User Maintenance Manual

DUAL HEAT PIPE THERMOCOUPLE HOMOGENEITY SCANNER MODEL 881

Guarantee

This instrument has been manufactured to exacting standards and is guaranteed for twelve months against electrical break-down or mechanical failure caused through defective material or workmanship, provided the failure is not the result of misuse.

In the event of failure covered by this guarantee, the instrument must be returned, carriage paid, to the supplier for examination and will be replaced or repaired at our option.

FRAGILE CERAMIC AND/OR GLASS PARTS ARE NOT COVERED BY THIS GUARANTEE INTERFERENCE WITH OR FAILURE TO PROPERLY MAINTAIN THIS INSTRUMENT MAY INVALIDATE THIS GUARANTEE

The company is always willing to give technical advice and assistance where appropriate. Equally, because of the programme of continual development and improvement we reserve the right to amend or alter characteristics and design without prior notice. This publication is for information only.

Contents

1 Unpacking And Initial Inspection

Our Packing Department uses custom designed packaging to send out your unit, but as accidents can still happen in transit, you are advised after unpacking the unit, to inspect it for any sign of shipping damage and confirm that your delivery is in accordance with the packing check list. If you find any damage or that part of the delivery is missing notify us or our agent and the carrier immediately. If the unit is damaged you should keep the packing for possible insurance assessment.

2 Before You Use The Equipment

Please read the maintenance manual and familiarise yourself with all warnings, hazards and safety information. Regularly inspect the equipment, accessories and electrical leads. Do not use if there is any sign of damage. Keep the equipment clean, only use a damp cloth. Do not use solvents or allows liquids to enter the case.

3 Electricity Supply

Before connecting to the electricity supply please familiarise yourself with the parts of the manual relevant to your model.

Your unit's supply voltage requirement is specified on a label on the instrument along with the serial number. Only connect to a power supply matching the requirement stated on the equipment.

4 ⚠ The Unit Must Be Earthed

This equipment is a Class 1 Appliance and must be earthed (grounded). Use the supplied power cord and plug it directly into an AC outlet with a protective earth.

If using an alternative cord ensure it is of adequate rating.

If fitting a plug to the cable we have supplied the cable is colour coded as follows:

Colour	Function
Green/yellow	Earth (Ground)
Brown	Live (line)
Blue	Neutral

Do not use the equipment if it is not correctly earthed. If in doubt consult Isothermal Technology Ltd or a qualified electrician.

5 Regulatory Information

This product complies with the Essential Protection Requirements of the following Directives:
Electromagnetic Compatibility (EMC): EMC Directive 2014/30/EU
To Harmonised Standard: EN 61326-1:2013
Low Voltage Directive (LVD): LVD Directive 2014/35/EU
To Harmonised Standard: BS EN 61010-1:2010

To ensure compliance please ensure that connecting leads are fully screened.

This product conforms with Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 as amended by (EU) 2015/863 on the restriction of the use of certain hazardous substances in electrical and electronic equipment as listed in Article 4.

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6 ⚠ Cautionary Note

Operators of this equipment should be adequately trained in the handling of hot and cold items. It is important the user has been trained about the selection and use of liquids over a wide temperature range. It is expected that personnel using this equipment will be competent with the management of apparatus which may be powered or under extremes of temperature and are able to appreciate the hazards which may be associated with and the precautions to be taken with, such equipment.

7 ⚠ Safety Warnings

7.1 Environmental Conditions
- Operating temperature: 5-40°C (41-122°F)
- Relative Humidity: 5-80% - non-condensing

7.2 Do Not Modify or Disassemble
- Do not use the apparatus for jobs other than those for which it was designed, i.e., the calibration of thermometers
- There are no user serviceable parts inside. Do not dismantle or modify the apparatus. For repair information contact Isothermal Technology Ltd
- For equipment with fans, the fan should be kept free from dust build up; a soft brush or vacuum cleaner may be used on the external grill

7.3 Beware Of Electrical Considerations
- The equipment is for installation category II (transient voltages) and pollution degree II in accordance with IEC 664 at altitudes to 2000 metres
- Sensor Input Connection must never exceed 30V with reference to ground
- Thermostat test inputs should be voltage free: isolate from any voltage source during test

7.4 Be Careful Where It Is Used
- The equipment is not for use in hazardous areas or in an environment close to flammable materials or gases
- The equipment must be used on a flat level surface, with adequate space around it for air flow and avoid blocking ventilation slots
- Ensure free space above the unit to avoid risk of burn or fire
- The equipment should only be used indoors
- Site in a way that allows access to the power switch, and to allow the cable to be disconnected
- Avoid excessive heat, humidity, dust and vibration ensuring it will not be subjected to dripping or splashing liquids

7.5 Be Careful with Extremes of Temperature
- In normal use the calibration volume, inserts and probes will become very hot and present a burn hazard
- Do not remove inserts, probes or handle the equipment when it is hot or cold.
- Allow the equipment and accessories to reach a temperature between ambient and 70°C before switching off or storing the equipment in its case
- Do not use the equipment outside its recommended temperature range
- Operating the equipment at extremes of temperature for extended periods may call for early replacement of the heating assembly
- Wear appropriate protective clothing

8 Consider The Environment

The equipment should be recycled or disposed of in a proper way; following the Waste Electrical and Electronic Equipment (WEEE) directive

9 Introduction

9.1 Thermocouple Basics

The operation of a thermocouple relies on the Seebeck effect, which causes an emf to be generated in any region of a thermoelement exposed to a temperature gradient. Two dissimilar thermoelements can be used in a circuit and the difference in emf between the elements used to infer a temperature. In contrast to any other temperature sensor, any part of the thermocouple can be made to serve as the sensing element. Therefore, any variations in the properties of either thermoelement can lead to an error in the indicated temperature.

Undesirably, nearly all thermocouples develop non-uniformities (inhomogeneities) in their thermoelements during normal use. As such, the performance of a thermocouple is often related to its exposure to various temperatures, where on the thermocouple those exposures have occurred, and for how long. If one is to assess the accuracy of a thermocouple, then the inhomogeneity of the thermocouple is a major concern. There are many reported methods to measure inhomogeneity; these and the theory underlying homogeneity scanning are now well developed [1]. The *MSL Scanner* is currently the most accurate reported in the literature. Scanners of this type are an essential tool in estimating the effects inhomogeneities have on thermocouple temperature measurements.

There are four main mechanisms responsible for inhomogeneity: cold-work, atomic structure reordering (alloys only), oxidation and chemical diffusion. Both cold-working and reordering are reversible effects. In base-metal thermocouples (Types T, K, J, E, N) most cold-working can be annealed out at temperatures between 200 °C and 500 °C [2-4]. However, removal of cold-work in rare-metal thermocouples (Types B, R and S) can require temperatures as high as 1500 °C [5-7]. Reordering in alloys occurs when the thermocouple is exposed to temperatures sufficient to allow the lattice structure to adopt new lower-energy states. In most thermocouple alloys this reordering process occurs between 200 °C and 600 °C. Above 600 °C there is sufficient energy to cause disordering of the lattice structure. The last group of effects, oxidation and chemical diffusion, lead to permanent irreversible changes in the base-metal thermoelements and generally occur at temperatures greater than 600 °C. In rare-metal thermocouples irreversible damage is usually caused by either poisoning or contamination. Poisoning can occur when foreign material enters the protective sheath in vapour form at high temperatures, usually through fine cracks or breakages of the protective alumina sheath. Contamination of the pure platinum thermoelement is problematic for Types R and S at temperatures over 1100 °C and is caused by either rhodium vapour transfer [8-11] or leeching of trace amounts of iron from the alumina.

9.2 Scanner Basics

A homogeneity scanner is a device used to interrogate the Seebeck coefficient of thermocouples. The most accurate scanners use a single narrow temperature gradient. By moving this gradient along the length of the thermocouple, only the region exposed to the temperature gradient will generate an emf, as is shown in Fig 1. Any deviations in this emf from the reference function or some average value will indicate the presence of an inhomogeneity. Clearly, the width of the temperature gradient will determine the scanner's resolving potential and its ability to detect inhomogeneities. Therefore, the scanner must expose the thermocouple to a temperature gradient narrower than the gradient in any likely application.

Illustration of scanner theory
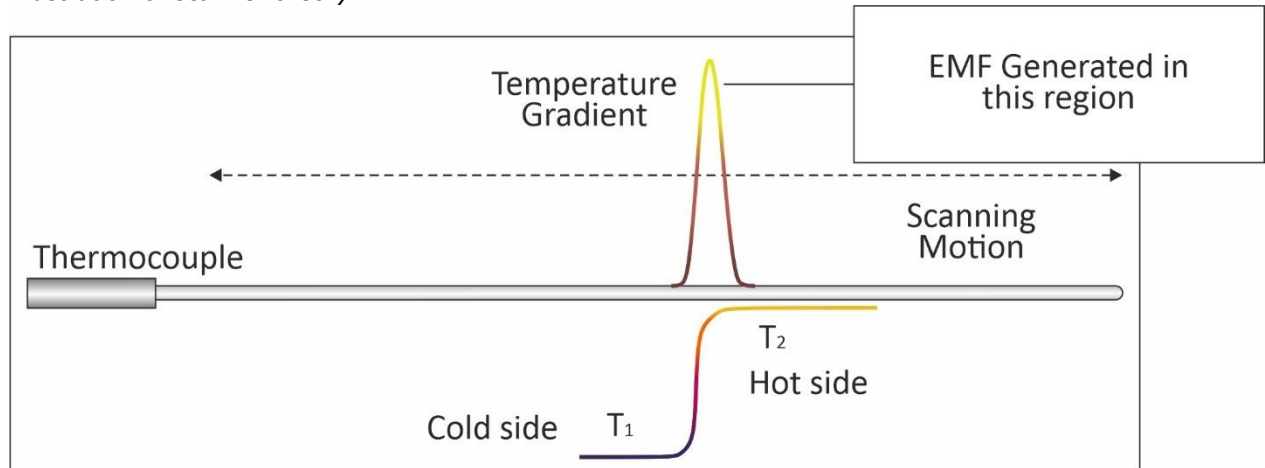
9.3 The Homogeneity Scanner

The homogeneity scanner uses several methods to carefully control the temperature gradient region during scanning, keeping it both thermally symmetric and narrow. The scanner is composed of two closely spaced heat pipes operating at different temperatures, T_1 and T_2, as shown in Fig. 2. The bottom, high-temperature heat pipe, uses steam whereas the top, low-temperature heat pipe, uses acetone. The thermocouples are exposed directly to the steam of the lower heat pipe and the steam is prevented from escaping and heating the upper heat pipe with the use of a thin silicone rubber membrane (the septum). The use of a septum also makes possible a very small gap between the two heat pipes, ensuring the scanner has the highest practicable spatial resolution by maintaining a small temperature gradient region (dT/dx). During scanning the thermocouple is moved continuously from the low-temperature heat pipe to the high-temperature heat pipe. The speed of the scanning operation is chosen to match the speed of thermal conduction occurring within the thermocouple. A benefit of using steam is that it is non-contaminating. Therefore, the thermocouple can be in direct contact with the heating medium. This direct contact between thermocouple and steam allows all the energy released during the state change of vapour-to-liquid to be imparted to the thermocouple. The result of this means the thermocouple temperature can be rapidly raised to that of the steam temperature. Consequently, thermocouples can be scanned at far higher speeds than traditional oil-bath based scanners. Oil-bath scanners will often employ a re-entrant tube, used to prevent contamination, but which inherently limits heat transfer.

Functional diagram of scanner hardware
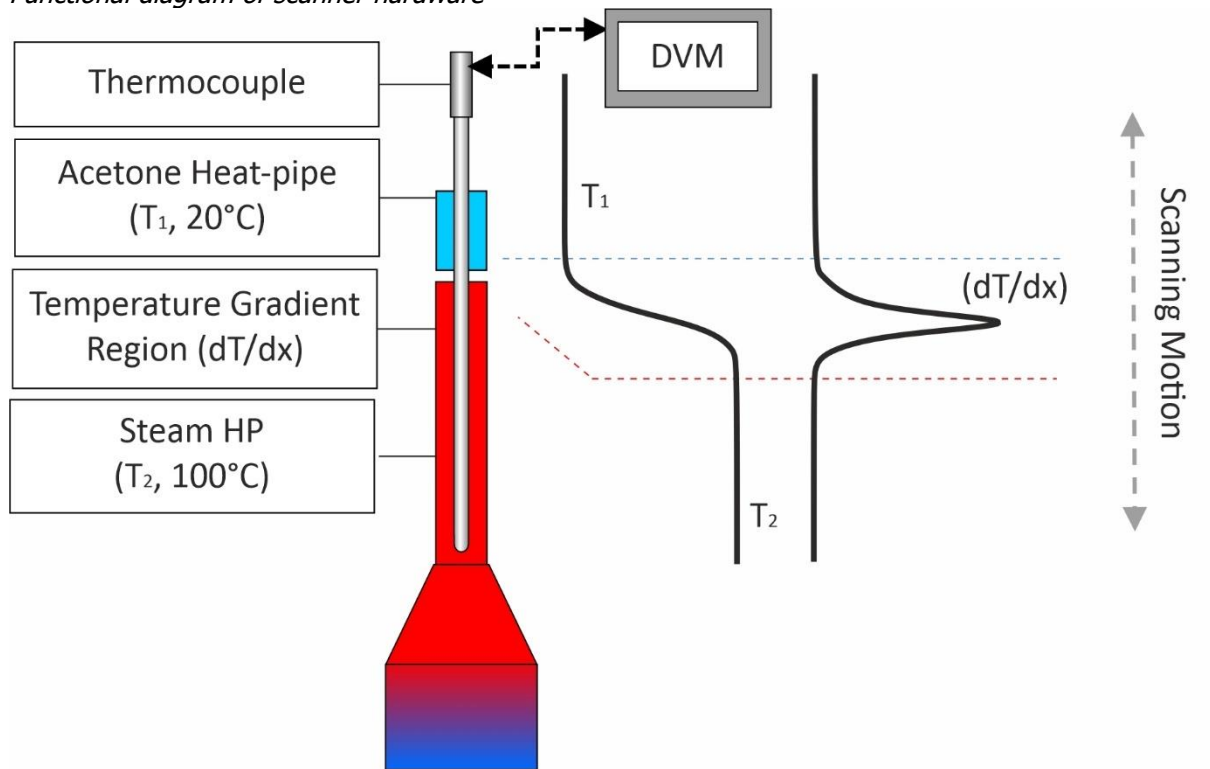
10 Assembly of Scanner

10.1 Upper and Lower Mounting Sections

The upper and lower mounting sections are made using extruded rectangular aluminium tube. The upper section is used to mount the linear-slide and the stepper motor. The lower section holds the boiler unit, condenser, septum assembly and acetone heat pipe assembly.

The following steps should be followed to assemble the scanner;

- Slide the top section into the bottom section.
- Attach the sections together using 2 x M6 nuts.
- Remove the top panel
- Make the necessary electrical connections within the unit.
- Replace the top panel ensuring the flexible fill tube is located correctly into the top pf the fixed fill tube directly below the top panel.
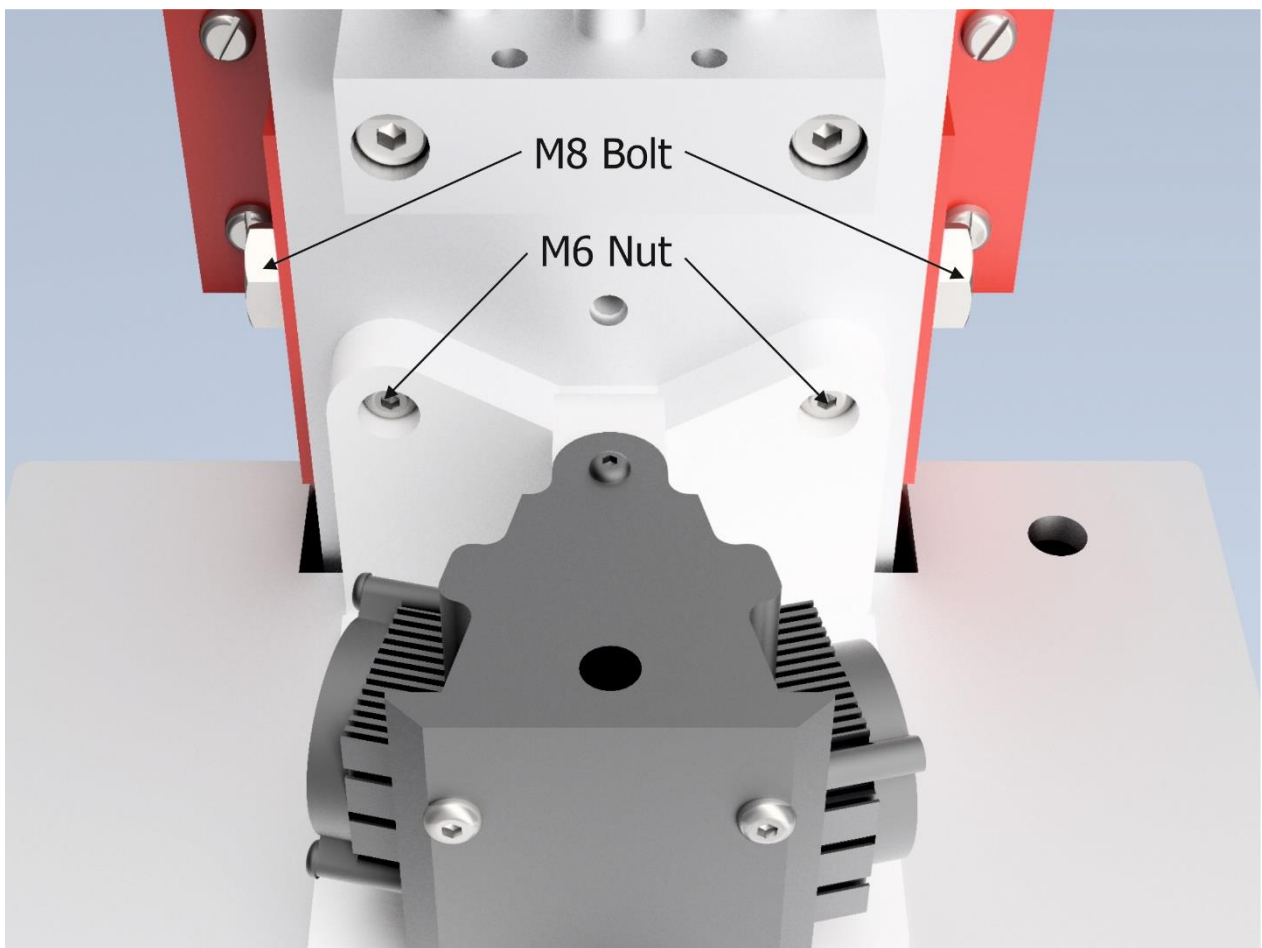
The side brackets can now be fitted and the unit located and fixed to a wall or vertical support.

11 Hardware components

11.1 Electronics

The scanner can now be connected to the control box as below.
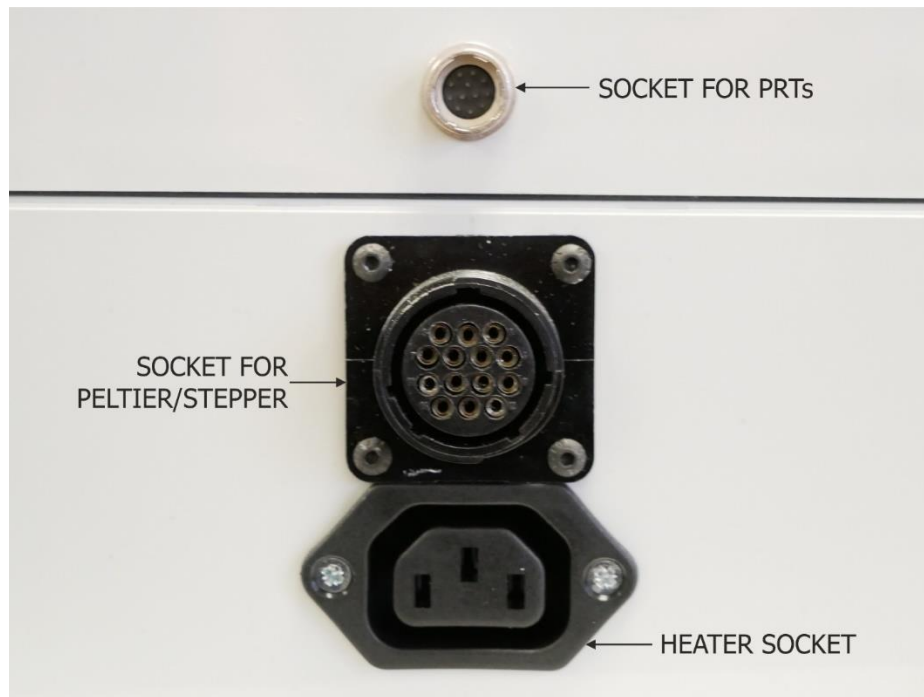
The controller box contains two switch mode power supplies, a USB Hub, a DC-DC 12 V/5 V USB boost regulator, a 4 channel PRT logger, a Peltier control unit and a stepper motor control unit.

Functional diagram of electronics
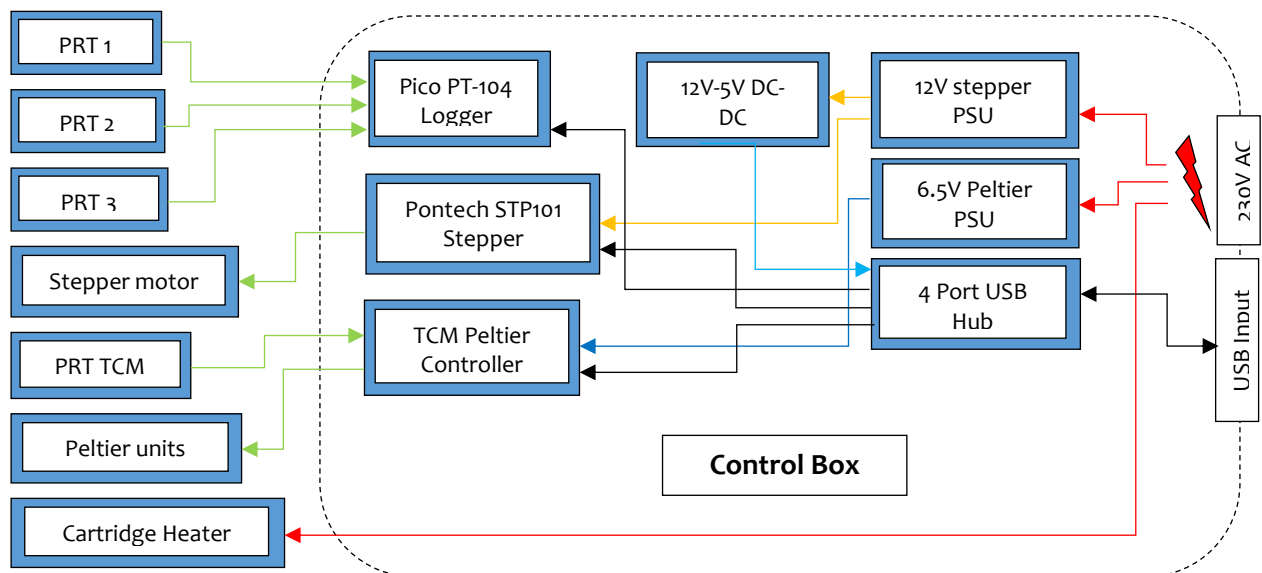
The hardware solutions chosen for the three essential systems are:
- A PICO PT 104 4-channel 4-wire logger with three calibrated PRT temperature sensors
- An Electrons Dynamics TCM (Temperature Control Module) 5A Peltier controller
- A Pontech STP 101 Stepper controller

11.1.1 PRT temperature monitoring system

To gather accurate inhomogeneity data three key temperatures are needed with uncertainties less than 20 mK. These temperatures correspond to the junction box, the upper acetone heat pipe and the lower steam heat pipe. The three PRTs were connected to the Pico PT 104 logger and calibrated as a system in a stirred liquid bath at multiple points. A third order polynomial was then fitted to the calibration data and a set of coefficients calculated. These calibration coefficients are embedded in the scanner software.

11.1.2 Peltier control system

The temperature of the upper acetone heat pipe is controlled with an Electrons Dynamics Type M 5A controller. Connected to the TCM is a miniature control PRT, this is mounted on the right side of the copper jacket used to house the acetone heat pipe. An offset temperature adjustment is provided in the software to allow the user to finetune the heat pipe temperature.

11.1.3 Stepper motor controller system

The Pontech STP101 stepper motor controller was chosen because of its wide input voltage and current range, its ability to drive bipolar and unipolar motors, its static and moving current control, its use of a ASCII communication interface and its on-board configurable auxiliary inputs/outputs. The linear slide is 1200 mm long, has an M10 thread with a pitch spacing of 2 mm.

11.1.4 Digital voltmeter (DVM)

Accurate inhomogeneity data is reliant on a high-quality DVM. By default, the scanner software detects any available GPIB SCPI capable meters, which have a valid command file accompanying the scanner software (see Section 4, Software). The meter must be capable of acquiring readings at speeds greater than or equal to 300 ms. An example of a suitable meter is the Keithley 2182A nanovoltmeter. At the time of shipping the software has been tested with the following meters: Keithley 2182A, Keithley 2002 and Agilent 34410A.

Connection to the DVM is made via a switched shorting box. An appropriate Lemo plug is provided in order to allow the user to make the necessary connection from the DVM to the shorting box. The wiring diagram is shown below.
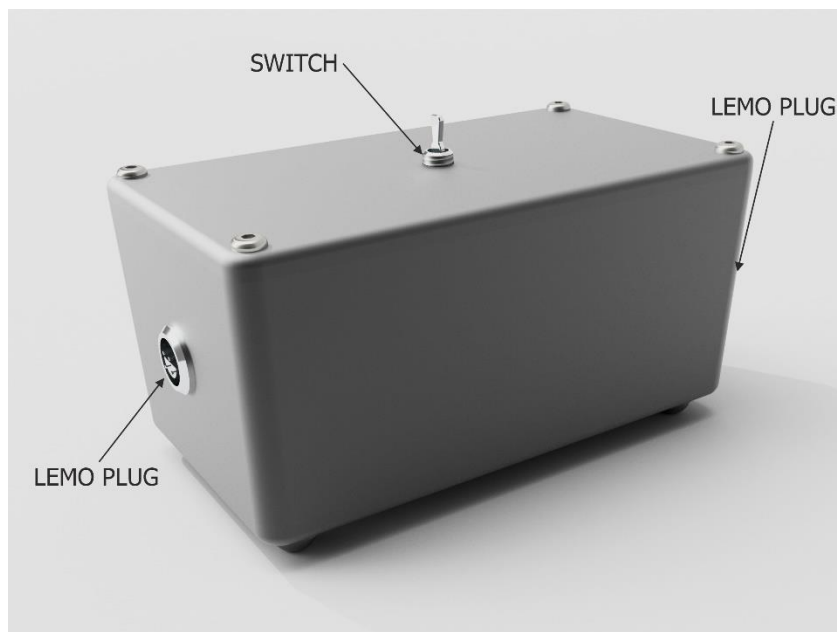
Internal circuitry of the shorting box.
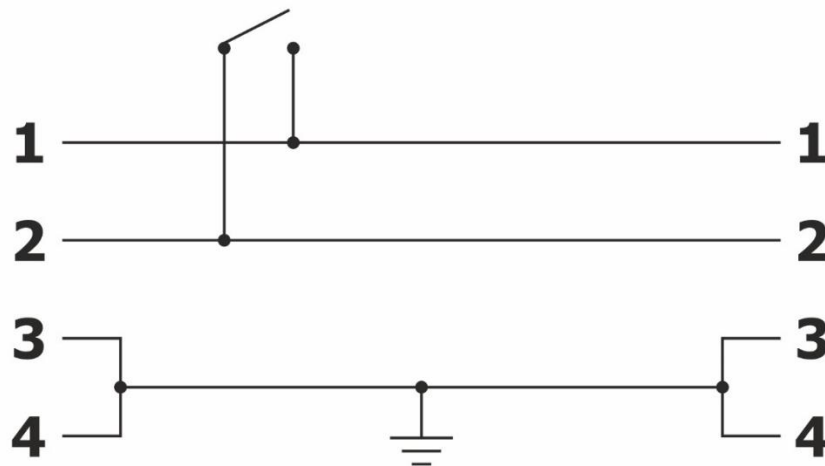
11.2 Acetone Heat pipe

The function of the acetone heat pipe is to regulate the temperature of that part of the thermocouple entering the gradient region of the scanner and ensure it is at the same temperature as the reference junction. This small closed heat pipe is shaped like a truncated triangular prism. This shape enables a pair of Peltier units mounted either side of the prism faces to have a large contact area with the heat pipe. The scanner is supplied with a single heat pipe having a 4.5 mm diameter hole. The heat pipe is designed to be removeable allowing other heat pipes with smaller diameter holes to be manufactured should scanning of thinner thermocouples be required. A calibrated PRT mounted in a re-entrant tube at the rear of the heat pipe is used to determine the temperature of the thermocouple prior to immersion in the steam heat pipe (referred to as the 'septum' temperature). A second smaller uncalibrated PRT is mounted on the copper retainer, adjacent to the right Peltier element. This PRT is connected to the TCM Peltier control unit within the controller box. The acetone heat pipe can be slowly inserted into the copper jacket taking note of the heat pipe orientation, with one end marked top and also taking care not to inadvertently knock the rear mounted Prt. Once inserted the brace plate can be secured using the 4 screws provided.
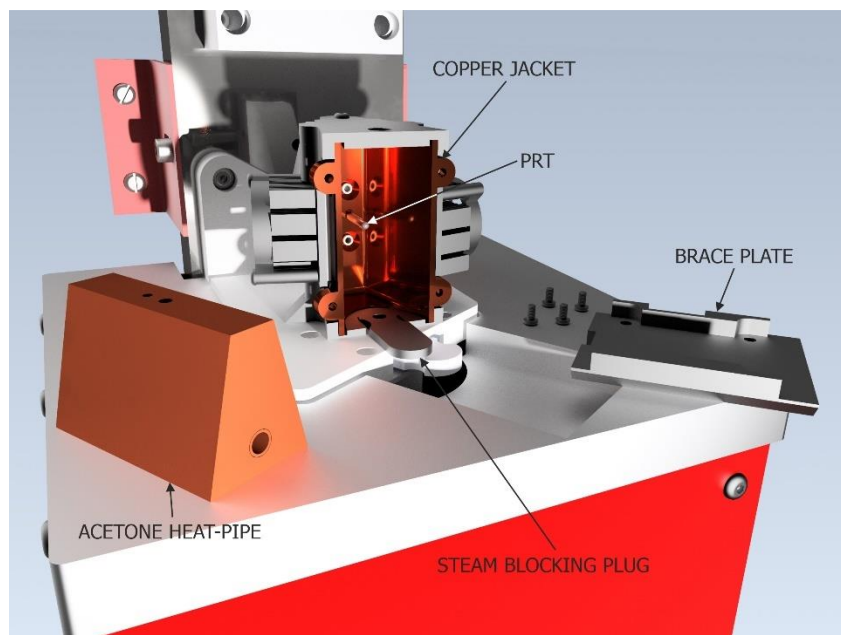
Copper heat pipe above is pointing at a fan, hard to differentiate parts
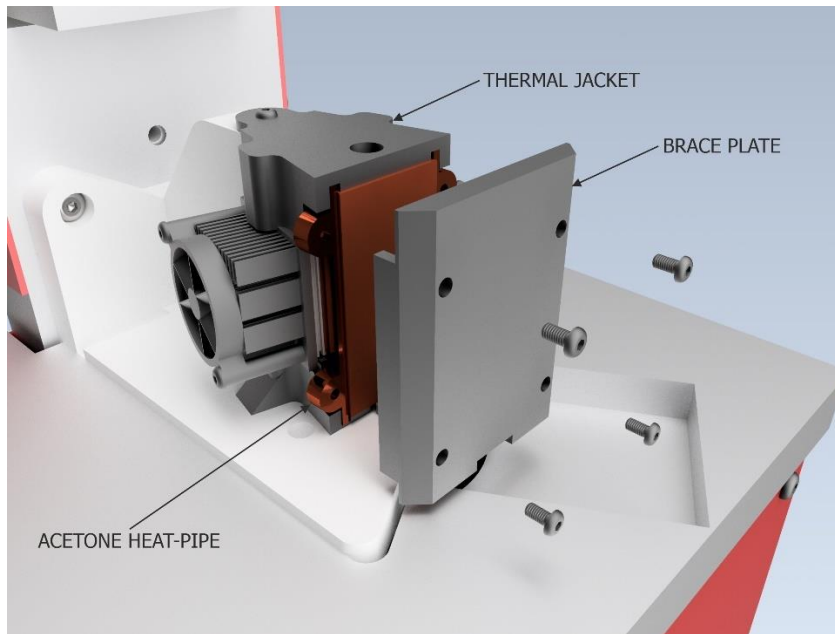
11.3 Septum

The silicone rubber septum is a critical component in the operation of the scanner as it prevents the escape of steam from the high-temperature steam heat pipe whilst also occupying minimal height. These two features allow the two heat pipes to be closely spaced, thus enabling a very narrow temperature gradient to be applied to the device under test (DUT). The septum is made from a 0.2 mm thick silicone rubber membrane. The silicone septum is carefully positioned centrally over the steam guide (tweezers may help) and then held in position with a small 'O' ring. The steam guide and septum are then placed into the PTFE Septum holder. Two large rubber 'O' rings are located at the top and bottom of the septum holder to provide the outer steam seal. The assembly can then be inserted between the steam blocking plug and the steam heat pipe. During normal operation, it is expected the silicone septum will need periodic replacement due to wear.
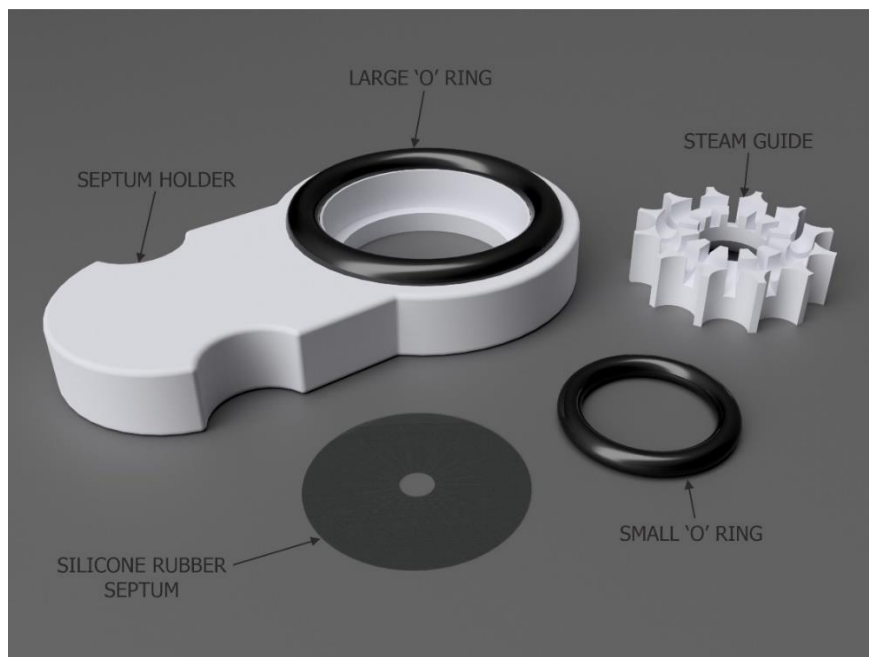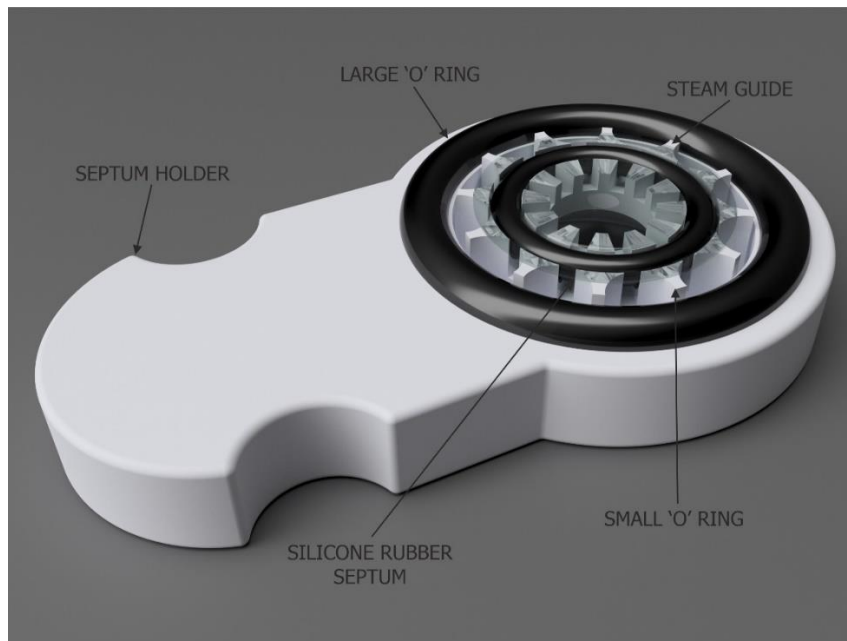
11.4 Junction Box

A junction box is used to provide easy connectivity between the thermocouple leads and the scanner system. This configuration removes the necessity of long lead wires and an ice-point reference. The junction box is designed to respond very slowly to external temperature perturbations. Any temperature gradients in the junction box will result in inaccurate measurements of the junction temperature. The scanner is therefore best sited away from the direct influence of air conditioning units and opening/closing doors or windows. The scanner uses a calibrated platinum resistance thermometer (PRT) to monitor the junction box temperature, enabling accurate software calculations of the compensation emf. The compensation calculations use the standard thermocouple reference functions [12]. The system is comparable to a common thermocouple readout device, which incorporates cold-junction-compensation. IMAGE OF JNT BOX ANNOTATED

11.5 The Steam Heat pipe

At the base of the steam heat pipe is a boiler unit with an internal volume of 1 litre. To initially fill the boiler unit prior to use there is a filler hole on the top right side of the scanner top plate. The scanner is supplier with a 0.5l syringe and this should be fully charged with distilled water and introduced via the filler hole. The boiler is fitted with a sight tube on the lower right side of the unit for assessing the level of water inside and a drain to allow easy removal of water when the boiler is not in use. It is important not to overfill the boiler unit, as doing so will interfere with the steam-return system, preventing the steam entering the condenser tube. A symptom of overfilling is a pressurised steam column causing excessive steam to be emitted from the rubber septum and a fluctuating steam temperature. If by accident the boiler is overfilled, the excess water can be easily drained.

The steam heat pipe is a pressure-controlled heat pipe using the atmosphere as the buffer gas. The steam temperature is dictated by the local atmospheric air pressure and will change continuously with the weather. The steam temperature must be known reasonably accurately to define one of the two temperatures used in assessing the performance of a scanned thermocouple, the other required temperature being the junction temperature. The software continuously monitors the steam temperature via a calibrated PRT mounted in the top of the steam-return path. The steam heat pipe is fully insulated, the steam return path consists of an uninsulated stainless-steel pipe that is attached to a heatsink in order to condense the steam prior to re-introduction into the boiler.

SIGHT TUBE

WATER DRAIN
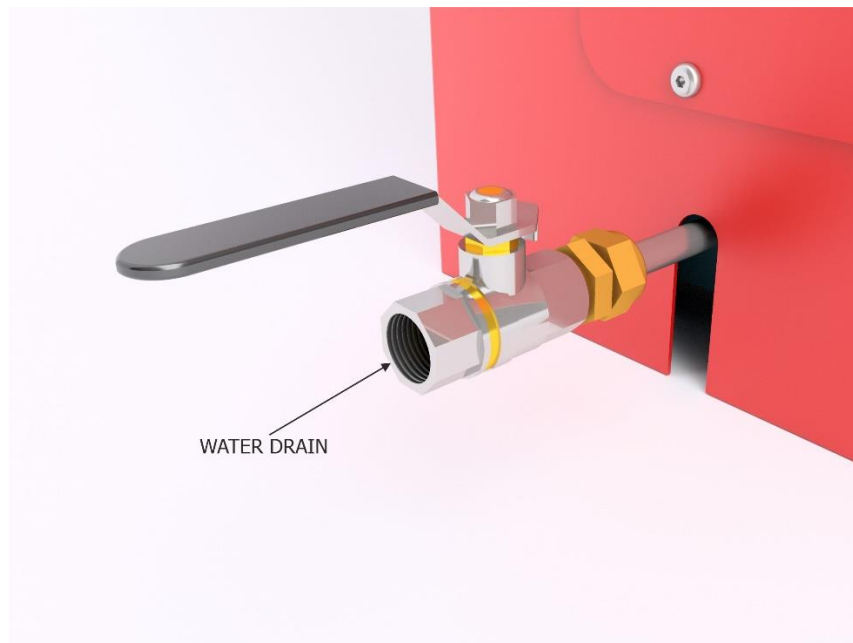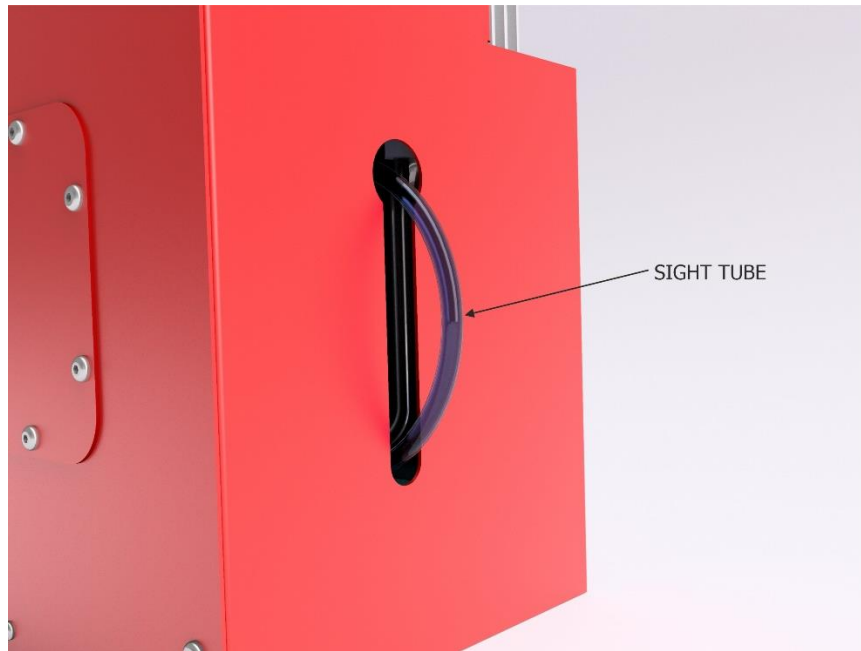
11.6 Linear Slide and v-clamp

The linear slide carries the junction box and a V-clamp for securing the device under test (DUT). Alignment of the V-clamp with the upper Acetone heat pipe not only ensures accurate positioning of the DUT and its entrance into the acetone heat pipe but it is also essential to avoid potential damage occurring to the DUT during a scan. Alignment is carried out using the correct sized alignment tool (that closely matches the diameter of the DUT). The alignment tool is placed into the acetone heat pipe and the linear slide is activated (via the software) to bring the V - clamp down to the level of the alignment tool. Whilst adjusting the level of the V- clamp, care must be taken to avoid running the V-clamp into the alignment tool. Once the V- clamp is over the alignment tool make the necessary x-y adjustments of the V-clamp until the alignment tool is held in the bottom of the V section. The V- clamp adjustments screws can now be tightened.

Alignment of linear-slide V-clamp and Acetone heat pipe

ALIGNMENT
TOOL
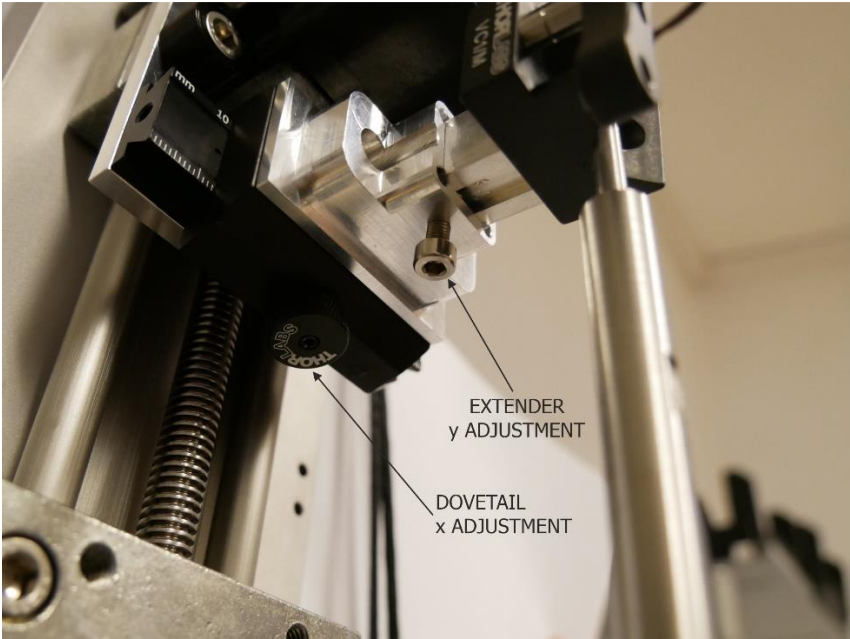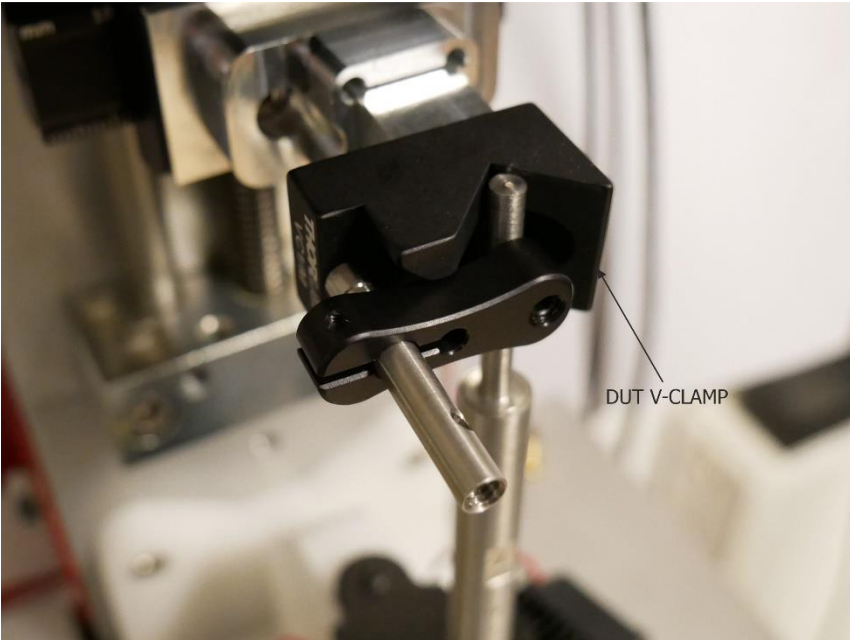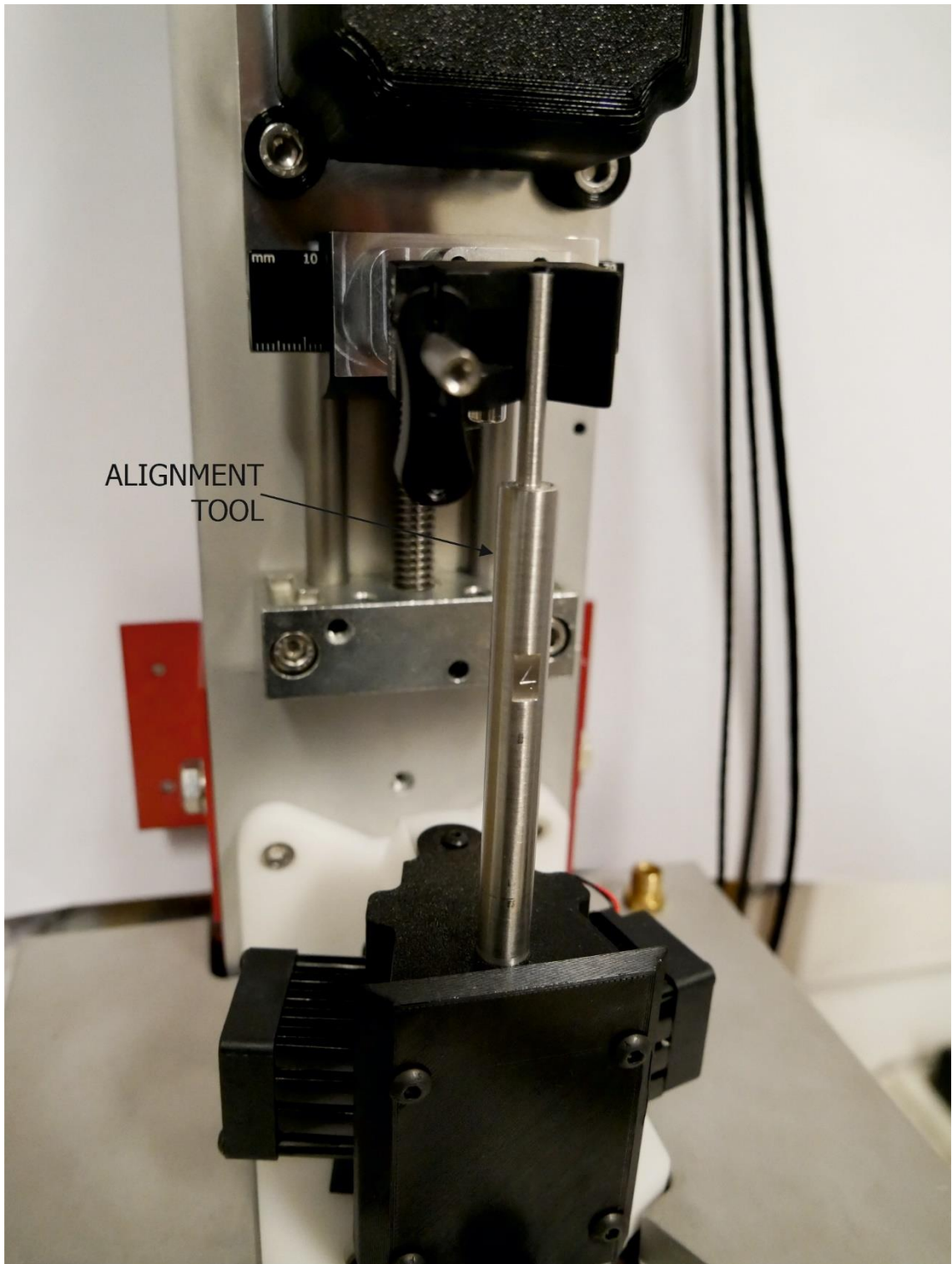
12 Scanner and ISO Analyser Software

12.1 Software Installation
Software installation should follow the sequence below;
- Run setup
- Opt to restart the PC later
- The driver installer should start automatically however it can also be run from the installation directory.
    - Unzip support files and wait
    - Install Pico driver (device PT104-USB)
    - Install NIPIB
- Create a blank ''Default Coeff.txt'' file in the application directory (this will eventually be programmed with specific calibration coefficients for Prt's fitted to the scanner, these coefficients can be found on the calibration certificate supplied with the scanner)
- Restart PC

12.2 Scanner Software
The software system is designed to communicate with the Pico logger, the STP101 Stepper motor controller, the TCM Peltier controller and the DVM. The software has been developed in National Instruments LabVIEW (2010). Ensure the hardware drivers for these devices and the LabVIEW 2010 run-time engine have been installed before opening the software. The user can initiate manual and automatic movements of the DUT while recording the position, emf and temperatures of the junction box and the two heat pipes. Any software-initiated movement of the linear-slide will be recorded in memory and displayed in a graph panel, but will not be written to disk until the user selects *Save*.

Scanner user interface
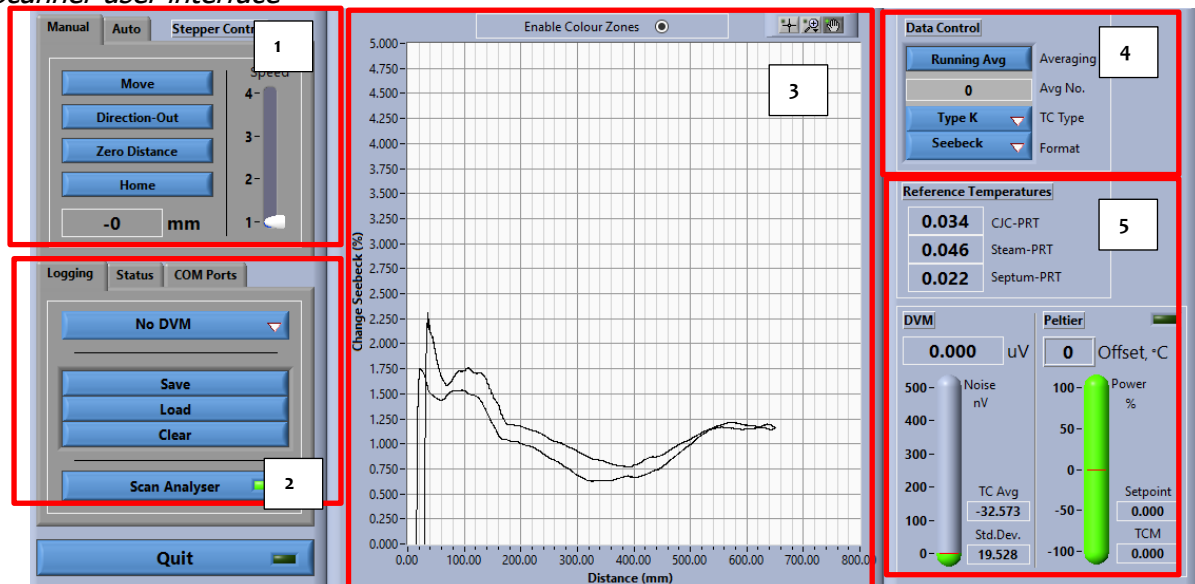
The user interface panel is roughly segmented into five regions:
1. *Manual and automatic controls* – Used for linear-slide operation and movement.
2. *Logging, hardware status and DVM* – Sets graph options, provides information on device communication, allows selection of DVM and allows access to Scan Analyser feature.
3. *Graph panel* – Provides the user with real-time plots of DUT scanning.
4. *Data control* – Allows formatting of graphical data.
5. *System indicators* – Provides the user with information on DVM stability and Peltier load.

12.3 Manual and Automatic Controls

12.3.1 Manual control
At the top of the *Manual* tab are the speed selector and current relative position for the linear-slide. Below these are selector buttons which control its motion, direction of travel, homing and zero position. The speed selector can be moved between four positions (1 - 4); the speeds at each of these positions are, respectively, 60 mm/min (1), 120 mm/min (2), 250 mm/min (3) and 400 mm/min (4). The *Move* command is used to start and stop the linear-slide. The current distance travelled will be displayed during its motion. The *Direction* button will determine whether the linear-slide moves upwards or downwards. The *Home* button will set the linear-slide moving in a direction which will return it to the zero position. Pressing the *Zero* button will make the current position the new zero position and will also set the distance indicator to zero.

12.3.2 Automatic control
Scanning of a DUT should not be attempted until the steam temperature has stabilised at a value close to 100 °C for at least 15 minutes (warm up time is about 1-2 hours). To perform an automated scan, the user should follow these steps:
1. Using manual control move the linear-slide to a height suitable to scan the DUT. Press the *Zero* command when the linear-slide is at the desired position. The *Set Distance* is roughly equal to DUT length minus 110 mm, and should be approximately equal to the distance between the top of the acetone heat pipe and the V-clamp.
2. Ensure the DUT is securely held in the linear-slide V-clamp.
3. If using an alumina sheathed thermocouple, ensure a silicone rubber cap has been placed over the tip.
4. The tip of the DUT should be inserted into the acetone heat pipe and be resting on the steam plug
5. Depress the terminal buttons on the junction box and insert the DUT wires, making sure they are fully inserted in their respective terminals.
6. The scanning speed can be set using the Immersion Control selection where there is a choice between Alumina (60mm/min) and MIMS (120mm/min).
7. The scan length can be set by changing the Immersion (mm).

12.4 Logging, Hardware Status and DVM
This region allows the user to save, load and clear data, inspect the hardware connection status and set the DVM.

12.4.1 Logging tab
The logging tab can be used to load, save and clear data in the graph panel. At the end of a scan, data should be saved to disk with the extension of *.csv (comma separated variable). **Note:** The load function will only accept data in this format. The reason to use the *.csv format is to allow files to be opened in many different text readers and spreadsheet capable applications. **Note:** If the software is stopped at any stage during a scan the data will be lost and a repeat scan will be needed. Restarting the software will cause a *clear graph* command to be sent to the graph panel.

12.4.2 Status tab
The status tab displays the current communication status for each of the connected devices: the stepper motor controller (Stepper), the digital voltmeter (Meter), the temperature logger (Pico) and the Peltier controller (Peltier). If communication is lost with any of these devices a software flag will be raised, the status tab will be selected and a red indicator will be shown next to the failed device/s. During normal operation, all device indicators should be green.

12.4.3 Com port tab

During initialisation the software needs to carefully allocate and recall which instruments are on what communications serial port. Both the Peltier controller and the stepper motor controller use serial communications. To discover what port these devices are on the software lists all available serial ports and then tries a device specific query on each. If it gets the correct response the device is allocated a software tag, which is displayed in the com port tab. When the software is closed, or stopped, these serial ports are closed and released. In the very unlikely event of a software crash the serial ports may not be closed properly and a restart of the computer will be necessary.

12.4.4 Digital voltmeter selection

At start-up, the software will automatically detect available GPIB SCPI capable instruments. As part of the instrument detection process the software will send each connected GPIB instrument a reset (RST*) command followed by an identification command (IDN*?). If the desired voltmeter is not shown, check it has a unique channel number, is not being used by another process and has an appropriate command text file stored in the same folder as the scanner software (e.g., Keithley 2182A Initialisation.txt).

A DVM noise indicator is shown on the right with the current DVM value displayed directly above. The noise indicator allows the user to determine when the DUT is sufficiently stable to begin a scan. The noise level will vary depending on the quality of the meter. Minor thermal transients will be introduced when the DUT is placed in the scanner. It will take approximately 5 minutes for these transients to dissipate. This equilibration process should be evident from the noise indicator. By clicking on the maximum value of the indicator its value can be changed if needed. For example, a Keithley 2182A nanovoltmeter will normally be stable to within 10-40 nV, prior to starting a scan. However, large inhomogeneities near the tip of the DUT may result in greater instability and noise. Next to the noise indicator are average and standard deviation indicators. These values are derived from the last 50 readings and provide the user with useful feedback on the progression of kneel-over and the homogeneity of localised regions.

To use other meters, construct a simple text file with a format like the DVM initialisation text files stored in the folder containing the scanner software. The first entry in the text file should be the upper noise limit for the DVM (typically between 100 nV – 1000 nV). The next two entries are respectively the SCPI reset and identification commands (*RST and *IDN?). After successful identification, the software will then configure the DVM, using commands to set DC voltage, range, resolution, Power line cycles, averaging (if any), filtering (if any). The final command in the text file is the command to read the DVM voltage (e.g., meas:volt:dc?). It is important that the read command is placed last in the command list.

12.5 Graph Panel

By right clicking on the *x* and *y* graph-panel scales the user can select between different scale range values, including automatic and manual scales. In the top right of the graph panel there are three graph selector options, signified using a *cross*, a *magnifier* and a *hand*. The *cross* allows the user to select the plot, the *magnifier* allows zoom options and the *hand* allows the plot to be dragged within the graph area. The user can also right click on the graph to export the data directly into a spreadsheet or document.

12.6 Data Control

Depending on the reason for the scan, the user has several options available to display the scan data. In order, these are *Averaging, Avg. No., TC Type and Format*. In instances where the DVM resolution is low the user can apply a running average to the scan data, simply selecting *Averaging* and entering the number of points to be averaged over. The *TC Type* ring menu provides standard thermocouple transforms for all common thermocouple types. If TC Type is set to *none* the *Format*

menu will be greyed out and the graph ordinate will be displayed in microvolts, as read from the DVM with no cold-junction-compensation applied. The abscissa will always be displayed in millimetres. With a TC type selected the user can then choose the format: temperature (*TEMP*), Delta Seebeck (*Seebeck*), relative emf (*Rel EMF*), delta-emf (*Delta-EMF*), and delta-temperature (*Delta-TEMP*). These format options will use the cold-junction temperature to calculate an appropriate compensation emf. A compensation emf is needed to correct for the junction not being at 0 °C. The formats are explained as follows:

- *TEMP* – The temperature of the thermocouple as a function of immersion. For an Ideal thermocouple, the plotted temperature should be the same as the steam temperature.
- *Seebeck* – Possibly the most useful display, shows the difference in Seebeck coefficient between the reference functions and the DUT as a percentage.
- *Rel EMF* – The corrected relative emf output of the DUT as a function of immersion. This value will depend on the steam temperature, which can fluctuate daily and seasonally with changes in atmospheric pressure.
- *Delta EMF* – Displays the difference in emf between the reference functions and the DUT at the steam temperature.
- *Delta TEMP* – Displays the difference between the DUT measured temperature and the steam temperature.

The format can be changed at any time without altering the scan in progress. Recorded data includes the raw emf, distance and calibrated PRT readings. Therefore, scans can be viewed later with an appropriate format applied.

12.7 System Indicators

12.7.1 Reference temperatures
Three reference temperatures are displayed, these being the steam, septum and CJC- PRT (junction box) temperatures. The septum temperature refers to the acetone heat pipe temperature. Ideally, the septum temperature and CJC temperature should be very similar. A Peltier unit is used to control the septum temperature, so under normal operation the septum and CJC temperature should remain within 0.5 °C of each other. Fine adjustment of the septum temperature is possible using the TCM Peltier controller offset feature. This offset corrects for the difference in reading between the calibrated septum PRT and the TCM Peltier control PRT (uncalibrated and externally mounted). *Displayed Setpoint = CJC temperature + Offset.*

12.7.2 Peltier TCM output
A display shows the current % of full output for the TCM Peltier unit, allowing the user to assess the cooling power. With the steam plug in or during normal scanning operation the output should be between 40 % and 50 %. However, a rapid withdrawal of the DUT from the scanner will drag heat up into the acetone heat pipe, causing the Peltier unit to work harder to match the temperatures of the junction and septum. The Peltier output indicator can also be used to alert the user of a septum tear or steam leak. If either of these situations arises the acetone heat pipe will be heated from steam escaping between the septum and DUT, thus causing the Peltier unit to operate at a higher output.

12.8 Iso Analyser Software

Previously measured scans can be loaded into the analyser software, from the dropdown boxes the thermocouple type and choice of Y axis for the graph can be made. The split scan feature allows the user to look at the both the inward and outward scan or just the inward scan. It is recommended that the inward scan only is used for determining the uncertainty. Colour zones can be enabled in order to establish the uncertainty associated with specific regions of the scan. The colour zones are user definable by placing the min/max cursors at the corresponding min/max distance of interest. The region in green denotes the region of interest and is used to determine the total inhomogeneity and is given as a % and as a peak-peak uV value. The mean and standard deviation plus difference in X and Y values for the green band region are also provided.
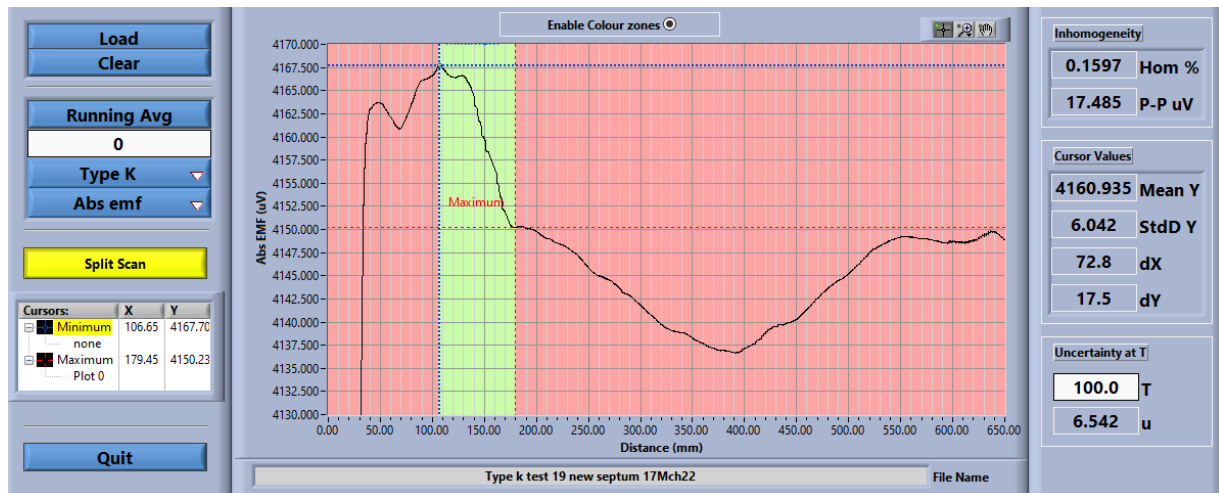
12.8.1 Procedure for determining uncertainty due to inhomogeneity based on scan data

To provide the best estimate of this value a scan is needed of the DUT at the end of calibration (after being thermally imprinted from the calibration procedure)

Using the *ISO Scan Analyser*, Adjust the green region to encompass the part of the thermocouple that will be used by the customer (avoid the kneel-over region at the start of the scan and the region at the end of the scan where any annealing process might have been inadequate). The software will provide the peak-to-peak value in uV between the two cursors. The % value is the level of DUT inhomogeneity at the scanning temperature, based on the reference function at the scanning temperature.

To calculate $u(T) = \pm [\text{P-P}/(\text{emf}(T_{scanner}) - \text{emf}(T_{ambient}))/\text{Root}(12)] \times \text{emf}(T)$
- $u(T)$ is the uncertainty in uV
- P-P is the peak-to-peak uV value provided by *ISO Scan Analyser*
- $\text{emf}(T_{scanner})$ is the reference function emf (uV) at 100C
- $\text{emf}(T_{ambient})$ is the reference function emf (uV) at 20C
- $\text{emf}(T)$ is the measured emf at the temperature of interest

e.g. for a Type S at 1000C with P-P value of 0.5uV, u would be [0.5/(646-113)/Root(12)] x 9593 = 2.6 uV or 0.22C

13 Scanning

At the start of the scan, where there is very poor immersion, the dominant heat transfer will be in the radial direction. All the heat must pass through the thermally insulating sheath to get to the inner thermoelements. As the thermocouple immersion increases the heat conduction will switch from radial to axial. The thermoelements themselves will start to act as thermal highways, having less thermal resistance than the sheath. Therefore, the user should expect to see the emf signal rapidly change from vertical to horizontal (kneel-over) during this transition. For alumina-sheathed thermocouples of nominally 4 mm diameter this process normally occurs in the first 40 mm. For MIMS thermocouples this process is quicker and should occur in the first 20 mm, however the location of the junction within the metal sheath will play some part in this transition. Consequently, the scanner cannot reveal inhomogeneity data near the thermocouple junction, where there will be large thermal conduction errors. Only the region following kneel-over can be used to assess thermocouple inhomogeneity. For alumina-sheathed thermocouples kneel-over is complete after about 80 mm, and for MIMS, about 40 mm. **Note:** There is an approximate 10 mm gap between the start of the scan and the tip passing through the septum. Therefore, scans that depend on positional accuracy should be offset by 10 mm to allow for this. If kneel-over occurs slowly this usually indicates a problem with the thermocouple or scanner.

Below is a simple procedure for operating the scanner;
1. Fill the boiler with distilled water so that the sight tube indicates the boiler is half full, approximately 0.5l.
2. Make all necessary connections between the scanner and control box and power up the control box and DVM.
3. Now start the software, this will initialise the DVM and confirm that the control box can communicate with all component parts.
4. On the connector/shorting box between the DVM and the scanner ensure this is in the short position, the DVM will read close to zero.
5. The water in the boiler will take 20-30 mins to boil, use this time to prepare the scanner and DUT.
6. Choose the appropriately sized silicone septum to suit the OD of the DUT and fit this to the steam guide, securing it in place with a small O-ring.
7. Place the steam guide and septum into the septum holder and insert into the scanner.
8. With the steam plug removed check septum alignment by aiming a light through the steam plug entrance, looking down the acetone heat pipe hole the septum hole should be central to this.
9. Once aligned insert the steam plug – the steam plug should be a relatively tight fit, it is important that the steam plug is always in place when not scanning as the escaping steam will interfere with the Temperature Control Module (TCM) control and stability.
10. Using the software in manual mode bring the V-clamp close to the bottom of the slide.
11. Using the correct sized alignment tool, centralise the thermocouple support to the acetone heat pipe hole.
12. Again, in manual mode raise the V-clamp to the desired scan height.
13. At this point use the 'zero' function in the software – this will be the 'home' position to which the slide will return once the inward scan is complete.
14. If the DUT is ceramic sheathed then an appropriately sized silicone end cap should be fitted – this ensures steam does not enter the bores of the ceramic therefore affecting the scan results.
15. Now place the DUT into the acetone heat pipe (it will rest on the steam plug) and secure the DUT in the V-clamp using the hex keys.
16. Connect the thermocouple wires to the push terminals on the linear slide and insulate.

17. Now the software can be set to the thermocouple type of the DUT and the type of scan required.
18. In 'Auto' mode set the thermocouple construction type (Ceramic or MIMS) and set the scan length required.
19. When the software indicates that the boiler has reached stability then an 'Offset' can be inputted to account for the difference between the CJC Prt temperature and the Septum Prt temperature.
20. Prior to commencement of a scan the system must be stable – CJC and Septum with 0.1 °C of each other, the TCM power should be <50% indicated by the power bar changing from yellow to green and the DVM zero indication should be <100nV.
21. Once these have been satisfied the scan can be started.
22. To do this the connector/shorting box should be switched to connect whilst simultaneously removing the steam plug and then the software should be set to run immediately, at this point a sharp blow of air through the steam plug entrance will clear any residual moisture from the acetone/steam interface.
23. The scan will now run and the kneel-over can be observed on the graph.
24. Once the inward scan is complete the DUT will return to its original position (home), this part can be sped up by choosing 'Return' on the thermocouple construction type.
25. As soon as the scan has been completed re-insert the steam plug and switch the connector/shorting box to short.
26. The scan can now be saved as a .csv file to a desired location.
27. The 'Log Viewer' software can be accessed through the main software, this can be used to analyse the scan and from here the scan can be exported to excel for further processing.
28. If a second scan is required it is advised to wait 30 mins to allow the DUT to cool and the system to re-stabilise before the next scan is started.
29. If another thermocouple is required to be scanned then repeat the procedure above – prior to inserting the thermocouple into the acetone heat pipe it is advised to remove any condensed moisture from inside the acetone heat pipe hole with some tissue, this ensures consistent results.

14 Maintenance

Aside from regular checking of the septum condition and possible long term periodic recalibration of the Pt100's used in the scanner there is very little maintenance required. If anything enters the boiler through the top of the scanner, please consult Isotech for advice.

15 Common Problems

15.1 Failure to Kneel-Over

Perhaps the most common problem when scanning thermocouples is failure for the plotted signal to 'kneel-over' correctly. Kneel-over is a transition in the dominant thermal conduction path, from radial to axial within the thermocouple. Kneel-over should occur over approximately 20 mm, as the signal is seen to rise vertically and then curl to horizontal. Incorrect kneel-over can be identified as a very slow rise in signal with an indistinct transition between the two thermal conduction modes. Several faults can cause this to happen, so it can be hard to diagnose what part of the system is causing the problem. However, the most common causes are:

- An unstable steam temperature
- A septum misalignment or tear
- Moisture in the insulator
- Residual heat from a prior scan
- A severe inhomogeneity about the hot junction

Each of these items will now be elaborated on.

Kneel-over transition showing radial to axial thermal conduction
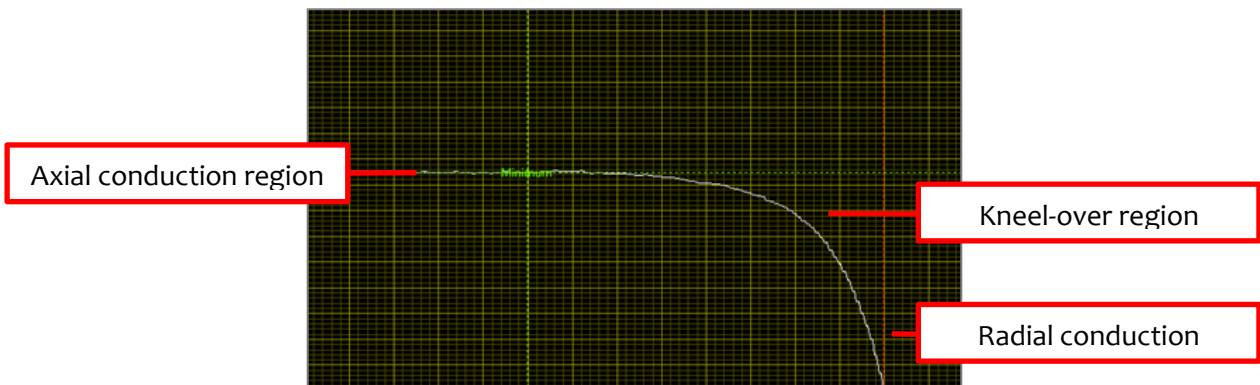
15.1.1 Steam temperature not stable

The steam temperature of the scanner should be stable for a period of at least 15 minutes prior to starting a scan. The warm up time is typically about 1-2 hours. Starting a scan before the heat pipe is at equilibrium will cause excessive cooling and a reduction in signal. The error will be proportional to the difference in temperature between the steam monitoring PRT and the steam column beneath the septum.

15.1.2 Septum misalignment

The septum needs to form a tight seal around the thermocouple during scanning. Any failure of this seal will allow steam to escape, heating the acetone heat pipe and making the Peltier unit work harder. Check to see the Peltier output power is lower than 40 % at idle or during scanning. Any misalignment of the septum to the DUT may result in the DUT pulling the septum to one side, thus allowing steam to escape past the septum. A bent or kinked DUT will also cause this to happen. The first thing to check is that the V-clamp is in alignment with the acetone heat pipe (section 3.6). Next remove the steam plug, shine a light where the steam plug enters the unit and carefully look down the hole in the top of the acetone heat pipe, the hole in the septum should be seen centrally aligned with the hole in the acetone heat pipe. The septum retainer cup position can be adjusted to centralise the hole in the septum. A steam leak can also be caused by a damaged septum. Periodic checks should be made by removing the retaining cup and inspecting the septum.

15.1.3 Moisture in the insulator

Moisture in the insulator will rob heat from the thermoelements, causing additional thermal inertia, as heat is required to change this moisture from liquid to vapour. A silicone rubber cap is provided for use with alumina sheathed thermocouples. The cap should be fitted over the tip of the thermocouple prior to scanning. However, careless application of the cap may cause the thermocouple wires to puncture the cap, thus allowing moisture into the alumina bores. A puncture can be revealed by placing the cap over the tip of a squeeze bottle containing water. A gentle squeezing of the bottle should provide enough pressure to reveal any leaks. Any moisture in the alumina will need to be removed by baking the thermocouple in a furnace at 100 °C for at least hour.

A similar moisture problem can occur with MIMS thermocouples in which the metal sheath has been compromised, usually by oxidation. For a non-grounded thermocouple, an electrical resistance lower than about 10 kΩ between the thermoelements and the sheath will indicate the presence of moisture. MIMS thermocouples with a perforated sheath should be considered useless and disposed of. A sheath failure should be a warning that the internal thermoelements have already been compromised.

15.1.4 Residual heat from prior scan

The thermocouple temperature, prior to scanning, must be as close as practicable to the acetone heat pipe temperature for the scanner to make accurate measurements. Hence, when making multiple scans of the same unit allow adequate time for the thermoelements within the insulator to equilibrate and for the Peltier unit to cool the acetone heat pipe. It is recommended that 30 minutes be waited between scans.

15.1.5 Severe inhomogeneity about the hot junction

For thermocouples that have suffered severe contamination or oxidation it is possible for the Seebeck coefficient to be greatly reduced near the hot junction. This reduction can give a slow kneel-over like what would be observed for the previous scanner faults. Therefore, the user should first rule out the other causes before diagnosing the DUT as severely damaged. A repeat scan with a near identical profile is usually sufficient to verify correct scanner operation.

15.2 Failure to Communicate With Hardware

Occasionally when the software starts it may fail to register one of the hardware components. In such instances the software should be closed and the power cycled on the control box, waiting at least 10 s before powering on. With the power cycled reopen the software. If the problem persists, restart the computer as it is likely there has been a conflict in the hardware settings or a serial port locked open. A loss of communication with the control box can cause the software to lockup or stop during normal operation. Check the USB connections, then close and restart the software.

15.3 Peltier Unit Operating at Maximum Output

The Peltier unit can be forced to operate at its maximum output (set to 65 %) for several reasons. The most common of these are: the steam blocking plug has not been inserted while the scanner is idle; the returning scanned thermocouple has dumped a large amount of heat into the acetone heat pipe; or the septum is misaligned or damaged.

15.4 Scan Does Not Complete

If the linear-slide mount is not correctly aligned with the acetone heat pipe the thermocouple may become jammed and even break. Check clearances between these two items. Loss of communication with the stepper motor controller may also cause this fault; check the com port tab.

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