0.75, D=0.1

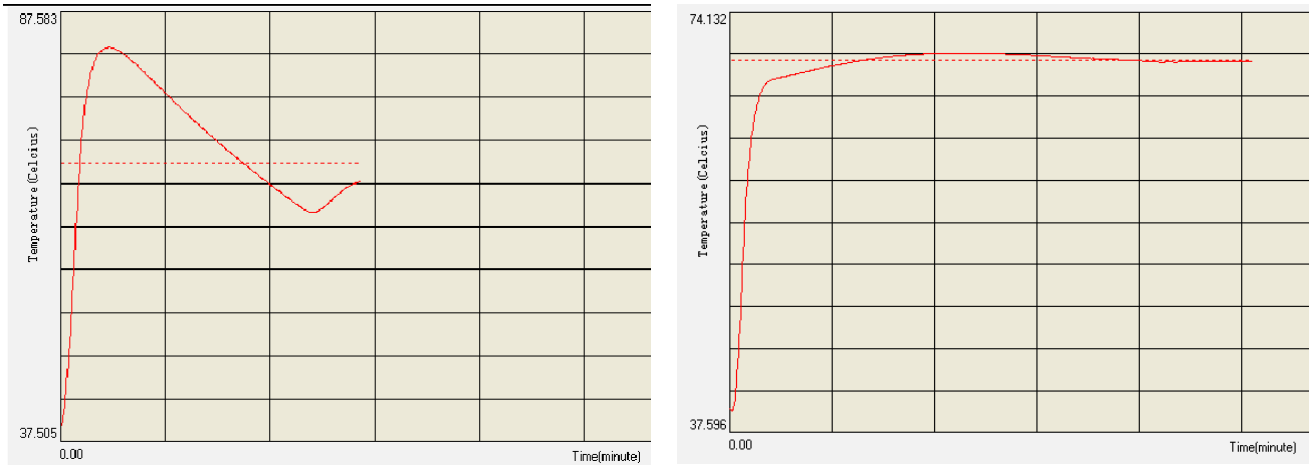

Figure 25: Incorrect D-term tuning. Left side (D too small): P=10, I=0.75, D=0.01, Right side (D too large): P=10, I=0.75, D=1

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4.1.3 PID Tuning Interface

To change mK2000B PID parameters, the InstecApp PID software The PID Parameter Table is used to View/Alter the PID parameters of the controller. There are three independent sets of PID values visible in the PID setting tool: "HeatingOnly", "CoolingOnly", and "HeatingAndCooling". These groups correspond with the Control Mode setting in the Process Control area. Different parameters are required for each Control Mode since higher thermal dynamics of the system are different depending on the temperature control method. For example, more aggressive PID values can be used with HeatingAndCooling since the controller can compensate for potential overshoots.

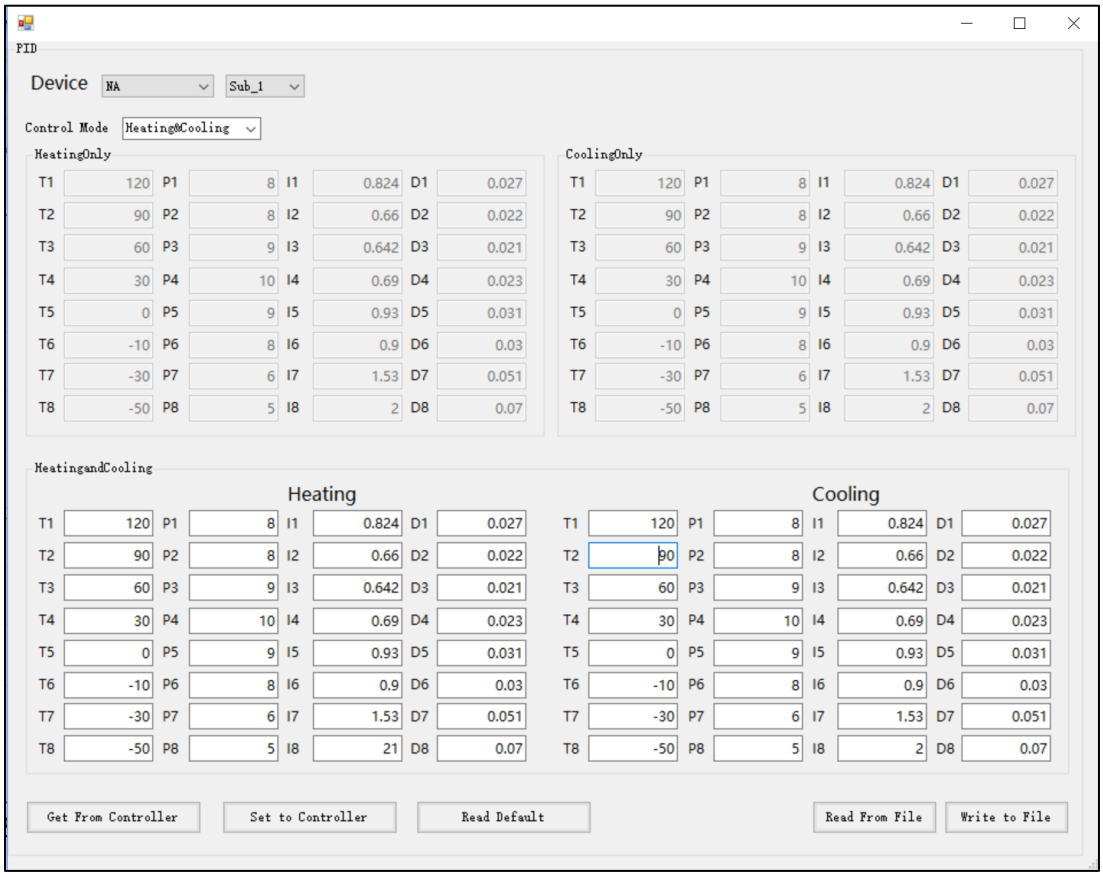

***Figure 26**: PID Parameter Window*

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Table 1: PID Parameter Window interactive element breakdown.

Command/ Parameter	Description
'Subsys'	Choose to activate a selected subsystem (for multi-subsystem controllers ONLY)
'Control Mode'	"Heating Only" (without Negative PP), "Cooling Only" (without Positive PP), and "Heating &. Cooling"
"Get from Controller"	Read currently used PID values from your controller
"Send to Controller"	Write the currently entered PID values to your controller
"Read Default"	Read factory default PID values from your controller
"Write to file"	Save the PID Table as a .csv file
"Read to file"	Load a previously saved PID table from a file

4.1.4 PID Troubleshooting tips

Although the parameters found experimentally via the procedure in section 4.1.2 are accurate, the time required to determine them is significant, especially when factoring in all 8 temperature zones and all three operational modes. To save time it is recommended to use the factory tuning, or a single experimentally found tuning within one zone, and then modify it as needed based on the troubleshooting guide below.

PID Troubleshooting steps

1. Signal reaches target temperature rapidly with a large overshoot.
    1) Increase proportional parameter, decreasing P-term effect.
    2) Increase differential parameter, increasing D-term effect.
2. Unable to reach target temperature consistently. Most of the time, the actual temperature is higher than the target temperature when cooling, or lower than the target temperature when heating.
    1) Decrease proportional parameter, increasing P-term effect.
    2) Decrease integral parameter, decreasing D-term effect.
3. Signal reaches the target temperature, but oscillates around the target temperature.
    1) Increase integral parameter, decreasing I-term effect.
    2) Increase differential parameter, increasing D-term effect.

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4.2 mK2000B Programming/ Custom PC Applications

In many cases where multiple pieces of equipment are being used for an experiment, it can be beneficial to use a single piece of software to control and interface with each device, including the mK2000B. The mK2000B communicates with external equipment via SCPI over a virtual COM port. These commands are text-based and are very easy to work with from a programming perspective, meaning that is very simple to add mK2000B support to applications built in Python, LabVIEW, MATLAB, or C#. To aid in custom software development, *INSTEC* offers a complete SCPI command reference guide alongside multiple SDKs. To access these resources, use the link below to download our programming resource guide.

Programming Resource Guide: **www.instec.com/programs/sample-codes/mK2000VCP+mK2000B-SDK-Resources-v220804.pdf**

4.3 Utilizing Multiple Calibration Tables

To address systemic errors in temperature control caused by temperature gradients, the mK2000B is capable of storing and switching between up to 4 different PV calibration tables. This PV calibration is independent of the temperature sensor calibration, which is done by the sensor manufacturer to ensure absolute accuracy. Instead, the controller calibration is intended to correct errors between thermal block temperature and sample temperature caused by thermal gradients and loss. Table C1 typically contains the factory calibration, and should be left un-modified if possible. External monitor sensors (MV) only support a single local calibration table.

To utilize the variable calibration feature, the mK2000B must be connected to the InstecApp desktop application and connected to the ProcessControl sub-application. Locate the “Setup” tab, and select “Calibrate” to launch the calibration window shown in **Figure 27**. Upon initialization, the software will retrieve the calibration values for the active calibration table. Calibration tables can be modified and selected remotely via SCPI commands as well. See section 4.2 for more details.

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4.3.1 Calibration Window Overview

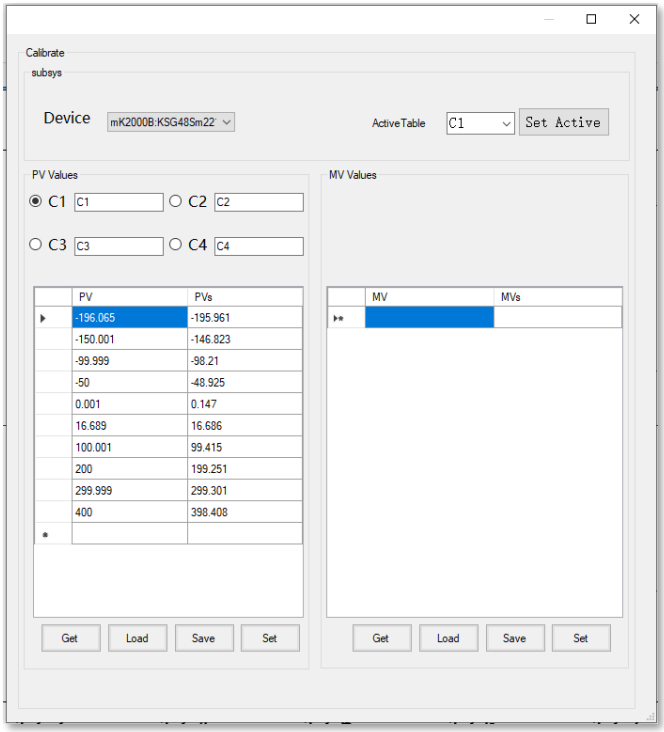

Figure 27: Calibration window inside InstecApp → ProcessControl

Table 4: Calibration window UI Element description

Command	Description
'Subsys'	The 'Subsys' parameter is used to switch between mK2000B subsystems for controllers equipped with multiple PID loops. For single-loop controllers, this field will remain blank.
"Set Active"	The "Set Active" button is used to set the active calibration table used by the mK2000B subsystem. To choose which table is active, use the 'ActiveTable' dropdown menu to select the desired table, then use the "Set Active" button to confirm the change.
C1-C4 Fields	Used to switch between the 4 calibration profiles within the calibration window. Selecting each item will automatically send a "Get" command to retrieve the most recent calibration values. Each field (i.e. C1-C4) can be renamed to reflect the usage.
'PV' and 'PVs'	Data pairs for primary sensor calibration
'MV' and 'MVs"	Data pairs for monitor sensor calibration
"Save"	Used to save all currently entered data pairs for the selected table.
"Load"	Used to load calibration table data from a saved file into the calibration window

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"Get"	Used to retrieve the calibration data pairs for the selected table
"Set"	Used to send the currently entered data pairs to the controller
Right-click in the calibration table area to access the following commands	
"ClearAll"	Clears all data pairs from the selected tale
"Insert"	Inserts a new table entry above the selected row
"Delete"	Deletes the currently selected data pair

4.3.2 Calibration Window Operation

Each calibration table consists of a list of sequential data pairs. Each data pair contains a target value (PV) which is the raw measured value of the primary temperature sensor and the "sample" value (PVs) which is the value measured by an external sensor. The data pairs stored inside the table are used to linear-fit the controller sensor value to more accurately reflect the sample temperature. It is recommended to divide the total temperature range into 50-100 °C intervals and to record PVs data for each setpoint. Be sure to allow for 0.5 to 1 hour for each data pair to allow for the temperature to equalize through the system. Once each data pair has been entered, use the "Set" button to write the new calibration table to the controller. **When setting a new calibration curve, a password will be requested. When prompted, enter '123456' into the dialogue window.**

To swap between calibration tables, use the "Set Active" button and "ActiveTable' dropdown menu in the top right-hand corner of the calibration window. It is recommended to save a copy of the calibration tables using the "Save" button before modifying calibration tables.

Calibration Password: When setting a new calibration curve, a password will be requested. When prompted, enter '123456' into the dialogue window.

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Chapter 5. Maintenance and Troubleshooting

While the mK2000B is designed to be highly reliable and easy to use, there are times when the controller may malfunction or behave unusually. This section will cover periodic maintenance for the mK2000B and common troubleshooting steps, including error codes and potential fixes.

5.1 mK2000B Maintenance

The mK2000B is designed to require as little periodic maintenance as possible, however, 2 major things should be considered periodically:

1. **Stage/Plate/Chuck recalibration.** Over time, your Stage/Plate/Chuck will change slightly from a thermodynamic perspective; the surface finish may become rougher, sensor contact may decrease, and parts may change shape due to thermal cycling. To ensure your instrument provides the most accurate temperature reading, it is recommended that the system be returned to *INSTEC* once every 2 years or so for re-calibration. It is required that both the Stage/Plate/Chuck and the mK2000B controller be returned together for re-calibration, as this leads to the most accurate and reliable calibration.
2. **mK2000B Firmware/ InstecApp Software Update.** *INSTEC* is constantly improving and expanding the firmware and software for the mK2000B. Unfortunately, updates of new SW/FW are not automated, meaning that new updates must be distributed manually. Software updates can easily be provided via email, but some mK2000B firmware updates must be performed manually by an *INSTEC* technician. It is recommended to check with *INSTEC* every 1-2 years for new software/ firmware updates. A great time to update mK2000B firmware is during the recommended 2-year recalibration.

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5.2 mK2000B Troubleshooting/ Service

During operation, the mK2000B will display error codes on the integrated LCD in response to unusual behavior. Descriptions of each error code and potential causes/ solutions are given in **Table 5**. For situations when an error code is NOT displayed, consult **Table 6**. For general troubleshooting advice. It is always recommended to contact **support@instec.com** for advice when issues arise. You can also contact *INSTEC* directly at 1+ 303-444-4608 and ask for customer support.

Table 5: Error Code descriptions

Error Code	Description	Potential Cause
"Error Code 1: PV temperature outside of Stage/Plate/Chuck range"	This EC triggers when the PV temperature exceeds the hard limit set by *INSTEC* for the Stage/Plate/Chuck	Sample cooling may not be working as intended. Ensure all cooling accessories are plugged in, enabled, and connected to the mK2000
		Verify that all connectors are fully inserted and mechanically secured
		The controller may have an internal hardware issue, Contact suppport@instec.com
"Error Code 2: PV temperature outside of controller range"	This EC triggers when the PV temperature exceeds the soft limit set by the user.	Sample cooling may not be working as intended. Ensure all cooling accessories are plugged in, enabled, and connected to the mK2000
		Verify that all connectors are fully inserted and mechanically secured
		The controller may have an internal hardware issue, Contact suppport@instec.com
"Error Code 3: MV temperature outside of range"	This EC triggers when a connected monitor sensor detects a temperature outside of its permitted range.	Verify that all connectors are fully inserted and mechanically secured. Verify that sensor is properly secured to whatever it is measuring
"Error Code 4: TSP exceeds permitted range"	This EC is triggered when the user attempts to enter a value for TSP that exceeds the soft/hard limit for the controller.	Verify that the controller range is consistent with the specifications agreed upon before delivery
"Error Code 5: Temperature difference exceeds permitted range"	This EC is triggered when the temperature difference between the PV and MV values exceeds the predetermined limit. This feature is typically disabled by default.	Verify that the MV sensor is correctly attached to the sample and that the connector is fully inserted.
"Error Code 8: Frame temperature limit	This EC is triggered when the temperature of the Stage/Plate/Chuck frame exceeds the predetermined limit.	Verify that all frame cooling accessories are connected and enabled.

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exceeds limit”		
“Error Code 9: Output current exceeded limit”	This EC is triggered when the controller output current exceeds the limit.	This is most likely an internal hardware failure, please contact support@instec.com
“Error Code 10: Lost Connection with Powerboard”	This EC is triggered communication between critical internal components is disrupted.	This is most likely an internal hardware failure, please try power-cycling the controller. If the issue persists, contact support@instec.com
“Error Code 11: Output voltage exceeds limit”	This EC is triggered when the controller output voltage exceeds the limit.	This is most likely an internal hardware failure, please contact support@instec.com
“Error Code 12: Connected Stage/Plate/Chuck does not match controller”	This EC is triggered when a stage that is not configured for the mK2000B temperature controller is connected. It can also indicate a hardware malfunction in the Stage/Plate/Chuck.	Verify that the Stage/Plate/Chuck matches the controller by confirming the input voltage/ current. It is common for users with multiple *INSTEC* systems to confuse controllers between multiple systems, but each controller is unique to a single Stage/Plate/Chuck

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Table 6: Basic troubleshooting advice for the mK2000B

Symptom	Possible Cause	Potential Solution
Controller does not power on (Power switch does not illuminate)	Unit is not powered	Verify power cable is fully inserted and AC outlet is active
	Input fuse is blown	Replace with the included backup fuse (See APPENDIX I)
	Internal components have failed	Contact support@instec.com for assistance
Controller Powers on, but Home screen never appears	Poor connection to Stage/Plate/Chuck	Verify grey service cable is fully inserted, gently manipulate cable to check for defective socket or wire insulation
	mK2000B firmware is improperly configured or became corrupted	Contact **support@instec.com** for assistance
	Internal components have failed	
mK2000B runs, but sample temperature does not change	Error code is present	Check error code against **Table 4**, address accordingly
	Stage/Plate/Chuck is not connected	Verify that the Stage/Plate/Chuck service cable is fully inserted and mechanically secured
	Stage/Plate/Chuck may be damaged	Follow troubleshooting steps within Stage/Plate/Chuck manual to verify sensor/ heater health
	Output Fuse may be blown *(Only for models equipped with output fuse)*	Check and replace output fuse if necessary (See APPENDIX I)
	Blockage in LN2 lines restricts flow	Abort experiment then follow Dewar cleaning and stage/plate/chuck bakeout instructions in section 3.1 of LN2-P manual
	LN2-Dewar has insufficient LN2	Refill Dewar using LN2 rated funnel if needed
	Temperature measurement is incorrect	Verify mK2000 controller is correctly configured, verify sample temperature visually or by touch (Safety first!)
	Internal components have failed	Contact support@instec.com for assistance

5.3 Safe Mode

If the mK2000B fails to boot and will not connect to a PC via USB or ethernet, the controller can be booted into SAFE mode, which will allow for additional troubleshooting steps to be taken. To enter safe mode, start by turning off the mK2000B. Next, turn on the controller, and wait until the "INSTEC" text appears on screen. When visible, place one finger on the touchscreen in the center of the "INSTEC" text, and wait until the controller boots into safe mode.

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Appendix I – User Replaceable fuses

Figure A1: *User replacable AC Input Fuse Holder (left), and AC Input Fuse Drawer (right)*

All mK2000B units come standard with a user-replaceable fuse located on the AC input port, visible in **Figure A1**. The replacement fuse specification is always printed below the fuse holder in white text and is different depending on the input voltage. To access this fuse, first, disconnect the controller from AC Power. Next, it is recommended to use a small flathead screwdriver to pry open the fuse drawer. It may take some force to remove the fuse drawer. Once removed, inspect the fuse to visually verify that the fuse is intact, and use the continuity setting on a digital multimeter to verify continuity.

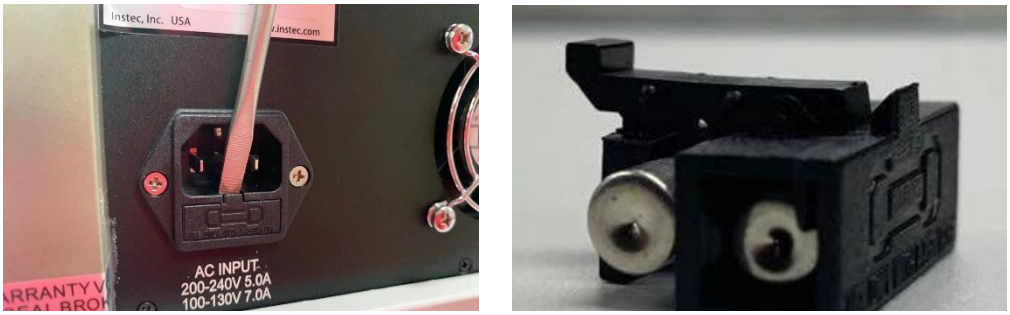

Figure A2: *User replacable Controller output fuse holder (left), and output fuse holder (right)*

Some mK2000B controllers that are used for large plates and chucks, or high-temperature stages/plate/chucks come equipped with an output fuse to protect the stages/plates/chucks from short circuit damage, as shown in F**igure A2**. On occasion, this fuse can be blown and should be replaced in the field. A spare fuse is NOT included with the controller by default. Be sure to carefully inspect the fuse to determine the minimum rating specification, and never replace the fuse with another that does not meet those minimum specifications.