USER MANUAL **STPSYS05**

Surface thermal properties measuring system

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Warning statements

⚠ To avoid ground loops, do not connect the ethernet port and the USB port of STPSYS05's MCU at the same time.

⚠ Do not use sensor cables longer than 3 metres.

⚠ When using the external trigger input, do not exceed maximum input voltage. Exceeding the trigger input voltage may permanently damage STPSYS05's MCU.

⚠ Putting more than the specified maximum heater voltage across the heater wiring can lead to permanent damage to the heater and can pose both an electrical as well as a fire hazard. Do NOT connect STP05 to mains.

Hukseflux
Thermal Sensors

Contents

List of symbols

Quantities	Symbol	Unit
Voltage output	U	V
Sensitivity	S	mV/K
Temperature difference	ΔT	K
Thermal resistance	R	m·K/W
Thermal conductivity	λ	W/(m·K)
Thermal diffusivity	α	m^2/s
Heater power	P	W
Linear dissipation density	$\dot{Q}$	W/m
Hot joint location	y_1	m
Cold joint location	y_2	m
Heater length	L	m
Temperature	T	°C
Time	t	s

Subscripts

Not applicable

Introduction

STPSYS05 is a non-invasive, easy-to-use and affordable system for measuring the thermal conductivity at the surface of a specimen. Applications include:

- measurement of thermal conductivity combined with an estimate of thermal diffusivity, for material characterisation purposes
- comparative thermal property measurements for quality control purposes, relative to a "known" reference specimen

The system can be connected to a local area network (LAN) or USB port and offers an intuitive and simple to use graphical user interface that you can access via your web browser. STPSYS05 is available as a complete measuring system, the STP05 sensor is also offered as a separate 'sensor only' product.

Figure 0.1 *STPSYS05's STP05 sensor, also available as a 'sensor only', is meant for measuring the thermal conductivity of materials at their interface. The bottom view of STP05 on the left shows it is equipped with a heater (line source), a temperature difference sensor (thermopile) and a temperature sensor (thermistor).*

STPSYS05 is a practical system for measuring the thermal conductivity at the surface of materials. The measurement method has many advantages, and requirements for specimen preparation and dimensions are limited. Performing a measurement is easy and fast: simply place the sensor on a smooth flat surface of your material and you can measure its thermal conductivity. STPSYS05 is suitable for materials in the 0.1 to 15 W/(m·K) range (see the manual for rated measurement ranges and expected uncertainties). Materials include plastics, stone, rock, composites, soils, pastes and foodstuff.

The STPSYS05 system consists mainly of a Measurement and Control Unit (MCU) and the STP05 sensor. STP05 combines a heater (line source) with two temperature difference sensors (thermopiles) placed on either side of the heater. When STP05 is placed on a specimen and power is applied to the heater, this creates a temperature difference which is measured by the thermopiles. The measurement is steady-state; interpretation is easy. The thermal conductivity is calculated by the software of the MCU from the heater power and the measured temperature differences. In addition to the thermal conductivity, information about the thermal diffusivity and volumic heat capacity can be obtained from the time response of the thermopile signals.

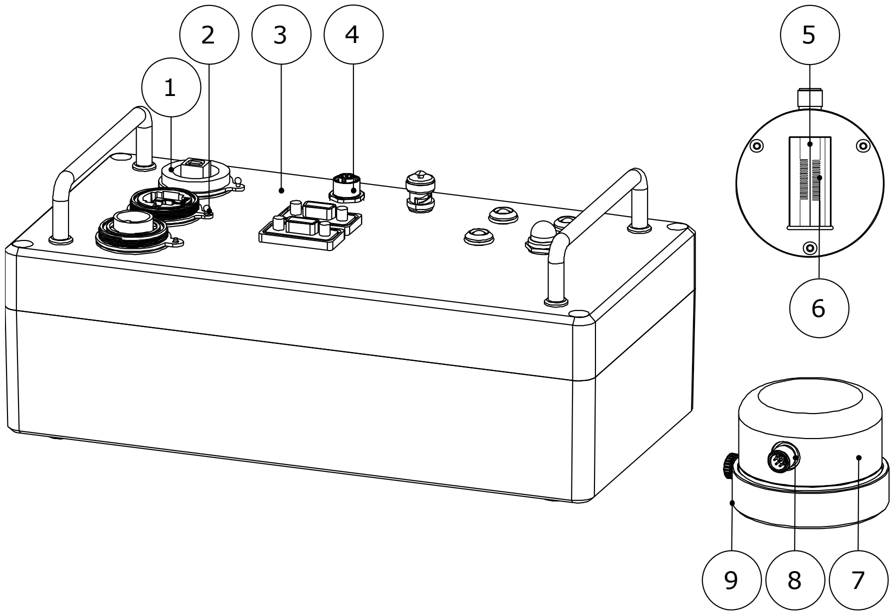

Figure 0.2 *Overview of the STPSYS05 system: (1) USB port, (2) ethernet port, (3) MCU Measurement and Control Unit, (4) connector for STP05 sensor, bottom view of STP05 sensor with (5) heater (line source) and (6) thermopile, (7) body of STP05 sensor, (8) STP05's connector, (9) protective cap*

STPSYS05 advantages

- affordable
- non-invasive: all that is required is a smooth flat surface over the sensor area and sufficient specimen thickness below that surface. There is no need for specific specimen dimensions.
- single-sided testing: only one specimen is required.
- fast to work with: smart sensor design reduces sensitivity to thermal shocks and gradients. The time needed to stabilize before a measurement is short, in the order of 5 minutes.
- easy-to-analyse steady-state measurement of thermal conductivity.
- intuitive and easy to use graphical user interface, accessible using your web browser. No software installation required on your PC.

Suggested use

- specimen testing in material science labs
- quality control and verification of consistency of materials
- educational purposes; use in student labs

How to employ STPSYS05

STPSYS05 can be used to measure thermal conductivities in the range from 0.1 to 15 W/(m·K). In addition to the thermal conductivity, STPSYS05 gives an estimate of the thermal diffusivity.

STP05 sensor is placed on a smooth surface of the material of which the thermal conductivity is to be measured. For higher accuracy results, glycerol may be used as a thermal contact fluid to ensure minimal interfacial thermal resistance between the sensor and the material. The measurement can be monitored and controlled via the MCU.

Figure 0.3 *STP05 sensor being applied on a smooth flat surface of a suitable specimen. STPYS05's MCU performs measurements, data storage and calculation of the measurement result.*

Calibration & performance assessment

STP05 is supplied with a calibration certificate stating the sensitivity and the thermal resistances of the sensor. For calibration purposes, STPSYS05 system includes a calibration reference specimen.

Rated operating conditions

STPSYS05 can be used in laboratory as well as industrial environments. STP05 sensor can be used to perform measurements at temperatures from -20 °C to +80 °C and STP05 is protected against ingress of water, rated IP67.

User interface: MCU is a web server

The MCU performs measurements, data storage and calculation of the measurement result. It acts as a web server that can be connected to any local area network. A user interface is available as a web page.

Alternatively, the MCU can be connected to a PC via USB. In that case the web page is available via "Ethernet over USB" or a virtual Ethernet link. If you type the MCU's IP address (192.168.66.1 by default) into your web browser, you have access to the user interface.

Parameters such as the heater power setting, total measurement time and specimen description can be entered through the user interface. A thermal conductivity measurement is then started by a simple click of a button. During the measurement, the user interface displays live information such as the measurement progress, remaining measurement time, heater power, temperature difference and absolute temperature. At the end of the measurement, the system automatically calculates and displays the measured thermal conductivity. The system also determines a characteristic time and if possible a thermal diffusivity estimate.

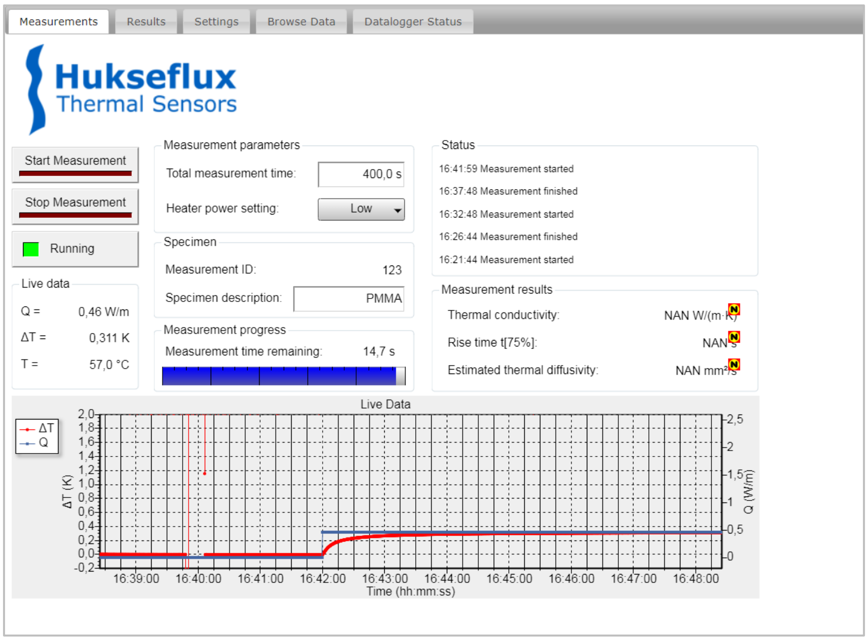

Figure 0.4 *STPSYS05's user interface: the main screen is used to start measurements, display live data and results*

Ordering STP05 sensor only

STP05 is also available as a "sensor only". In this configuration the user must provide a stable switchable power supply to power the heater, an Ohm meter to measure the thermistor electrical resistance and a high-resolution voltmeter to measure the thermopile output voltage and voltage across the heater. When ordering an STP05 only, the user is responsible for data analysis.

See also

- THASYS Thin heater apparatus for thermal conductivity measurement
- THISYS Apparatus for thermal conductivity measurement of thin samples
- TP02 and TP08 needle based thermal properties sensors. TPSYS02 turn key measuring system for needle-based sensors.
- TP01 thermal properties sensor.

1 Ordering and checking at delivery

1.1 Ordering STPSYS05

The standard configuration of STPSYS05 includes an STP05 sensor and a measurement and control unit.

Common options are:

- STP05 sensor only
- Campbell Scientific CR1000KD Keyboard/Display for operating the system without a PC

1.2 Included items

Arriving at the customer, the STPSYS05 delivery should include:

- 1 x STP05 surface thermal properties sensor with protective cap
- 1 x STPSYS05 MCU measurement and control unit
- 1 x sensor cable, 1.5 m
- 1 x USB cable with Bulgin connector, 2 m
- 1 x 12 VDC power supply, with 4 interchangeable AC plugs (AUS, EU, GBR, USA)
- 1 x product certificate
- 1 x USB flash drive
- 1 x reference specimen
- 1 x carrying case

Figure 1.2.1 *STPSYS05 system with its MCU, STP05 sensor and carrying case*

2 Instrument principle and theory

STPSYS05 consists of two main parts: the STP05 sensor and the STPSYS05 MCU (Measurement and Control Unit).

2.1 MCU Measurement and Control Unit

STPSYS05's MCU performs three tasks. Firstly, it performs measurements and collects data, secondly it processes that data and finally it provides a user interface:

- The MCU powers STP05's heater and measures the heater voltage, the heater current, the thermopile voltage and the thermistor resistance.
- Based on these measurements, the MCU computes and displays data such as the temperature difference, the heater's linear dissipation density and the temperature of the sensor. After a measurement has been completed, STPSYS05's MCU computes the thermal properties of the specimen such as the thermal conductivity and the thermal diffusivity estimate.
- STPSYS05's MCU provides a user interface. STPSYS05 acts as webserver. It can be connected to ethernet or USB. A graphical user interface is available via a web browser. The user interface provides a convenient way to start and monitor measurements and to view results. It also allows users to enter the sensor parameters required for the correct data processing into the software. Finally, it provides a way to retrieve data from the MCU.

STPSYS05's MCU has multiple drives: the CPU drive and the CRD drive. The CPU drive is used to store the software. The CRD drive is used to store the web interface and the measurement data.

Figure 2.1.1 *STPSYS05's Measurement and Control Unit*

2.2 STP05 sensor

STP05 is a device for measuring the thermal conductivity of specimens at the interface, making it a non-invasive method. In addition to measuring the thermal conductivity, the device can also be used to estimate the thermal diffusivity.

Figure 2.2.1: *STP05 with a schematic view of the cylindric thermal field (isotherms). STP05 is conveniently placed at the surface of the specimen, and the heat from STP05's line-source penetrates several millimetres into the material; the measurement is representative for this entire volume.*

2.2.1 General theory

STP05 consists of a linear heat source (constantan heater wire), a temperature difference sensor (thermopile) and a temperature sensor (thermistor), see Figure 2.2.1.1. When a voltage is applied across the heater wire, a temperature gradient is created around the heater wire that extends into both the specimen and the sensor backing material.
By making a four-terminal measurement of the heater current I_{heater} and the heater voltage U_{heater} one can accurately determine the dissipated power per unit length L of the heater wire, the so-called linear dissipation density:

$$\dot{Q} = \frac{U_{\mathrm{heater}} \times I_{\mathrm{heater}}}{L}$$

A thermopile with hot joints close to the heater and cold joints further away from the heater is used to sample the resulting temperature profile. The temperature difference ΔT between the hot joints and the cold joints of the thermopile generates a voltage $U_{\mathrm{t.p.}}$ across the thermopile leads that is proportional to this temperature difference:

$$\Delta T = \frac{U_{\text{t.p.}}}{2\pi S} log\left(\frac{y_2}{y_1}\right)$$

Here y_1 is the distance from the hot joint of the thermopile to the heater, y_2 is the distance from the cold joint to the heater (see figure 2.2.1.1) and S is the sensitivity of the sensor (to the thermal conductivity, see below).

The thermopile is not sensitive to temperature gradients perpendicular to the interface. This makes measurements of the thermal properties of a specimen less sensitive to temperature differences between the sensor and the specimen. Furthermore, since the thermopile is located symmetrically on either side of the heater measurements are less sensitive to linear temperature gradients along the surface. These aspects of the sensor reduce the required stabilisation times and allow users to start measurements more quickly.

The temperature difference depends on the thermal properties of the specimen, the thermal properties of the sensor and the dissipated power per unit length in the heater wire, the so-called linear dissipation density. If the linear dissipation density and thermal properties of the sensor are known, the thermal properties of the specimen can be deduced from the thermopile signal. Section 2.2.2 and 2.2.3 describe how the thermal conductivity and thermal diffusivity estimate are computed.

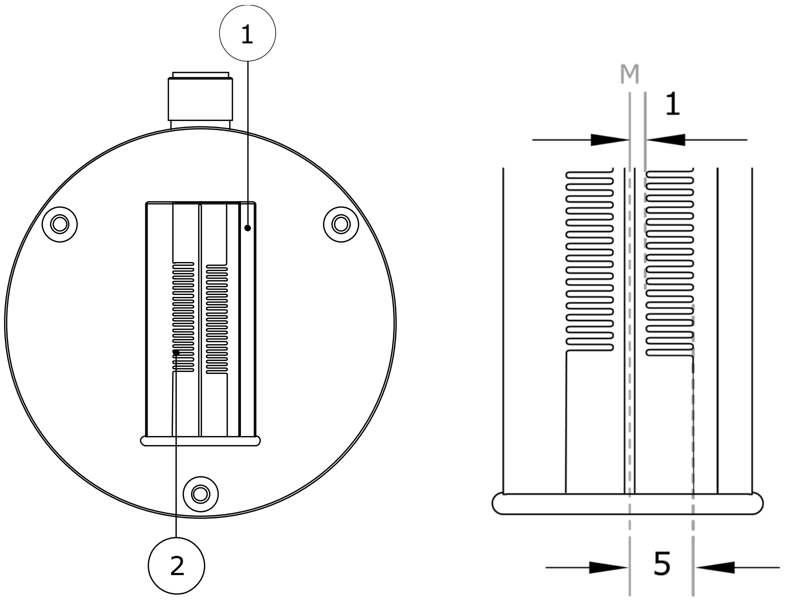

Figure 2.2.1.1: *Left: schematic of the sensitive surface (bottom) of the STP05 indicating the heater (1) and the thermopile (2). Right: zoom-in on the heater and the thermopile indicating the distance y_1 from the centre of the heater to the hot joint of the thermopile and the distance y_2 from the centre of the heater to the cold joint of the thermopile*.

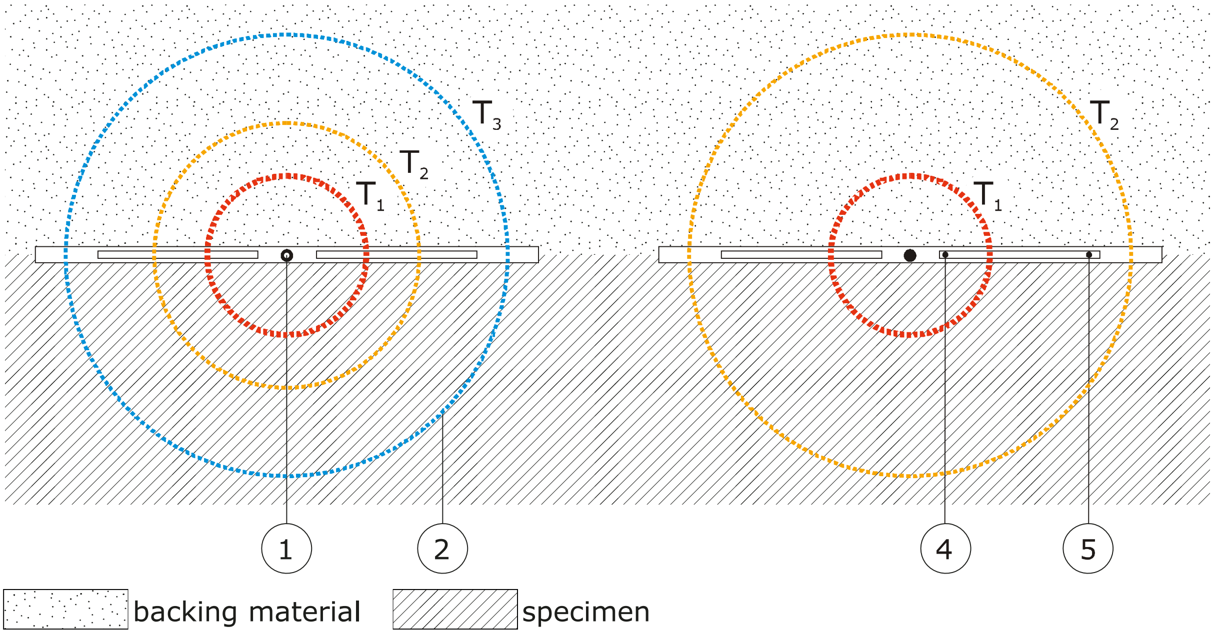

Figure 2.2.1.2: *Cross-sectional view showing the specimen and the sensor backing material. Heat dissipated by the heater (1) diffuses into the specimen and the sensor backing material. In the steady-state a cylindrical temperature distribution occurs as illustrated by the isotherms (2) with temperatures $T_1 > T_2 > T_3$. For specimen with a high thermal conductivity (left) the temperature gradient is steeper and the temperature difference between the hot joint (4) and the cold joint (5) of the thermopile is larger as compared to a specimen with a lower thermal conductivity (right).*

2.2.2 Thermal conductivity calculation

When the heater is switched on, the temperature difference between the hot and cold joints of the thermopile will start increasing. After a while a steady-state will be reached in which the temperature difference does not change any more over time. The thermal conductivity is calculated based on the steady-state thermopile output voltage. At the end of a measurement, STPSYS05's MCU will estimate this steady-state thermopile voltage by taking the average value of the last few data points. It is therefore important that the measurement time is long enough to reach the steady-state. The model used to calculate the thermal conductivity considers thermal resistances in series and parallel to the specimen. The parallel thermal resistance accounts for heat flows through the sensor. The serial thermal resistance accounts for the thermal resistances between the heater and the specimen and between the thermopile and the specimen. The thermal conductivity is given by:

$$\lambda = \frac{R_{\mathrm{par}}\left(\frac{2 \cdot S \cdot \dot{Q}}{U_{\mathrm{t.p.}}}\right) - 1}{R_{\mathrm{par}} - R_{\mathrm{ser}}\left[R_{\mathrm{par}}\left(\frac{2 \cdot S \cdot \dot{Q}}{U_{\mathrm{t.p.}}}\right) - 1\right]}$$

The sensitivity S (in mV/K), parallel thermal resistance $\mathrm{R}_{\mathrm{par}}$ (in m·K/W) and serial thermal resistance R_{ser} (in m·K/W) can be found on the calibration certificate delivered with the

STP05. STPSYS05's MCU will automatically calculate the thermal conductivity once a full measurement cycle is complete. More details can be found in the Appendix.

2.2.3 Thermal diffusivity estimate

The moment the heater is switched on heat starts to diffuse from the heater wire into the two half-planes surrounding the heater, the sensor backing material and the specimen. The time it takes for the heat to spread depends on thermal properties of both the sensor backing material and the specimen. If the thermal conductivity of the specimen, the thermal conductivity of the backing material and the thermal diffusivity of the backing material are known, it is possible to get an estimate for the thermal diffusivity of the specimen. Such an estimate is based on the time response of the thermopile voltage to a step response of the heater power.
In the last 10 % of increase of the thermopile voltage towards its steady-state value, the time response is well described by a function of the form:

$$f(t) = p_0 + p_1 \cdot t^{-1}$$

p_0 is the steady-state value of the thermopile output voltage, p_1 is the coefficient of the leading term in the Puiseux series for long times t. At the end of a measurement the STPSYS05 determines the parameters p_0 and p_1 (in mV and mV·s, respectively). Based on these parameters, an estimate of the effective thermal diffusivity of the sensor and the specimen combined can be obtained:

$$\alpha_{\mathrm{eff}} = \frac{\lambda + \lambda_{\mathrm{b}}}{\left(\frac{\lambda}{\alpha}\right) + \left(\frac{\lambda_{\mathrm{b}}}{\alpha_{\mathrm{b}}}\right)} = \frac{y_1^2 - y_2^2}{8 \cdot log(y_2/y_1)} \left(\frac{p_0}{p_1}\right)$$

where y_1 and y_2 are the locations of the hot and cold joint of the thermopile respectively, α_{b} and λ_{b} describe the effective thermal diffusivity and conductivity of the sensor itself and α and λ are the estimated thermal diffusivity and thermal conductivity of the specimen. From the above equation it follows that the thermal diffusivity estimate for the specimen is given by:

$$\alpha = \frac{\lambda}{\frac{\lambda + \lambda_{\mathrm{b}}}{\alpha_{\mathrm{eff}}} - \frac{\lambda_{\mathrm{b}}}{\alpha_{\mathrm{b}}}}$$

The parameters α_{b} and λ_{b} can be found on the calibration certificate delivered with STP05. At the end of a measurement, STPSYS05's MCU automatically computes and displays the thermal diffusivity. More details about the thermal diffusivity estimate can be found in the Appendix.

2.2.4 Temperature measurement

STP05 is equipped with a thermistor to measure the sensor temperature. The temperature (in degree Celsius) can be determined from the electrical resistance of the thermistor:

$$T = \frac{298.15\ \mathrm{K}}{1 + \left(\frac{298.15\ \mathrm{K}}{\beta_{25/85}}\right) log\left(\frac{R}{R_{25}}\right)} - 273.15\ \mathrm{K}$$

The temperature sensor is located inside STP05, i.e. not at the interface between STP05 and the specimen. It is to be used as an indication of the temperature only. The thermistor resistance at 25 °C (R_{25}) and the thermistor beta factor ($\beta_{25/85}$) can be found on the product certificate.

3 Specifications

STPSYS05 is a measuring system for measuring thermal properties of specimens.

Table 3.1 *Specifications of STPSYS05 (continued on next page)*

STPSYS05 SPECIFICATIONS	
Description	surface thermal properties measurement system
Measurand	thermal conductivity
Measurand in base SI units	thermal conductivity in W/(m·K)
Rated measurement range	0.1 to 15 W/(m·K)
Typical repeatability[1] at 0.2 W/(m·K)	0.005 W/(m·K)
Typical repeatability[1] at 1.0 W/(m·K)	0.005 W/(m·K)
Typical repeatability[1] at 15 W/(m·K)	0.15 W/(m·K)
Estimated limit on systematic measurement error at 0.2 W/(m·K)	± 0.04 W/(m·K)
Estimated limit on systematic measurement error at 1.0 W/(m·K)	± 0.1 W/(m·K)
Estimated limit on systematic measurement error at 15.0 W/(m·K)	± 1.5 W/(m·K)
Measurand	sensor temperature
Measurand in base SI units	sensor temperature in °C
Rated measurement range	-20 to +80 °C
Optional measurand	thermal diffusivity estimate
Optional measurand in base SI units	thermal diffusivity estimate in m^2/s
Rated measurement range	$(0.05$ to $1.0) \times 10^{-6}$ m^2/s
Limiting thermal conductivity range	0.1 to 2.0 W/(m·K)
Specimen requirements	
Minimum recommended specimen thickness	25×10^{-3} m
Minimum required specimen area	75×10^{-3} m diameter disc
Measurement surface requirements	flat (surface should not be curved) smooth (surface should not be rough)
Included cables	sensor cable (1.5 m) USB cable (2 m)
Gross weight STPSYS05 system including carrying case and packaging	approx. 9 kg
Net weight STPSYS05 system including carrying case	approx. 5 kg
Carrying case STPSYS05 system	case of (480 x 385 x 190) mm
Storage and transport	
Limiting storage and transport temperature	-20 to +70 °C
Storage	sensor and MCU should be stored in a dry place. sensor should be stored with protective cap in place. MCU should be stored with the dedicated dust caps placed on connectors
STP05 SENSOR SPECIFICATIONS	
Connector type on sensor	male, 8 pin, circular M12-A connector
Maximum sensor cable length	3.0 m
IP rating sensor	IP67
Rated operating temperature	-20 to +80 °C
Temperature difference sensor	thermopile

Table 3.1 *Specifications of STPSYS05 (started on previous pages)*

STP05 SENSOR SPECIFICATIONS (CONTINUED)	
Thermopile hot joint location (distance from centre of heater)	0.001 m
Thermopile cold joint location (distance from centre of heater)	0.005 m
Typical thermopile electrical resistance	30 Ω
Nominal sensitivity	0.200 mV/K
Temperature dependence sensitivity	< 1 %/°C
Nominal parallel thermal resistance	1.90 m·K/W
Nominal serial thermal resistance	0.022 m·K/W
Heater length	0.06 m
Nominal heater electrical resistance	15 Ω
Maximum heater voltage	2 V
Temperature sensor	thermistor
Thermistor electrical resistance at 25 °C	10 kΩ ± 1 %
Thermistor beta factor β[25/85]	3570 K ± 3 %
Weight and packaging	
Gross weight STP05 sensor (if ordered as sensor only)	approx. 1 kg
Net weight STP05 sensor (including protective cap)	approx. 0.5 kg
Net weight STP05 sensor (without protective cap)	approx. 0.5 kg
STPSYS05 MCU SPECIFICATIONS	
Operating voltage	10 to 16 VDC
Recommended operating voltage	12 VDC
Typical current	20 to 200 × 10^{-3} A
Max. current	1 A
ON/OFF switch and Power ON LED	red Power ON LED is on when power is supplied to MCU
Sample rate	10 Hz
Data tables	RawData Results
Net weight MCU	3.95 kg
IP rating MCU	IP54
MCU Datalogger	Campbell Scientific CR1000X Measurement and Control Datalogger
Datalogger specifications	see CR1000X manual and specification sheet available from https://www.campbellsci.com/cr1000x
Internal system battery	AA, 2.4 A·hr, 3.6 VDC (Tadiran, TL-5903/S) for battery-backed memory and clock only
Internal memory card	ATP, 8 GB MicroSDHC Card Class 10, UHS-1 U1, SLC
User interface	
Connection	via LAN or "Ethernet over USB"
MCU user interface	web page via a web browser
Web browser requirements	HTML 5 support
Supported web browsers	Chrome 10 Firefox 4 Internet Explorer 9 Opera 11 Safari 5 (and later)
12 VDC connector	
Connector type on MCU	male, 2 pin, Bulgin Standard Buccaneer® connector

Table 3.1 *Specifications of STPSYS05 (started on previous pages)*

STPSYS05 MCU SPECIFICATIONS (CONTINUED)	
Sensor connector	
Connector type on MCU	female, 8 pin, circular M12-A connector
Thermal fuse current limit	1800 mA
Purpose	connecting STPSYS05 MCU to STP05 sensor
USB connector	
Connector type on MCU	female USB-B
Maximum USB cable length	5.0 m
Ethernet connector	
Connector type on MCU	RJ45 (shielded)
Isolation/protection	magnetic isolation TVS surge protection
Recommended ethernet cable type	STP
Maximum ethernet cable length	30 m
Trigger input connector	
Connector type on MCU	female BNC connector
Input impedance	5 kΩ
Pull-up resistance	100 kΩ to 5 V
Max. input voltage	10 V
Protection	TVS surge protection
Minimum trigger pulse width	5 ms
RS232 connector	
Connector type on MCU	female DB9 connector
CS I/O connector	
Connector type on MCU	female DB9 connector
Purpose	for connecting STPSYS05 MCU to optional Campbell Scientific CR1000KD Keyboard/Display (not included with STPSYS05)
POWER SUPPLY SPECIFICATIONS	
Power supply type	Friwo, FOX30-X, 12V/2500mA, FW8030/12, 1898155
Input voltage	100 – 240 VAC
Frequency	50 Hz / 60 Hz
Input plug type	AUS, EU, GBR, USA
Output voltage	12 VDC
Output current	2500×10^{-3} A
Output cable length	approx. 1750×10^{-3} m
Output connector type	female, 2 pin, Bulgin Standard Buccaneer® connector
SENSOR CABLE SPECIFICATIONS	
Sensor cable type	8 × 24 AWG, shielded, PUR outer sheat
Sensor cable diameter	$(5.9 \pm 0.2) \times 10^{-3}$ m
Sensor cable conductor cross-sectional area	0.25×10^{-6} m (24 AWG)
Sensor cable length	1.5 m
Temperature rating	-25 to +80 °C
IP rating	IP65, IP67
Connector 1	female, 8 pin, circular M12-A connector
Connector 2	male, 8 pin, circular M12-A connector or free cable end
Cable for connecting to STPSYS05 MCU	Phoenix Contact SAC-8P-M12MS/ 1,5-PUR/M12FS SH 1522985 (included with STPSYS05)

Table 3.1 *Specifications of STPSYS05 (started on previous pages)*

SENSOR CABLE SPECIFICATIONS (CONTINUED)	
Cable for connecting to custom equipment	Phoenix Contact SAC-8P- 1,5-PUR/M12FS SH 1522862 (not included with STPSYS05, optional if ordered as sensor only)
REFERENCE SPECIMEN	
Material	Casted polymethylmetacrylate (PMMA)
Thickness	25×10^{-3} m
Diameter	75×10^{-3} m
Weight	0.131 kg
Reference thermal conductivity	0.189 W/(m·K) at 20 °C
Uncertainty	± 0.035 W/(m·K)

[1] Repeatability at room temperature. Here repeatability is defined as the standard deviation of a set of measurements performed by the same person at the same location, done under similar conditions, on the same specimen using the same STP05 sensor. The person must be a skilled operator familiar with the measurement instructions in chapter 5.

3.1 Dimensions of STPSYS05

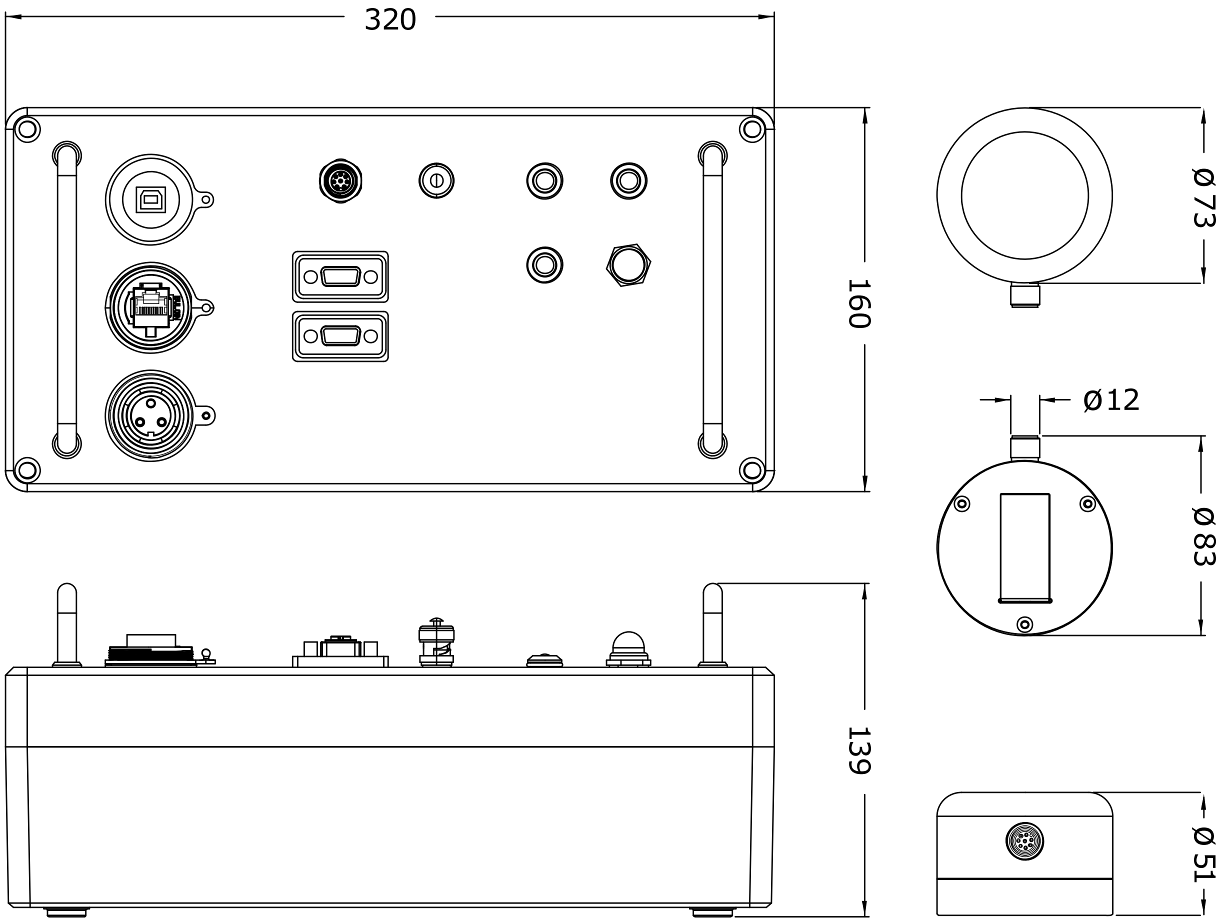

Figure 3.1.1 *Dimensions of STPSYS05 in x 10^{-3} m*

4 Installation, connection and calibration

This chapter describes how to set up STPSYS05 and to prepare the system for measurements. Before starting, it is recommended to check if all components are present. Preparation of the system consists of three steps:

1. hardware installation,
2. setting up a connection to STPSYS05 MCU,
3. and finally entering the STP05 parameters into the software and calibrating STP05.

4.1 Hardware installation

Needed for installation:

- power supply
- STPSYS05 MCU
- STP05 sensor
- sensor cable
- PC with free USB port or Local Area Network (LAN) port
- USB or ethernet cable

There are two options to connect the STPSYS05 MCU: either connect the STPSYS05 MCU directly to a PC or connect the STPSYS05 MCU to a Local Area Network (LAN). To connect to a PC, connect the 'USB' port on the MCU to a USB port on the PC using a UBS A to USB B cable. To use any PC in a LAN, connect the MCU to the LAN using an ethernet cable. Plug this cable into the 'Ethernet' connector on the MCU and into the appropriate connector on a switch, router or modem in the LAN. When connecting STPSYS05 MCU the cable requirements in the specifications chapter must be observed.

Connect STPSYS05 MCU to the power supply using the accompanying power adapter. Plug the adapter into your power outlet and connect to the '12VDC' connector on the MCU.

Finally, connect the STP05 sensor to the MCU using the M12-A connector labelled 'Sensor'.

Make sure to screw all the cable connectors tightly.

Turn the system ON by pressing the 'Power' button on the MCU. The 'Power ON' LED should light up. You are now ready to connect to the system. Following the instructions in section 4.2, you should now be able to access the interface and all data on the MCU.

⚠ To avoid ground loops do not connect the ethernet port and the USB port of the STPSYS05 MCU at the same time.

⚠ Do not use sensor cables longer than 3 metres.

4.2 Connecting to STPSYS05's MCU

STPSYS05 is operated using a web-based user interface, which is pre-loaded on the MCU. This section explains how to get access to the user interface via either a USB or ethernet connection. For more setup options, see the Appendix on advanced settings.

To connect to the MCU, there are two options: a direct ethernet connection or an ethernet over USB connection.

4.2.1 Direct Ethernet connection

To use this option, the MCU should be connected to your LAN with an Ethernet cable.

The system will be assigned an IP address automatically.

Open a web browser and enter http://STPSYS05 in the address bar. The web browser should now open the user interface.

If your network does not allow for systems to assign their own name, you need to manually enter the IP address of STPSYS05 MCU.

To find the IP address, you can use the Campbell Scientific LoggerLink app, available from https://www.campbellsci.com/loggerlink. In the LoggerLink app, you can search for STPSYS05 on your network using the search function under 'TCP settings'.

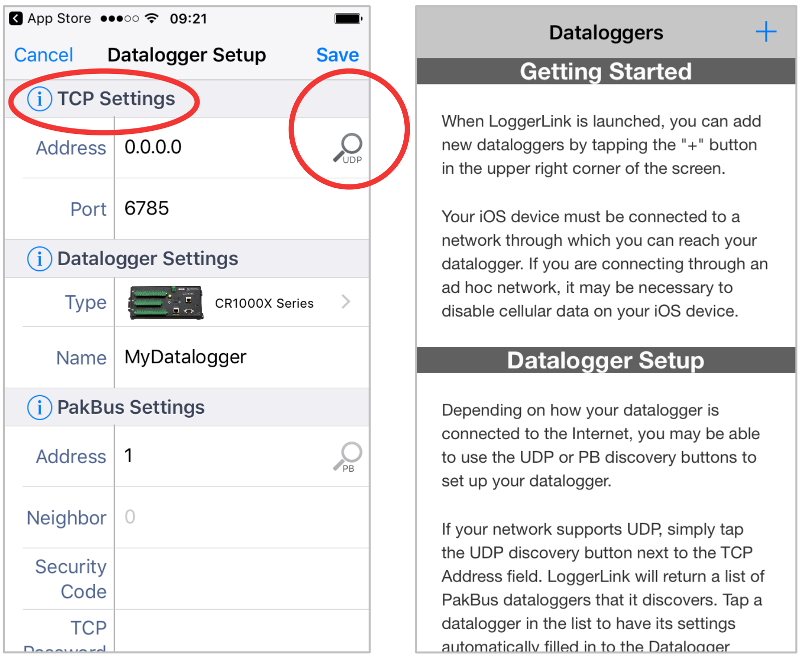

Figure 4.2.1.1 *Using the LoggerLink app to find STPSYS05's IP address*

Alternatively, you can find the IP address of STPSYS05 MCU using any IP scanner or the Device Configuration Utility from Campbell Scientific. More information on the Device Configuration Utility can be found in the Appendix.

Once a connection to the STPSYS05 MCU has been established, it is recommended to bookmark the URL in the web browser or to create shortcut on the desktop.

4.2.2 Ethernet over USB connection

To use this option, STPSYS05 MCU should be connected to a USB port on the PC. Use of the ethernet over USB connection requires the Microsoft RNDIS drivers to be installed. The drivers should install automatically upon connecting STPSYS05 MCU to the PC. Once this process is complete, open a web browser on the PC and enter the IP address for the USB port into your address bar. By default, the IP address is 192.168.66.1.

For easy access it is recommended to bookmark the IP address in the web browser or to create a shortcut on the desktop.

If the drivers are not automatically installed, install the USB drivers using the Campbell Scientific Device Configuration Utility, see the Appendix.

4.2.3 Logging into the STPSYS05 MCU

To make sure the STPSYS05 MCU can only be controlled by the authorised users on a shared network, first time use in a new browser or PC requires the correct credentials. A pop-up will appear asking you to enter your credentials. The credentials are:

Username: STPSYS05
Password: 4-digit serial number of the STPSYS05 MCU

4.2.4 Setting the clock

After successfully opening the interface, a final step is setting the clock on the MCU. To set the clock on the MCU there are two options.

4.2.4.1 Using the web interface (recommended):

In your web browser enter either: 'http://STPSYS05/utilities.html' or 'http://<IPADDRESS>/utilities.html' (where <IPADDRESS> must be replaced with the IP address), depending on your connection. Select either 'Sync with computer' or 'Set clock manually'. Click 'Set Station Clock'.

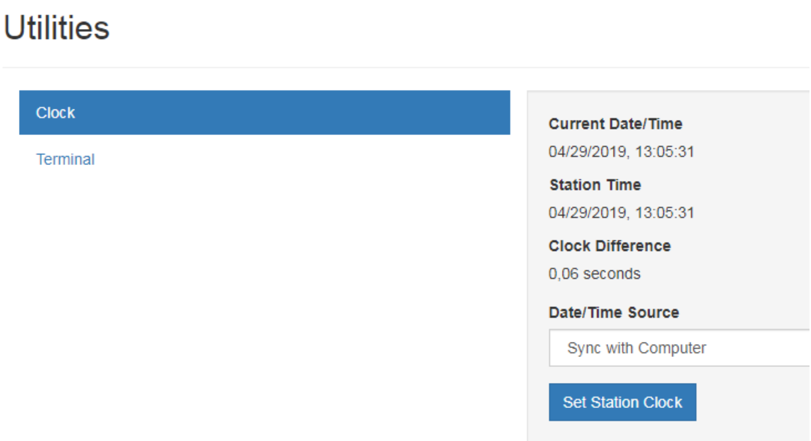

Figure 4.2.4.1.1 *Using the MCU utilities page to set the clock*

4.2.4.2 Using the Loggerlink App:

Alternatively you can set the clock using the Loggerlink App. When using the direct Ethernet connection, connect to the STPSYS05 MCU using the Campbell Scientific LoggerLink app. In the 'Status' menu, scroll down to the bottom and choose 'Set Clock'. You can choose to set the clock to the server time, or set a time manually.

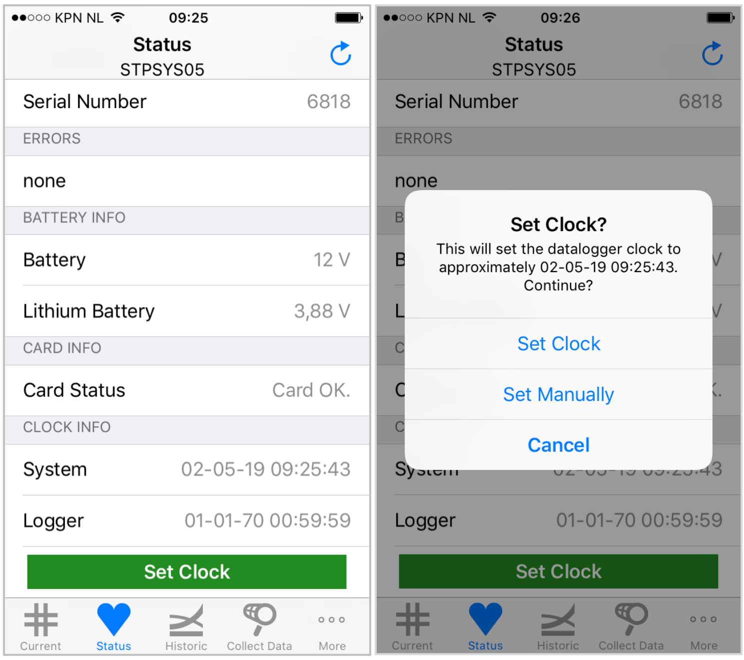

Figure 4.2.4.2.1 *Using the LoggerLink app when setting the STPSYS05 clock over Ethernet*

4.3 STP05 sensor parameters and calibration

4.3.1 The user interface

The user interface consists of 5 tabs. The 'Measurements' tab is used to start measurements and view measurement progress. The 'Results' tab displays current and previous measurement results. The 'Sensor properties' tab is used to enter sensor properties, control system settings and to start calibration measurements. The 'Browse Data' tab is used for data retrieval and the 'Datalogger status' tab is used to display datalogger functionality or errors. See Figure 4.3.1.1

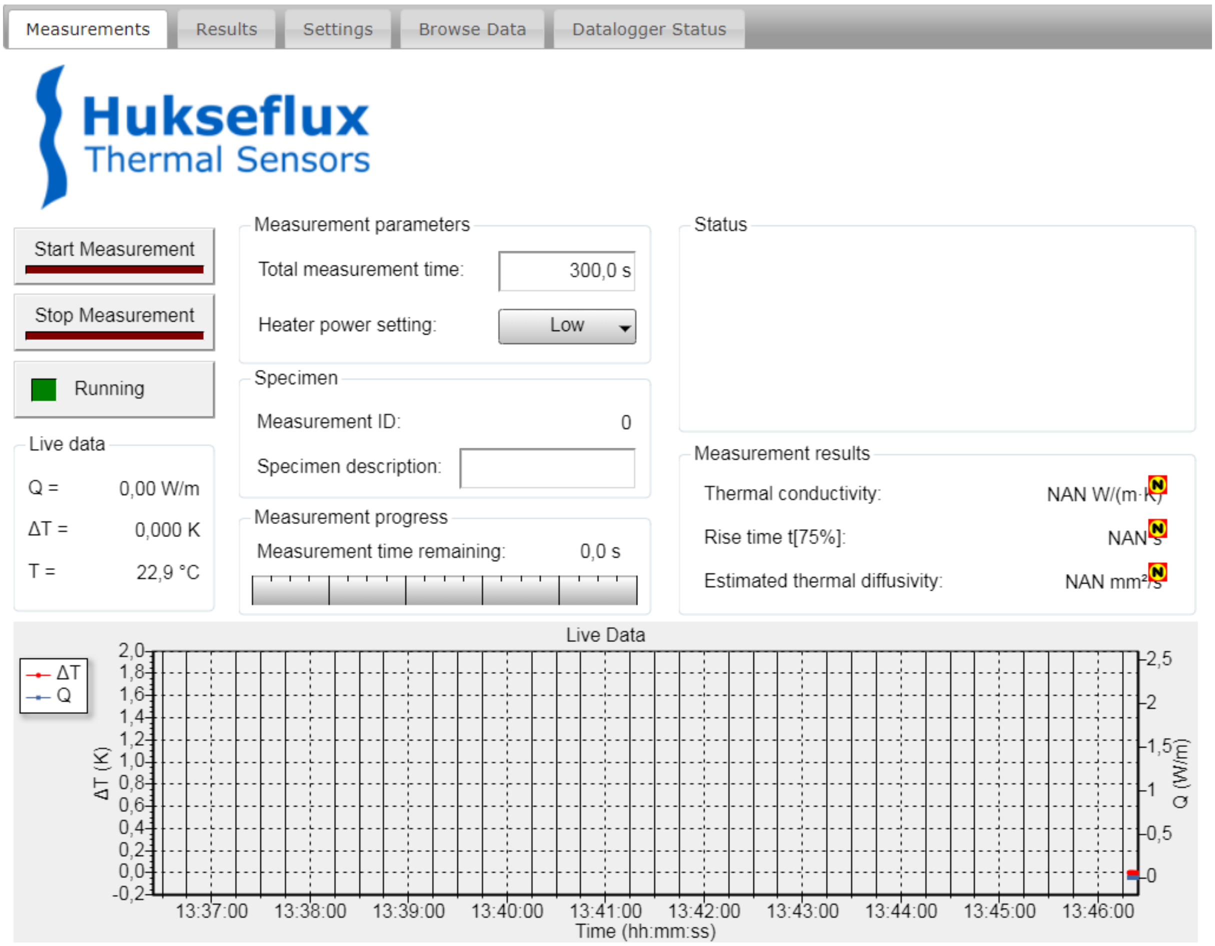

Figure 4.3.1.1 *The STPSYS05 user interface*

4.3.2 Entering STP05 sensor parameters in the software

Before using STP05 with STPSYS05 MCU, STP05 parameters must be entered into STPSYS05 MCU. Failure to do so will result in incorrect measurement results. Whenever a different or new STP05 is connected this procedure must be repeated. To enter the sensor parameters, select the ‘Settings’ tab in the interface. Adjust all ‘Sensor properties’ fields according to the values on the STP05 product certificate (see figure 4.3.2.1).

The sensor parameters in STPSYS05 MCU must be set such that they match the values on the STP05 product certificate. Failure to enter the correct sensor parameters into the STPSYS05 MCU can lead to invalid measurement results.

Sensor properties

Sensor serial number	1234
Hot joint location:	0,0010 m
Cold joint location:	0,0050 m
Heater length:	0,060 m
Sensitivity:	0,200 mV/K
Parallel thermal resistance:	1,800 m·K/W
Serial thermal resistance:	0,020 m·K/W
Thermistor resistance R[25°C]:	10,0 kΩ
Thermistor β[25°C/85°C]:	3.570 K
Backing material λ	0,00 W/(m·K)
Backing material α	0,00 mm²/s

Figure 4.3.2.1: *The "Sensor Properties" box in the "Settings" tab.*

To check if the parameters are correct and the system is functioning properly an initial calibration is necessary, see section 4.3.3.

4.3.3 Calibration

To calibrate the system, select the "Settings" tab in the web interface.

Enter the thermal conductivity value of the reference specimen supplied with the sensor into the "Thermal conductivity reference" field in the "Sensor calibration" box (see also chapter 3). Remove the protective cover from the STP05. Make sure the reference specimen and sensor are clean. Put a drop of glycerol (thermal contact fluid) on the specimen surface. Place the sensor on the reference specimen supplied with the sensor. Wait for the temperature difference to become smaller than 0.005 K and click the "Start Calibration" button in the "Sensor Calibration" box. This will start the calibration measurement. The LED's on the MCU below "Measurement Running" and "Heater ON" should now be on. Also, the "Calibrating" indicator as in figure 4.3.3.1 should now be on.

The progress and result of the calibration measurement can be monitored in the "Measurement" tab. Make sure that the sensor does not move during the calibration measurement. The calibration is successful if the measured thermal conductivity is within ±(15 % + 0.015 W/(m·K)) of the reference value. At the end of the measurement the calibration value will be displayed in the "Measurement Result" box and a message will be displayed in the "Status" box stating whether or not the calibration was successful.

If the calibration measurement is unsuccessful it is recommended to repeat the calibration measurement while making sure that:

- the sensor and specimen are clean,
- the temperature difference is close to zero at the start of the calibration,
- glycerol is being used as a thermal contact fluid,
- the sensor does not move during the measurement, and
- the STP05 sensor properties entered into the STPSYS05 MCU match those on the STP05 calibration certificate.

If the STPSYS05 MCU or system does not function properly, make sure that:

- the STPSYS05 MCU is connected to the power supply and switched on,
- the cable connected to the sensor is screwed on tightly

Follow the instructions in Chapters 4.1 and 4.2 again or read Troubleshooting in the Appendix.

If the calibration measurement remains unsuccessful, contact Hukseflux Thermal Sensors B.V. to send your sensor back for maintenance or recalibration.

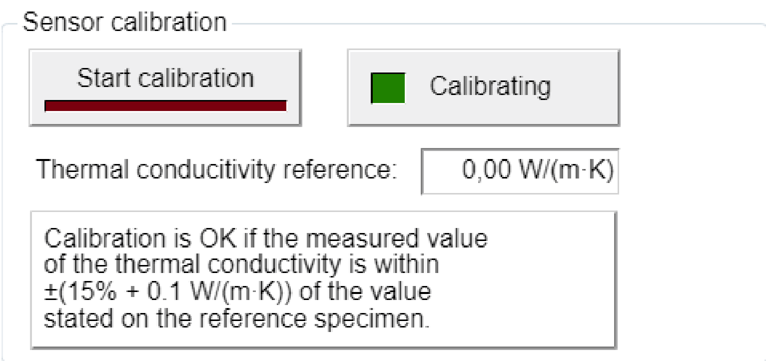

Figure 4.3.3.1: *The "Sensor calibration" box in the "Settings" tab*.

If the calibration is successful, the system is ready to perform measurements following the instructions in Chapter 5.

5 Making measurements

This chapter describes how to make reliable measurements. It assumes that the system has been properly installed and calibrated as described in Chapter 4. A good measurement requires an environment in which the system and sensor cannot be disturbed by movement or otherwise. Furthermore, it requires proper preparation of specimen and sensor, and time to check and interpret the results. It is advised to calibrate the system before every measurement campaign, when the system is altered or when a result is distrusted.

5.1 Before making a measurement

5.1.1 Checking sensor properties and calibration

Before starting a measurement make sure the sensor parameters entered into the STPYS05 MCU match those on the calibration certificate of the STP05 being used. If the parameters do not match, follow the instructions in section 4.3.2. It is recommended to recalibrate the system at the start of every measurement campaign. To do so, follow the instructions in section 4.3.3.

The sensor parameters in STPSYS05's MCU must be set such that they match the values on the STP05 product certificate. Failure to enter the correct sensor parameters into the STPSYS05 MCU can lead to invalid measurement results.

5.1.2 Preparing the measurement

Before making a measurement the specimen and sensor need to be prepared. Several steps may have to be taken to ensure that the specimen has a surface that is suitable for measurements with STP05 and to minimize thermal contact resistances between the specimen and STP05.

Before performing a measurement the following steps should be taken:

1. **Make sure the specimen has a smooth flat surface.** STP05 requires specimen to have a flat surface. STP05 is not suitable for use on curved surfaces. When preparing a specimen observe the minimum required specimen area and the minimum recommended specimen thickness as stated in Chapter 3. Make sure the specimen surface is smooth. If necessary polish the surface. Rough surfaces may lead to thermal contact resistances between the sensor and the specimen causing the thermal conductivity of the specimen to be underestimated.
2. **Remove the protective cover from the sensor.** STP05 comes with a protective cover to protect the sensitive surface whenever the sensor is not in use. This cap must be removed before making a measurement.
3. **Clean the specimen and sensor.** Make sure there are no finger prints, hairs, dirt or dust on either the specimen or the sensor. Any such pollution can increase thermal

contact resistances between the specimen and the sensor and can cause the thermal conductivity of the specimen to be underestimated.

4. **Place a drop of glycerol on the specimen surface**, see figure 5.1.1. Glycerol is used as a thermal contact liquid. Failure to use glycerol may lead to bad thermal contact between the sensor and the specimen, causing the thermal conductivity of the specimen to be underestimated.
5. **Place the sensor on the specimen.** Gently push the sensor down onto the specimen. Make sure the cable does not pull the sensor. If too much glycerol has been used the sensor will have a tendency start sliding, in that case reduce the amount of glycerol on the specimen. During the measurement the sensor should not move, as this would cause the thermal conductivity of the specimen to be overestimated.

Figure 5.1.2.1: *Place a drop of glycerol on the surface of the specimen in order to ensure optimal thermal contact between the specimen and the sensor.*

Do not slide the STP05 over rough surfaces, as this may damage the sensor foil containing the heater and thermopile.

5.2 Measuring thermal conductivity and diffusivity

After proper preparation of the specimen and sensor, a measurement can be started from the web interface.

1. **Set the specimen description, measurement time and heater power.** Select the "Measurements" tab in the web interface. In the "Measurement parameters" box, set the "Total measurement time" and "Heater setting" parameters.

   Specimen with a low thermal conductivity such as plastics typically require a lower heater setting and longer measurement times (e.g. "Low" and 300 s), whereas specimen with a higher thermal conductivity such as alloys and ceramics will require a higher heater setting and shorter measurement times (e.g. "High" and 150 s). Enter the "Specimen description" in the "Specimen" box. It is recommended to write down the specimen description and measurement ID in a lab journal.

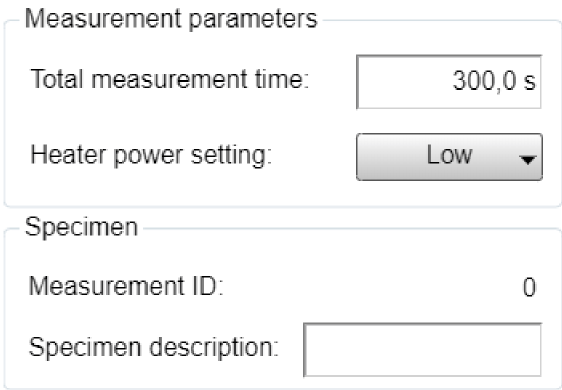

Figure 5.2.1: *The "Measurement parameters" and "Specimen" boxes in the "Measurements" tab.*

2. **Wait** for the temperature difference to become sufficiently small, <0.005 K, before starting a measurement. If this is not small, the estimate of the thermal diffusivity will be less accurate.
3. **Start the measurement.** In the "Measurements" tab click the "Start measurement" button. The "Measurement Running" indicator should light up as well as the Measurement Running and Heater On LED on the MCU itself. If the measurement does not start check the "Status" box for error messages.
4. **Results.** At the end of the measurement the system will calculate the thermal conductivity, characteristic rise time and estimate the thermal diffusivity. These will show in the "Measurement results" box. More extensive information on the result can be found in the "Results" tab.
5. **Checking the results.** Make sure that the result matches your expectation, a table with some common values can be found in the Appendix. Visually check if measurement looks good, examples are provided in Chapter 5.4. If unsure about the quality of the measurement, prepare again and repeat the measurement. If necessary change the settings.

A measurement can be stopped at any time by clicking the "Stop measurements" button. It can also be started by using the trigger input, for more information see the Appendix.

Make sure the sensor does not move during a measurement. Movement of the sensor during a measurement will cause the thermal conductivity to be underestimated.

When all measurements with an STP05 sensor have been completed, it is recommended to clean the sensor and remount the protective cover. The STP05 sensor can be cleaned with a soft tissue and/or washed with lukewarm water.

Avoid touching the sensor during a measurement as this may reduce thermal stability and/or may cause movement of the sensor, which can result in a reduced measurement accuracy.

5.3 Measurement results and data retrieval

Measurement data of STPSYS05 is stored in several data tables: the results table, the raw data table, the status table, the data table info table and the public table.

An overview of the measurement results can be found in the "Results" tab of the interface. The controls at the bottom can be used to navigate the data. To retrieve data from STPSYS05, select the "Browse data" tab in the user interface. A screen will show like figure 5.3.1.

The measurement results are stored in the "Results" table and the raw measurement data is stored in the "RawData" table. The table headers are presented in table 5.3.1 To view the last record of a table, click on the table name. To retrieve data, click "custom" next to the table name. This will open a custom data query window. There are several options for the data format and data query mode, see Table 5.3.1. For further analysis, choosing a TOA5 data format is usually most convenient.

Apart from the "Results" and "RawData" table, the data browser shows the "Status", "DataTableInfo" and "Public" tables. The "Status" table gives an overview of the status of the datalogger inside the STPSYS05 MCU. The "Public" table contains an overview of current values of variables kept in memory by the STPSYS05 MCU. The "DataTableInfo" table gives information about the data tables.

The raw data file can become very large. For retrieval of this data, any other format than TOA5 is discouraged.

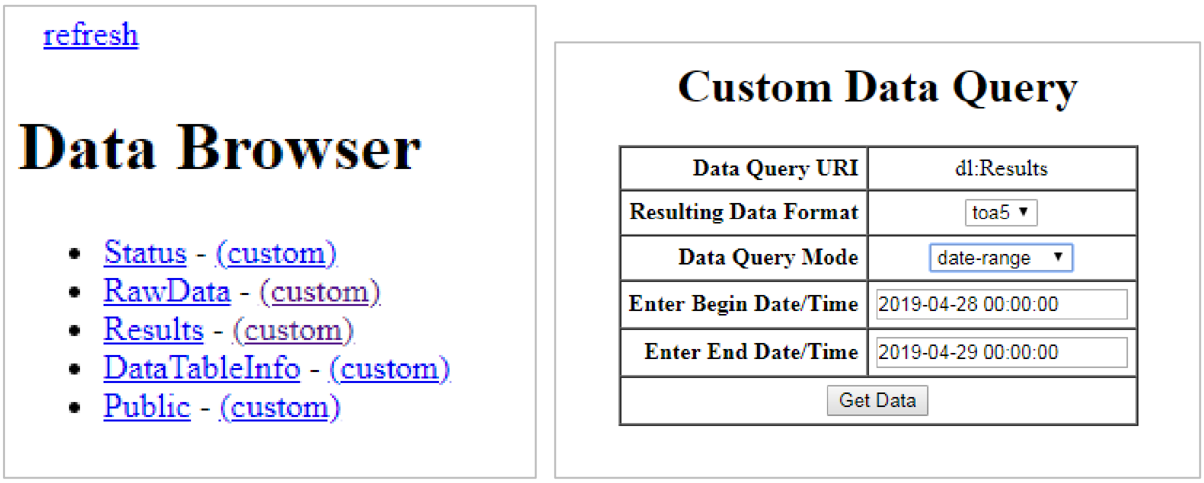

Figure 5.3.1 *Clicking 'custom' in the Data Browser allows for a custom data query. The image on the right depicts an example of data retrieval from the STPSYS05.These settings will download a comma separated file with data from one specific day.*

Table 5.3.1 *data retrieval definition and settings (continued on next page)*

Measurement results table definition (column headers)	TimeStamp: MCU timestamp Record: MCU record number MeasurementNumber: ID for measurement cycles, matches the MeasurementNumber in the "RawData" table for a corresponding measurement cylce SpecimenDescription TotalMeasurementTime: Setting for total measurement time in [s]. ThermalConductivity: Value of thermal conductivity in [W/(m·K)]. t75: Time for temperature difference to reach 75% of its steady-state value in [s] ThermalDiffusivityEstimate: Estimated value of thermal diffusivity in [mm^2/s] Final_dT: temperature difference between thermopile junctions at the end of the measurement in [K] Final_Qheater: power generated by heater at the end of the measurement in [W] Final_Uthermopile: Final (steady state) voltage measured by thermopile in [mV] Final_Temperature: Final temperature of sensor in [K] Coefficient0: p_0, first fit parameter for thermal diffusivity, the average offset in [mV] Coefficient1: p_1, second fit parameter for thermal diffusivity, the average slope in [mV·S] FirstRecord: first record number in RawData table LastRecord: last record number in RawData table SensorSerialNumber Sensitivity: sensitivity used for calculation in [mV/K] ParallelThermalResistance in [(m·K)/W] SerialThermalResistance in [(m·K)/W] HeaterLength in [m] ColdJointLocation in [m] HotJointLocation in [m]
Raw data table definition (column headers)	TimeStamp: MCU timestamp Record: MCU record number MeasurementNumber: ID for measurement cycles, matches the MeasurementNumber in the "Results" table for a corresponding measurement cylce SpecimenDescription Time: time of sample in measurement Uheater: Heater voltage in [mV] Iheater: Heater current [mA] Uthermopile: Voltage of sensor thermopile in [mV] Qheater: Power dissipated by heater in [W] dT: temperature difference between thermopile hot and cold joints in [K] Temperature: temperature of sensor in [°C]
Resulting data format options	html (hypertext markup language) json (java script object notation) toa5 (table output ascii version 5) tob1 (table out binary version 1) xml (extensible markup language)

Table 5.3.1 *data retrieval definition and settings (continued)*

Data query mode options	most-recent (most recent number of records) since-time (all data since a certain time) since-record (all data since a certain record number) data-range (all data within a certain time interval) backfill (most recent amount of seconds)

5.4 Measurement examples and pitfalls

The evaluation and interpretation of measurement results requires some basic understanding of the theory of the sensor. It is recommended to read Chapter 2. Although using the STP05 sensor is easy there are few pitfalls to watch out for. This section discusses some of the pitfalls of thermal properties measurements and how to recognize them. Many mistakes can be recognized by keeping an eye on the time trace of the temperature difference during a measurement. Time traces for correctly and incorrectly excuted measurements are shown below.

5.4.1 Example: correct measurement of Pyrex

Figure 5.4.1.1 shows a time trace of temperature difference and the linear dissipation density from a correctly excuted measurement of the thermal conductivity and diffusivity of a slab of Pyrex. The measurement is executed at low power for 300 seconds. Before the measurement starts the temperature difference is close to zero. At the start of the measurement the heater is switched on. The linear dissipation density shows a step response (blue line, right axis). The temperature difference due to this heating (red line, left axis) follows a smooth monotonically increasing curve. Initially the temperature difference increases fast, then the temperature increase slows down and eventually a steady-state is reached where the temperature difference does not change anymore. After the measurement has been completed the heater is switched of and the temperature difference gradually decreases back to zero.

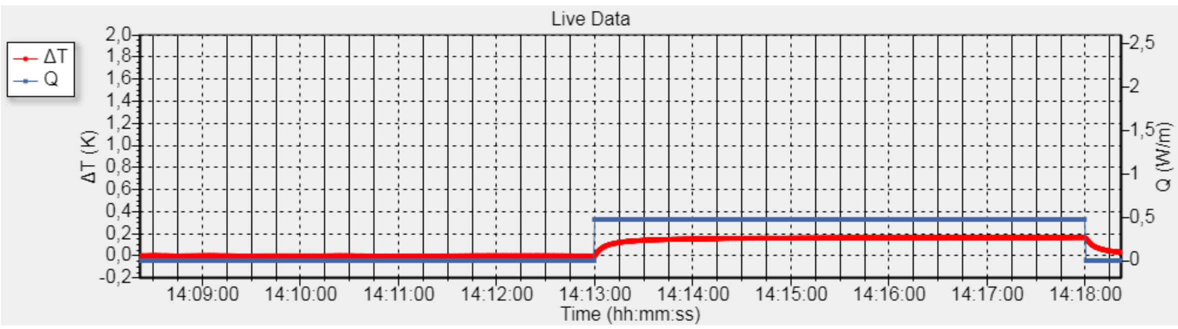

Figure 5.4.1.1 *An exemplary measurement of Pyrex. The measurement time is 300s on low power. The blue line shows the sensor's heater. The red smooth curve the thermopile temperature difference.*

5.4.2 Pitfall: movement of sensor

During a measurement the sensor should not move. Movement of the sensor can cause a sudden drop in the temperature difference. This will render the thermal diffusivity estimate measurement of the specimen invalid. In addition it may lead to an overestimate of the thermal conductivity of the specimen.

Figure 5.4.2.1 shows a time trace of the temperature difference and the linear dissipation density from a measurement on a slab of pyrex, similar to figure 5.4.1.1, however in this measurement the sensor moved during the measurement. Notice how the temperature difference curve (red, left axis) is not monotonically increasing, but instead shows sudden drops in the temperature difference.

Before the measurement make sure the sensor cable is not pulling the sensor. Avoid touching or moving the sensor during a measurement.

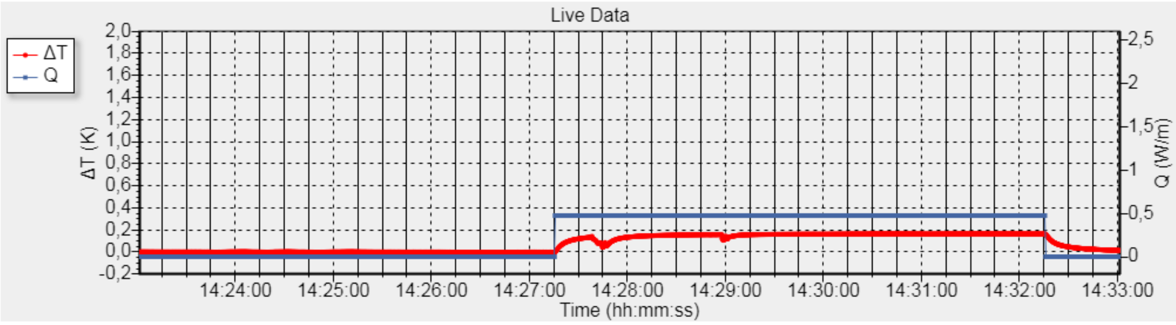

Figure 5.4.2.1 *An erroneous measurement of Pyrex: the sensor moved during the measurement. The measurement time is 300 s on low power. The blue line shows the sensor's heater. The red curve the thermopile temperature difference.*

5.4.3 Pitfall: total measurement time too small

The total measurement time should be large enough for the temperature difference to reach a steady-state. If the temperature difference is still increasing significantly at the end of a measurement the thermal conductivity of the specimen will be overestimated and the thermal diffusivity measurement will be invalid.

Figure 5.4.3.1 shows time traces of the temperature difference and the linear dissipation density of a measurement for which the total measurement time was chosen to be too short. Notice how the temperature difference is still increasing at the end of the measurement.

If the temperature difference does not reach a steady-state, increase the total measurement time and repeat the measurement. In general specimen with a lower thermal diffusivity require more time for the temperature difference to reach the steady-state.

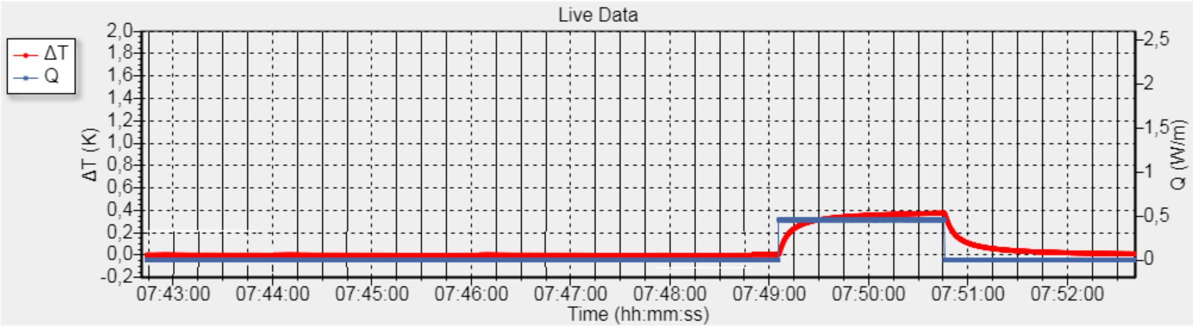

Figure 5.4.3.1 *An erroneous measurement of a material with a low thermal conductivity: the total measurement time was too short. The measurement time is 100 s on low power. The blue line shows the sensor's heater. The red curve the thermopile temperature difference.*

5.4.4 Pitfall: heater power too low or thermal conductivity too high

An accurate measurement requires a thermopile signal that is sufficiently large and not noisy.

Figure 5.4.4.1 shows a measurement of a stainless steel specimen measured for 100 seconds using low power settings. While the measurement time is sufficient, the temperature difference is very small (< 0.1 K). This may result in additional uncertainty in the measured thermal conductivity.

If the temperature difference signal is small or noisy increase the linear dissipation density by setting the heater setting to high and check if the thermal conductivity of the specimen falls within the rated measurement range for the thermal conductivity and the limiting thermal conductivity range for the thermal diffusivity measurement, see chapter 3. If the thermal conductivity falls within the former range, but not within the latter range the thermal conductivity measurement will be accurate, but the thermal diffusivity estimate will not be accurate.

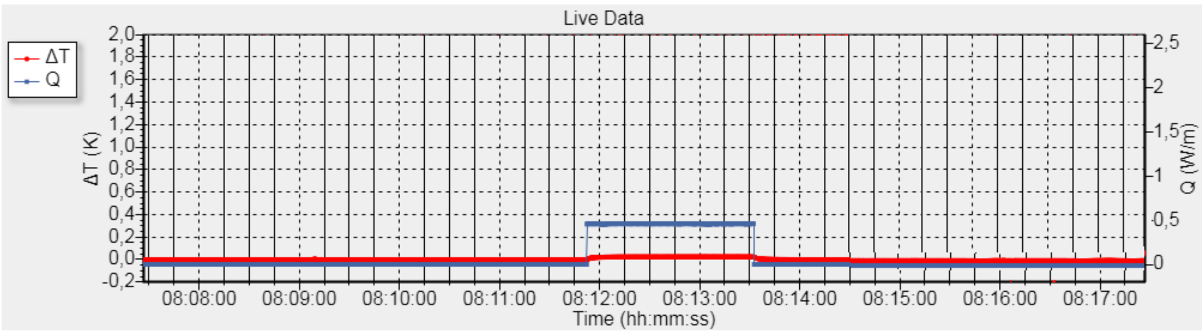

Figure 5.4.4.4 *An erroneous measurement of stainless steel: the heater power setting was too low. The measurement time is 100 s on low power. The blue line shows the sensor's heater. The red curve the thermopile temperature difference.*

5.4.5 Pitfall: non-smooth specimen surface, dirt or absence of contact fluid

A non-smooth specimen surface, a non-clean specimen or sensor surface and/or not using glycerol as a thermal contact fluid can cause increased thermal contact resistances between the STP05 sensor and the specimen. Thermal contact resistances will lead to larger temperature differences, causing an underestimate of the thermal conductivity of the specimen. This effect can be significant especially for specimen with a thermal conductivity greater than 1 W/(m·K).

Other than the steady-state value being larger than it should be these effects are not easily seen in the temperature difference time trace. If the measured thermal conductivity is significantly less than expected, make sure the specimen surface is sufficiently smooth. If necessary polish the surface. Make sure the specimen and sensor surface are clean. Use a drop of glycerol as a thermal contact fluid. See appendix 7.2.

5.5 Measurement summary

When performing a measurement, you can use this summary as a reference.

1. Check the system settings
2. Calibrate the sensor using reference specimen if measuring new batch of specimens
3. Prepare specimen:
    a. Make sure specimen is of correct dimensions and flat
    b. Prepare the specimen such that the surface is smooth
    c. Clean the sensor and specimen
    d. Place thermal contact fluid between sensor and specimen
    e. Place sensor gently but firmly on specimen, make sure there is no air between sensor and specimen
4. Set measurement time, heater power and specimen description. Use earlier similar measurements or the reference table in the Appendix to choose proper settings.
5. Start measurement once temperature difference has become sufficiently small (<0.005 K)
6. Check the results:
    a. Do the results comply with expectations (check with similar materials)?
    b. Is the measurement a smooth curve?
    c. Are there no errors in the status updates?

6 Maintenance and trouble shooting

To check the status of the datalogger, look at the 'Datalogger Status' tab of the interface.

For general maintenance on the system, like changing the station time, we recommend to use the Campbell Scientific LoggerLink app, available from https://www.campbellsci.com/loggerlink.

Alternatively, you can use Campbell Scientific Device Configuration Utility, available from https://www.campbellsci.com/devconfig. Use of this Utility is not recommended as it enables the user to accidentally change important datalogger settings.

6.1 Recommended maintenance and quality assurance

STPSYS05 measures reliably at a low level of maintenance. Unreliable measurement results are detected by scientific judgement, for example by looking for unreasonably large or small measured values. The preferred way to obtain a reliable measurement is a regular critical review of the measured data, preferably checking against other measurements.

Table 6.1.1 *Recommended maintenance of STPSYS05*

MINIMUM RECOMMENDED STPSYS05 MAINTENANCE			
	INTERVAL	SUBJECT	ACTION
1	every measurement	data analysis	Critically review the data. Look for any patterns and events that deviate from what is normal or expected. Inspect cable quality.
2	every measurement campaign	calibration	When changing the STP05 sensor, changing the environment of the STPSYS05, or when starting a new measurement campaign, calibrate the system and check the sensor settings.
3		lifetime assessment	Judge if the system will be reliable for another 2 years, or if it should be replaced.
4	> 3 years	battery replacement	The internal battery in the MCU is rated for a 3 year life with no external power source. If the battery is exhausted, contact Hukseflux Thermal Sensors B.V. for instructions.
5	2 years	recalibration	Recalibration by sensor manufacturer.

6.2 Trouble shooting

These instructions assume that the STPSYS05 is installed correctly and the user has a connection with the STPSYS05 MCU and is able to use the interface.

Table 6.2.1 *Trouble shooting for STPSYS05 (continued on next page)*

General	Inspect the sensors and MCU for any damage. Check the condition of the cables. The sensor's active surface should be smooth. Check the CR1000X Station Status for error messages (in the 'Datalogger Status' tab of the interface. Compare the sensor parameters in the MCU to the values on the certificate.
The thermopile signal is erratic or unrealistically high or low.	Check if the sensor parameters entered into the STPSYS05 MCU match the values on the STP05 calibration certificate. If not adjust the sensor parameters in the STPSYS05 MCU (see section 4.3.2). Use a multi-meter to inspect the sensor cable for cable breaks. In the case of cable breaks replace the cable. Check the presence of strong sources of electromagnetic radiation (radar, radio, electromotors). In the case of electromagnetic interference move sensor away from the source of the interference. Visually inspect the sensor. The sensor's foil surface should be smooth and have no deep scratches. Check the electrical resistance of the thermopile according to the wiring table in the Appendix. Use a multimeter at the 100 Ω range. The typical resistance of the wiring is 0.1 Ω/m (added value of 2 wires). Infinite resistance indicates a broken circuit; zero or a lower than 1 Ω resistance indicates a short circuit. Typical resistance values for the thermopile are: • TP[H] to TP[M]: approximately 17 Ω • TP[M] to TP[L]: approximately 17 Ω • TP[H] to TP[L]: approximately 31 Ω Values are expected to be within ± 3 Ω of these values If the thermopile circuit is damaged contact Hukseflux Thermal Sensors B.V. to send the STP05 back for repairs.
The heater does not switch on.	Use a multi-meter to inspect the sensor cable for cable breaks. In the case of cable breaks replace the cable. Inspect the sensor. The sensor's foil surface should be smooth and have no deep scratches. Check the electrical resistance of the heater according to the wiring table in the Appendix. Use a multimeter at the 100 Ω range. The typical resistance of the wiring is 0.1 Ω/m (added value of 2 wires). Infinite resistance indicates a broken circuit; zero or a lower than 1 Ω resistance indicates a short circuit. Typical resistances for the heater are: • HTR USENS[+] to HTR USENS[-]: approximately 15 Ω • HTR SUPPLY[+] to HTR SUPPLY[-]: approximately 15 Ω • HTR USENS[+] to HTR SUPPLY[+]: < 1 Ω

	• HTR USENS[-] to HTR SUPPLY[-]: < 1 Ω The heater resistance is about 15 Ω, the precise value can be found on the product certificate. If the heater circuit is damaged contact Hukseflux Thermal Sensors B.V. to send the STP05 back for repairs.
The measured thermal conductivity is incorrect	Make sure the specimen thermal conductivity falls in the measurement range of the STP05 (see chapter 3). If the specimen thermal conductivity falls outside this range STP05 is not suitable for measuring the thermal conductivity of this specimen. Make sure the specimen and sensor surface are clean. Dirt on these surfaces can lead additional thermal contact resistance and may cause the thermal conductivity of the specimen to be underestimated. Make sure to use glycerol as a thermal contact liquid. Failure to do so may lead to thermal contact resistances causing the thermal conductivity to be underestimated. Make sure the sensor does not move with respect to the specimen during a measurement cycle. Movement during a measurement cycle can cause a drop in the temperature difference, causing the thermal conductivity to be overestimated. Make sure the total measurement time is long enough. The temperature difference must be allowed to reach a steady-state. Too short measurement times will lead to an overestimate of the thermal conductivity. If necessary increase the total measurement time. Perform a calibration measurement (see section 4.3.3). If the calibration fails, contact Hukseflux Thermal Sensors B.V. to ship the STP05 sensor back for recalibration and adjustment of the sensor parameters.
The STPSYS05 MCU does not respond.	Refresh the web page. If this does not solve the issue switch off the STPSYS05 MCU, disconnect the USB or ethernet cable and disconnect the adapter from the mains. Reconnect the STPSYS05 MCU and navigate to the web page.
The time stamps in the “Results” and “RawData” tables are incorrect	The clock of the STPSYS05 MCU needs to be set. See section 4.2.4 for instructions.

7 Appendices

7.1 Theory

This section describes the theoretical models for STP05. Users of STPSYS05 are not required to be familiar with the contents of this section in order to be able to use the device. However, users of a separate STP05 sensor without the STPSYS05 MCU may be required to understand the contents of this section. Readers of this section are assumed to have a firm knowledge of calculus and heat diffusion processes.

7.1.1 The steady-state model and the thermal conductivity

In a first approximation STP05 can be modelled as an infinitely long, infinitely thin, linear heat source at the interface between two semi-infinite media: the sensor backing material and the specimen. If the heat source is switched on at time $t = 0$ then the temperature at the interface at a distance y from the linear heat source is given by:

$$\mathrm{T}(x, y, z = 0, t) = -\frac{\dot{Q}}{4\pi}\int_0^1 du \frac{\alpha\alpha_\mathrm{b}\lambda\lambda_\mathrm{b}\mathrm{Ei}\left(-\frac{1}{\mathrm{u}\alpha + (1-u)\alpha_\mathrm{b}}\frac{y^2}{4\mathrm{t}}\right)}{[\mathrm{u}\alpha\lambda_{\mathrm{b}^2} + (1-\mathrm{u})\alpha_\mathrm{b}\lambda^2]^{3/2}[\mathrm{u}\alpha + (1-\mathrm{u})\alpha_\mathrm{b}]^{1/2}}$$

where α and λ are the thermal diffusivity and thermal conductivity of the specimen, α_b and λ_b are the thermal diffusivity and thermal conductivity of the sensor and $\mathrm{Ei}(\cdot)$ denotes the exponential integral. The integral performs a complicated weighting of the thermal properties of the specimen and the sensor body.

Although the temperature increases indefinitely in this model, the temperature difference between two points at the interface at a distance y_1 and y_2 from the heater wire will reach a steady-state:

$$\Delta T(y_1, y_2) = T(y_1) - T(y_2) = \frac{\dot{\mathrm{Q}}}{2\pi\lambda_\mathrm{eff}} log\left(\frac{y_2}{y_1}\right)$$

Where

$$\lambda_\mathrm{eff} = \frac{1}{2}(\lambda + \lambda_\mathrm{b})$$

Here the two media appear as two parallel thermal resistors. This model can be improved by replacing the thermal conductivity of the sensor body by an effective thermal conductivity R_par^{-1} that accounts not only for the thermal conductivity by the sensor body but also for the thermal conductivity by the metal traces of the thermopile. In addition a serial thermal resistance R_ser can be considered that accounts for the thermal resistance of the Kapton foil between the thermopile and the specimen. The effective thermal conductivity becomes:

$$\lambda_{\text{eff}} = \frac{1}{2}\left(\frac{1}{R_{\text{par}}} + \frac{1}{R_{\text{ser}} + \frac{1}{\lambda}}\right)$$

The thermopile in STP05 generates a voltage proportional to the temperature difference between the hot joint at and the cold joint at :

$$U_{\text{t.p.}} \propto \Delta T(y_1, y_2)$$

Therefore the effective thermal conductivity can be related to the steady-state output voltage of the thermopile:

$$U_{\text{t.p.}} = \frac{S\dot{Q}}{\lambda_{\text{eff}}}$$

Where S is the sensitivity. The thermal conductivity can be computed from the thermopile voltage as follows:

$$\lambda = \frac{R_{\text{par}}\left(\frac{2 \cdot S \cdot \dot{Q}}{U_{\text{t.p.}}}\right) - 1}{R_{\text{par}} - R_{\text{ser}}\left[R_{\text{par}}\left(\frac{2 \cdot S \cdot \dot{Q}}{U_{\text{t.p.}}}\right) - 1\right]}$$

The sensor parameters S, R_{par} and R_{ser} are determined via a calibration at Hukseflux Thermal Sensors B.V. and can be found on the calibration certificate shipped with each STP05.

7.1.2 The time-dependent model and the thermal diffusivity

To determine the thermal diffusivity it is necessary to look at the time evolution of the temperature difference. Using a Puiseux series expansion the temperature difference for sufficiently long times ($y_2^2/\alpha_{\text{eff}} \gg t$) can be written as:

$$\Delta T(y_1, y_2, t) = \frac{\dot{Q}}{2\pi\lambda_{\text{eff}}}\left\{1 - \frac{y_2^2 - y_1^2}{8\,log(y_2/y_1)}\frac{1}{\alpha_{\text{eff}}t} + \mathcal{O}(t^{-2})\right\}$$

with:

$$\lambda_{\text{eff}} = \frac{1}{2}(\lambda + \lambda_{\text{b}})$$

and:

$$\alpha_{\text{eff}} = \frac{\lambda + \lambda_{\text{b}}}{\left(\frac{\lambda}{\alpha}\right) + \left(\frac{\lambda_{\text{b}}}{\alpha_{\text{b}}}\right)}$$

Typically this is a good approximation in the last 10% of increase of the temperature difference toward its steady-state value. Similarly, since the thermopile output voltage is proportional to the temperature difference, the last 10% of increase of the thermopile voltage to its steady-state is well described by a function of the form:

$$f(t) = p_0 + p_1 \cdot t^{-1}$$

By determining the parameters p_0 and p_1 one can determine the effective thermal diffusivity:

$$\alpha_{\mathrm{eff}} = \frac{\lambda + \lambda_{\mathrm{b}}}{\left(\frac{\lambda}{\alpha}\right) + \left(\frac{\lambda_{\mathrm{b}}}{\alpha_{\mathrm{b}}}\right)} = \frac{y_1^2 - y_2^2}{8 \cdot log(y_2/y_1)} \left(\frac{p_0}{p_1}\right)$$

And finally the thermal diffusivity of the specimen:

$$\alpha = \frac{\lambda}{\frac{\lambda + \lambda_{\mathrm{b}}}{\alpha_{\mathrm{eff}}} - \frac{\lambda_{\mathrm{b}}}{\alpha_{\mathrm{b}}}}$$

The sensor parameters α_{b} and λ_{b} are determined via a calibration at Hukseflux Thermal Sensors B.V. and can be found on the calibration certificate shipped with STP05.

7.2 Glycerol

It is strongly recommended to use glycerol as thermal contact fluid when making measurements. This in order to reduce thermal contact resistances between the sensor and the specimen. Failure to do so can lead to false measurement results.

Glycerol is available from most pharmacies and can also readily be purchased from chemical suppliers such as:

- Sigma Aldrich
- Fisher Scientific

Users are responsible for obtaining and observing the material safety data sheet (MSDS) from their supplier of glycerol.

7.3 Table with thermal properties of common materials

Table 7.3.1 *Indicative thermal conductivity and diffusivity of common materials and material types. Accompanying recommended settings for measurement with STPSYS05. These values are intended to give the reader a feeling for the order magnitude of thermal properties of certain materials, they are intended to be used as literature values. For literature values of thermal properties we refer the reader to the "Handbook of Chemistry and Physics".*

MATERIAL	**THERMAL CONDUCTIVITY @ 293 K [W/(m·K)]**	**THERMAL DIFFUSIVITY @ 293 K [$\cdot 10^{-8}$ m²/s]**	**RECOMMENDED SETTINGS**
Glycerol	0.29	9	NOT RECOMMENED FOR THIS PRODUCT
(Insulating) Foam	< 0.1	<0.1	NOT RECOMMENED FOR THIS PRODUCT
Wood	0.05 – 0.5	214	Heater setting: Low Time: 300 s
Glass	1	43	Heater setting: Low Time: 300 s
Brick	0.6 - 1	27	Heater setting: Low Time: 300 s
Ceramics	>10	-	NOT RECOMMENDED FOR THIS PRODUCT
Stainless Steel	13-15	405	Heater setting: High Time: 150 s (thermal conductivity measurement only!)
Aluminium alloys Copper	175 390	405 11160	NOT RECOMMENDED FOR THIS PRODUCT
Plaster	0.2-0.7	29	Heater: Low Time: 300 s
Concrete	0.1 -1.8	66	Heater: Low or Medium Time: 300-200s
PVC	0.16	8	Heater: Low Time: 300s
(Insulating) Plastics	0.03	0.1	NOT RECOMMENDED FOR THIS PRODUCT
Leather	0.14	59	Heater: Low Time: 300s
Fused quartz Single quartz	1.46 2-12	140	Heater: Low Time: 300s Heater setting: Medium or High Time: 150-200 s

7.4 Using the external trigger input

The external trigger input can be used to start a measurement by means of an externally generated trigger pulse. This can be useful for automation purposes where the system is part of a larger setup, e.g. if measurements are being done at different temperatures in a climate chamber or on different specimen.

To use the external trigger input a BNC cable should be connected to the MCU. The external trigger pulses must meet the specifications listed in the specifications chapter. To arm the external trigger input, select the "Settings" tab in the web interface. In the "External trigger" box click the "Arm/Disarm Trigger" button. When the trigger is armed a measurement will start if an external trigger pulse is detected on condition that no measurement is already running.

When using the external trigger, observe the maximum input voltage and the minimum trigger pulse width as specified in chapter 3.

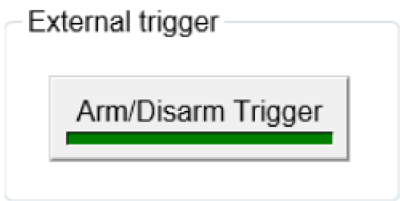

Figure 7.4.1: *The "External trigger" box in the "Settings" tab.*

When using the external trigger input, do not exceed maximum input voltage. Exceeding the trigger input voltage may permanently damage STPSYS05's MCU.

7.5 Using a Campbell Scientific CR1000KD Keyboard/Display

STPSYS05 can be operated without a PC through the Campbell Scientific CR1000KD Keyboard/Display with limited functionality. The Campbell Scientific CR1000KD Keyboard/Display is not included with the STPSYS05 and may be purchased separately.

The Campbell Scientific CR1000KD Keyboard/Display has to be connected to the DB9 connector labelled 'CS I/O' on the STPSYS05 MCU. It may be necessary to switch the STPSYS05 MCU power off and back on before the CR1000KD Keyboard/Display will function properly.

Figure 7.5.1: *The Campbell Scientific CR1000KD Keyboard/Display can be used to operate the system without a PC.*

When connected to STPSY05 MCU, the CR1000KD Keyboard/Display will generate the following menu tree:

- Measurement settings
  - Total measurement time
  - Specimen description
  - Heater setting
- Measurement control
  - Start
  - Stop
  - Running
  - Measurement time remaining
- Measurement results
  - Thermal conductivity
  - t[75%]
  - Thermal diffusivity
  - Measurement ID
- Status
  - Message 1
  - Message 2
  - Message 3
  - Message 4
  - Message 5
- Sensor parameters
  - Sensitivity

- Par. thermal resistance
- Ser. thermal resistance
- Backing material thermal conductivity
- Backing material thermal diffusivity
- Heater length
- Hot joint location
- Cold joint location
- Thermistor resistance at 25 deg. C
- Thermistor beta value

➢ Display settings
  - Turn Off Display
  - Back Light
  - Contrast Adjust
  - Display Timeout
  - Timeout

The menu can be navigated using the ▲, ▼, ◄, and ► keys. To select a menu item use the **Enter** ↲ key.

7.6 Campbell Scientific Device Configuration Utility

The Campbell Scientific Device Configuration Utility can be used for advanced troubleshooting or modifying the settings of the MCU. Some caution is advised however because the utility also allows users to delete or modify the STPSYS05 MCU software and web interface, which could render STPSYS05 MCU inoperable. The utility can be download from: https://www.campbellsci.com/downloads/device-configuration-utility

7.6.1 Finding the IP address using direct Ethernet connection

When connected via direct Ethernet you can use the utility to find the IP address.

In the Device Configuration Utility, select 'CR1000X Series' under the 'Datalogger' options. Make sure to check the 'Use IP Connection' box and click the '…' button next to the 'Communication Port' field. This shows the dataloggers and their IP address in the network.

When you have found the IP address of the STPSYS05, open your web browser and type the IP address in your address bar.

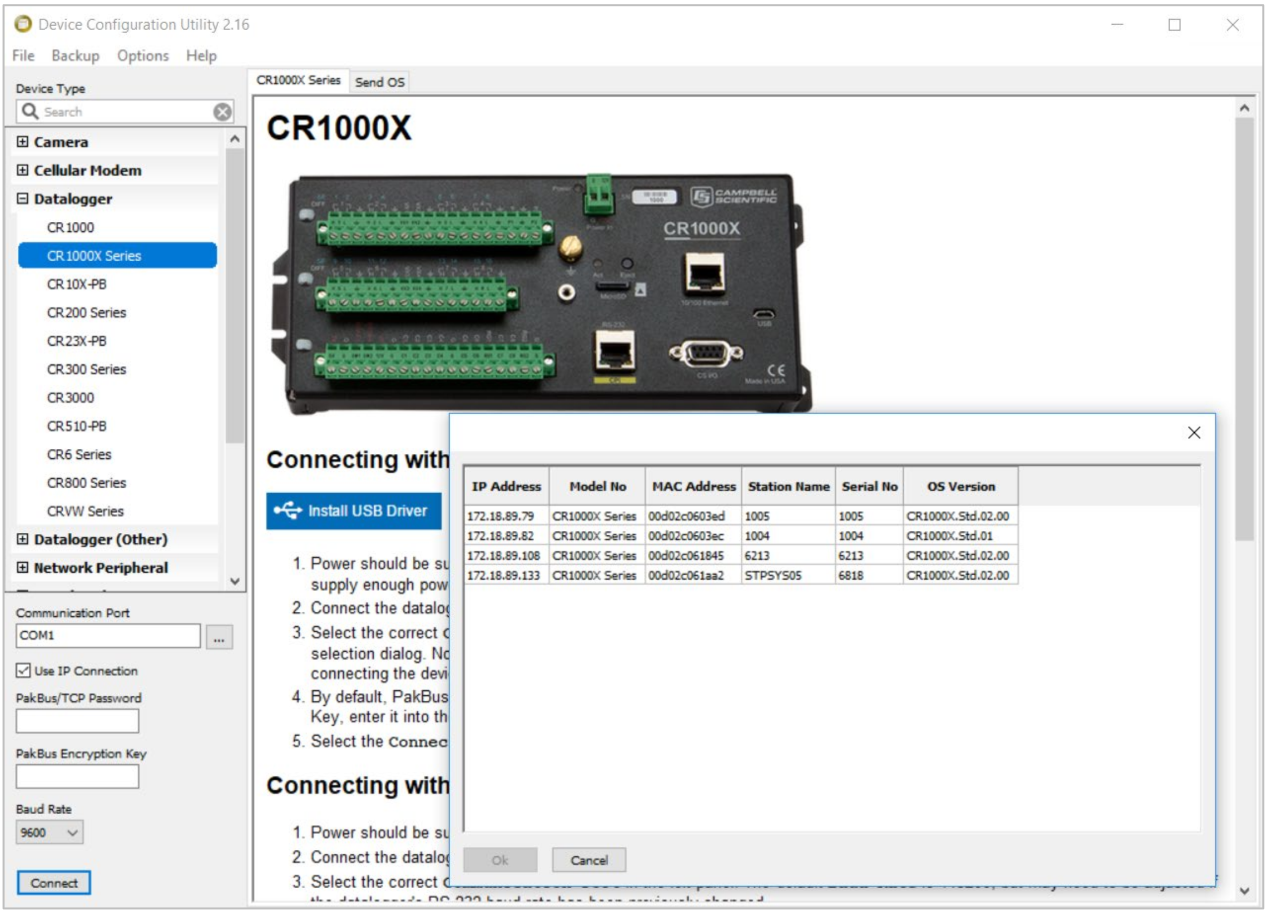

Figure 7.6.1.1 *Using the Device Configuration Utility to find STPSYS05's IP address*

7.6.2 Installing drivers manually

Under ‘Datalogger’, select ‘CR1000X series’ and choose ‘Install USB Driver’.

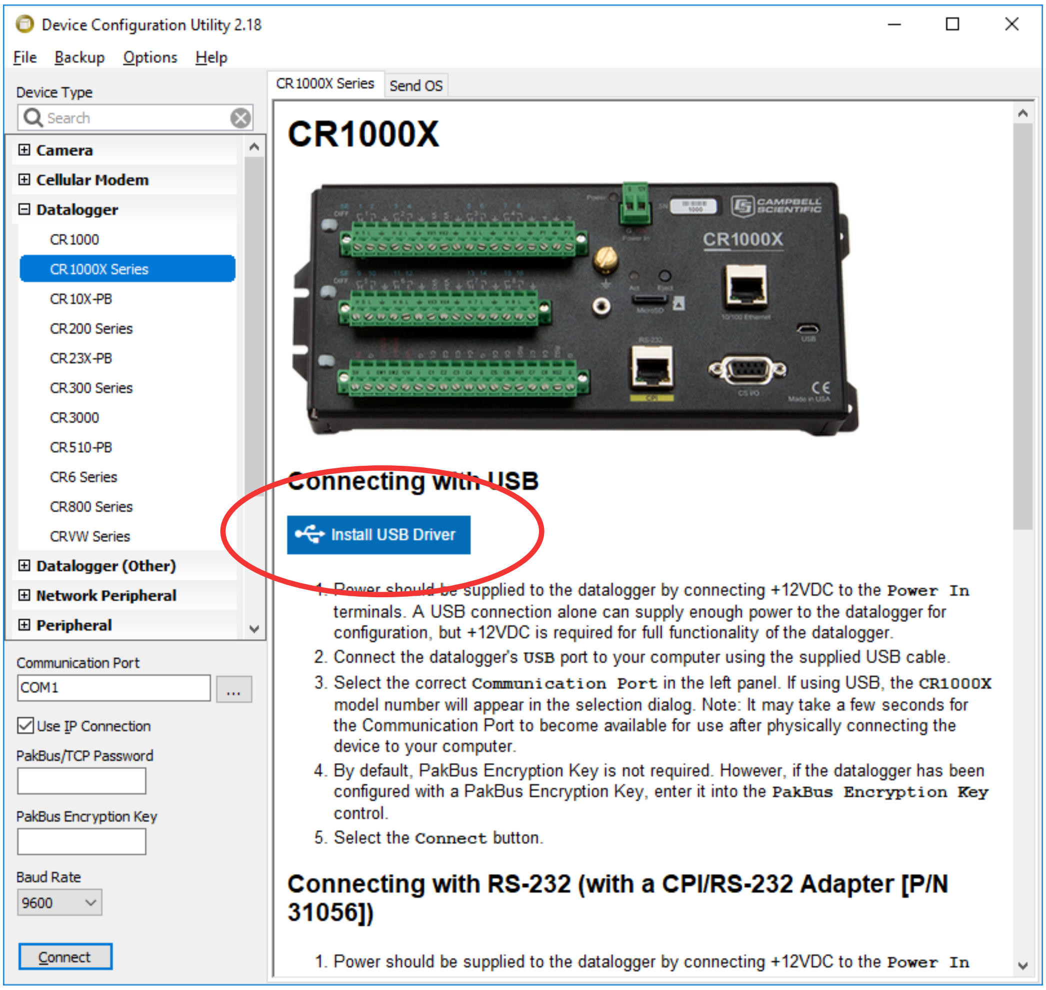

Figure 7.6.2.1 *Using the Device Configuration Utility when drivers are not installed automatically*

7.6.3 Setting the clock

Connect to the STPSYS05 using the Campbell Scientific Device Configuration Utility.

Under ‘Logger Control’, choose ‘Set Clock’ to set the STPSYS05 time to the reference time.

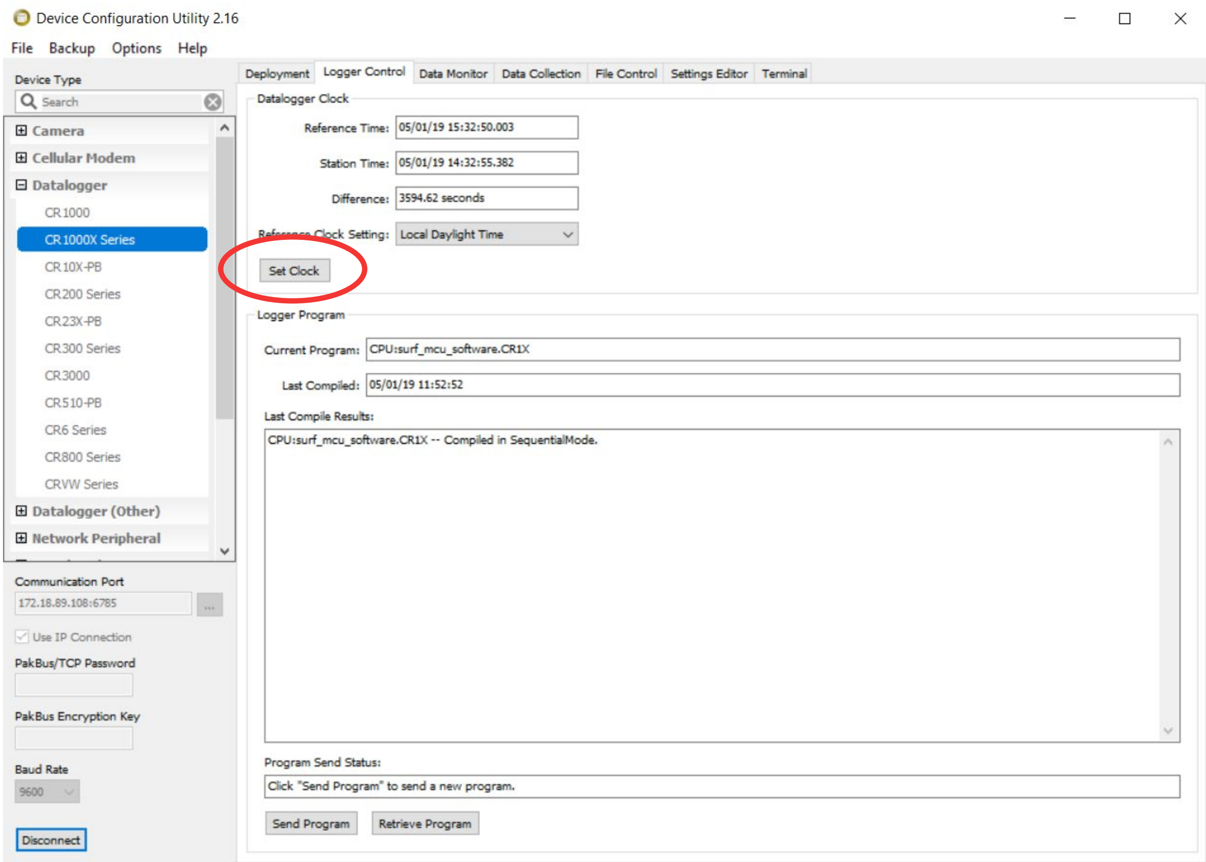

Figure 7.6.3.1 *Using the Device Configuration Utility when setting the STPSYS05 clock via Ethernet*

7.7 Ordering the sensor only

STP05 is also available as a “sensor only”. When purchasing STP05 without the STPSYS05 system, users must connect the sensor to their own equipment in order to use STP05. In addition, users must perform their own data analysis in order to determine the thermal conductivity and thermal diffusivity of specimens.

Figure 7.7.1 *STP05 as “sensor only”.*

7.7.1 Sensor connections

When connecting the sensor observe the cable requirements specified in chapter 3. The connections in STP05 are described in Table 7.7.1.1.

The user must provide a stable switchable power supply to power the heater. The maximum heater voltage specified in Chapter 3 must be observed. STP05 has 4 leads connected to the heater allowing the user to accurately measure the heater current and the heater voltage using a four terminal measurement. This information can be used to calculate the linear dissipation density.

A high-resolution voltmeter is required to measure the thermopile output voltage. The thermopile has three connections. The TP[H] and TP[L] connections allow the user to read the thermopile voltage. In addition, the TP[M] connection allows the user to separately determine the temperature differences to the left and to the right of the heater wire by measuring the TP[L] to TP[M] and TP[M] to TP[H] voltages. This information can be used to determine if there is a temperature gradient from left to right or the other way around. The thermistor is connected to NTC[+] and NTC[-] leads. By measuring the resistance between these leads the user can determine the sensor temperature. Note that the thermistor is not intended for high precision measurements of the surface temperature.

⚠ The GND, TP[M] and NTC[-] connections share a single pin on the connector.

⚠ The cable SHIELD is connected to the STP05 body.

⚠ Putting more than the specified maximum heater voltage across the heater wiring can lead to permanent damage to the heater and can pose both an electrical as well as a fire hazard. Do NOT connect STP05 to mains.

Table 7.7.1.1 *Wiring diagram: Pin numbers, wire colours and functions of STP05*

PIN	WIRE	FUNCTION
1	White	TP[H]
2	Brown	HTR SUPPLY [+]
3	Green	TP[L]
4	Yellow	HTR SUPPLY [-]
5	Grey	GND TP[M] NTC[-]
6	Pink	NTC[+]
7	Blue	HTR USENS[-]
8	Red	HTR USENS[+]
-		SHIELD

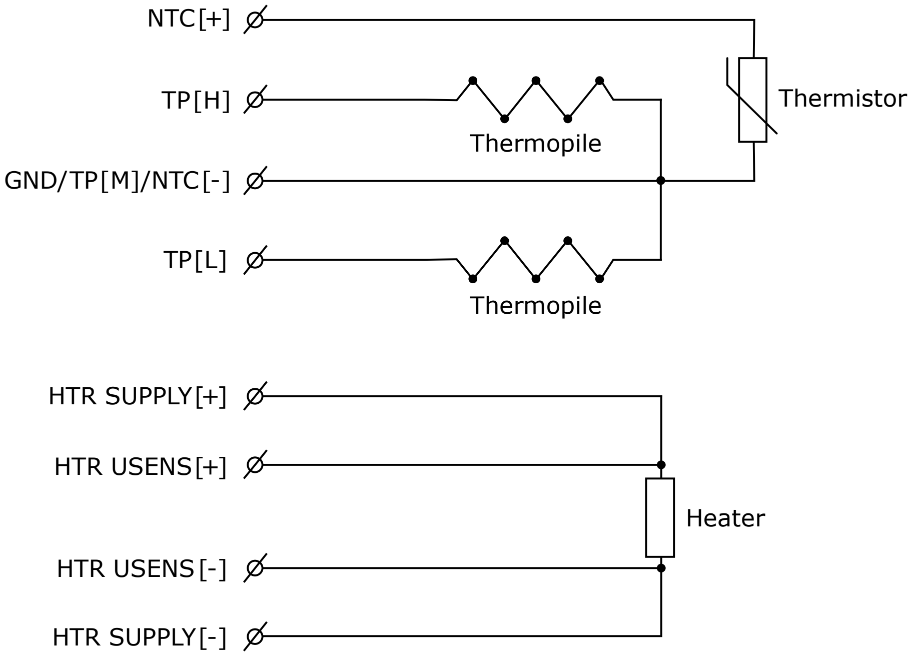

Figure 7.7.1.1 *Wiring diagram of STP05*

7.7.2 Performing measurements

Before making a measurement the specimen and sensor must be prepared. To do so follow the instructions in section 5.1.2. Once preparations have been completed measurements can be made.

If only the thermal conductivity of the specimen is to be measured, the heater can be switched on immediately. One must then wait until the thermopile output voltage reaches a steady-state value. Once a steady-state has been reached the heater current, heater voltage, thermopile voltage and optionally the thermistor resistance should be measured.

Measuring the thermal diffusivity is more complicated as this requires the time evolution of the thermopile voltage to be measured. To measure the thermal diffusivity wait until the thermopile voltage is stable and close to zero. At this point the heater can be switched on. Measurements of the heater current, heater voltage, thermopile output voltage and optionally the thermistor resistance should be made at regular intervals from the moment the heater is switched on. It is recommended to make measurements every 100 ms. The total measurement time must be long enough for the thermopile output voltage to reach a steady-state.

Users of STP05 “sensor only” are responsible for their own data analysis of the measurement results. The analysis is explained in chapter 2 and appendix 7.1. Users can use their preferred data analysis software such as Excel, Matlab, Octave, Python or OriginLab.

7.8 EU declaration of conformity STSPSYS05

We,	Hukseflux Thermal Sensors B.V. Delftechpark 31 2628 XJ Delft The Netherlands

in accordance with the requirements of the following directive:

2006/95/EG	The Low Voltage Directive
2011/65/EU	The Restriction of Hazardous Substances Directive
2014/30/EU	The Electromagnetic Compatibility Directive

hereby declare under our sole responsibility that:

Product model:	STPSYS05
Product type:	Thermal properties measuring system

has been designed to comply and is in conformity with the relevant sections and applicable requirements of the following standards:

Emission:	EN-IEC 61326-1:2013 for class A equipment
Immunity:	EN-IEC 61326-1:2013 using levels for industrial environments

Eric HOEKSEMA
Director
Delft
June 24, 2019

Hukseflux
Thermal Sensors

7.9 EU declaration of conformity STP05

We,	Hukseflux Thermal Sensors B.V. Delftechpark 31 2628 XJ Delft The Netherlands

in accordance with the requirements of the following directive:

2011/65/EU	The Restriction of Hazardous Substances Directive
2014/30/EU	The Electromagnetic Compatibility Directive

hereby declare under our sole responsibility that:

Product model:	STP05
Product type:	Thermal properties sensor

has been designed to comply and is in conformity with the relevant sections and applicable requirements of the following standards:

Emission:	EN-IEC 61326-1:2013 for class A equipment
Immunity:	EN-IEC 61326-1:2013 using levels for industrial environments

NOTE: STP05 has been tested in a specific system configuration

Eric HOEKSEMA
Director
Delft
June 24, 2019

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