TCS – Manual

TCS

Thermal Conductivity (TC)
and
Thermal Diffusivity (TD)
Scanner

For the first setup of the measurement apparatus, please refer to chapter

➡ **2. First setup of the TCS**

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0. Introduction: TCS hardware versions, TC mode and TC+TD mode

The TCS = Thermal Conductivity Scanner = OSI = Optical Scanning Instrument is able to measure thermal conductivity (TC) and thermal diffusivity (TD) on materials like rock samples or drill core samples. The TCS uses the optical scanning technlogy developped by Yuri Popov (see ➔ chapter 5 "The optical scanning technology").

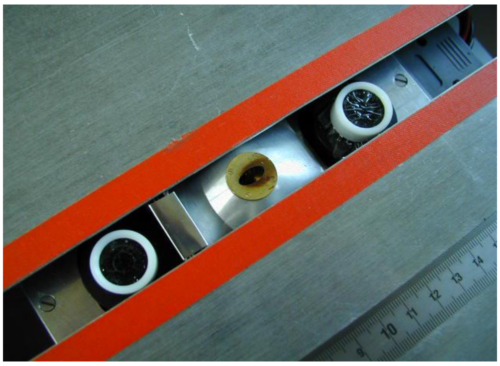
The optical scanning technology is based on the scanning using a focused, mobile and continuously operated near-point-like heat source in combination with infrared temperature sensors. The infrared sensors are measuring the temperature before and after heating. The determination of thermal properties is based on the comparison of temperature differences measured on **standard samples** (certified samples having known thermal properties) with temperature differences measured on one or more **unknown samples**.

The TCS Thermal Conductivity Scanner exists in one of three hardware versions. The hardware versions differ in the mechanical construction and in the type of infrared sensors installed. The TCS devices with device numbers from 1 to 24 are realized in hardware version 1 or 2. The TCS devices with numbers of 25 or greater (starting in the year 2014) are realized in hardware option 3. The TCS device number can be seen in the TCS main menu > Help > About TCS:

(1) TCS hardware version 1 = scanner + electronic supply unit + TC mode

This is historically the oldest version of the TCS, first introduced in 1999. The respective TCS device numbers are in the range of 1 to 24. These devices mayThe electronic supply unit contains all the electronics (stepper motor drive, data acquisition, infrared lamp supply, power supply). The scanner platform and the electronics unit are connected by a 25-wire cable. The electronics supply unit and the computer are connected by two serial data interfaces.

The sensor head is equipped with two 1-channel sensors.



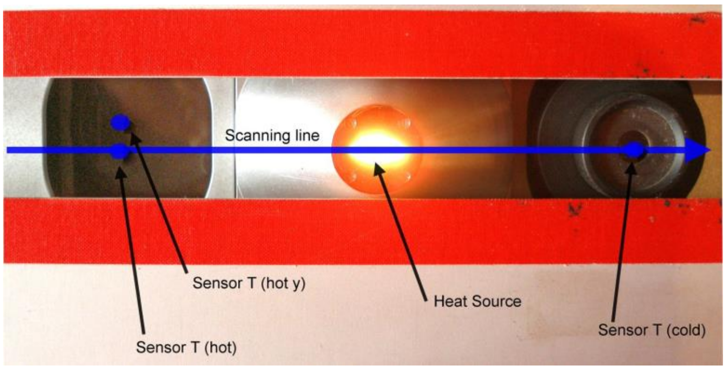
The optical head containing "hot" sensor (left), heat source (middle) and "cold" sensor (right). Movement during measurement conditions from the left to the right.

The TCS in hardware version 1 is able to measure thermal conductivity. The temperature before heating (sensor "cold") and the temperature after heating (sensor "hot"), each measured by 1-channel infrared sensors exactly inline to the scanning line are used for calculation of thermal conductivity (TC). The TCS machine equipped with these 1-channel sensors is not able to measure thermal diffusivity.

(2) TCS hardware version 2 = scanner + electronic supply unit + combined TC plus TD mode

The mechanical construction is like in option 1, electronics supply unit and mechanical platform are two separated devices. Two serial data interfaces connect the TCS machine with the computer. The respective TCS device numbers are in the range from 1 to 24.

The sensor "hot" is updated to a 2-channel version. The The 1-channel sensor "cold" remains the same. The 2nd channel of the sensor "hot" (= sensor "hoty") measures the temperature some millimeters off line.



The optical head containing the 2-channel sensor "hot" (left), heat source (middle) and sensor "cold" (right). The 2nd channel of the left sensor "hot y" measures the temperature somme mm offline the scannining line. Movement during measurement conditions from the left to the right.

The additional data of this sensor is used for calculating of thermal diffusivity (TD). The TCS is able to measure thermal conductivity exactly as in the TC mode. Additionally, the TCS machine is able to measure in the mode thermal conductivity plus thermal diffusivity (TC + TD mode).

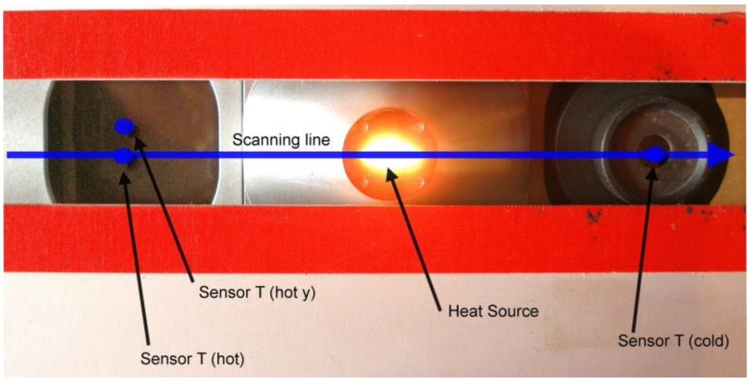
The hardware version 2 was introduced in 2007. Earlier TCS machines are not able to measure in the TC + TD mode. Version 1 may be upgraded to version 2. This requires an update in hard- and software, which must be done at the manufacturers workshop. The standard 1-channel sensor hot is replaced by a 2-channel sensor hot. Additionally, all calibrations are re-measured and updated.

See Popov et al. (1985) for a description of the measurement principle.

(3) TCS hardware version 3 = scanner unit including electronics + combined TC plus TD mode

The scanner unit contains all the electronics (stepper motor drive, data acquisition, infrared lamp supply, power supply). No separate device containing electronics is necessary. The scanner unit is connected with the computer by only one USB cable. This construction was introduced 2014. The TCS device numbers are 25 or greater.

The sensor head is equipped with the 2-channel sensor "hot" and the 1-channel sensor "cold". The TCS machines of this hardware version therefore are able to measure in the TC mode and in the combined TC+TD mode as well.



The optical head containing the 2-channel sensor "hot" (left), heat source (middle) and sensor "cold" (right). The 2nd channel of the left sensor "hot y" measures the temperature somme mm offline the scannining line. Movement during measurement conditions from the left to the right.

1. Components of the TCS

The TCS = Thermal Conductivity Scanner = OSI = Optical Scanning Instrument consists of the following components:

Scanner unit including sample platform and the optical head. The optical head includes the heat source, infrared sensors, stepper motor and electronic supply unit.

This picture shows the scanner unit of the actual TCS hardware version (TCS device number ≥ 25).

See ➔ chapter 1.1.

Power unit and power cable

USB data cable for connecting computer with scanner unit.

Earlier hardware versions of the TCS (device numbers ≤ 24) consist of the scanner unit plus an additional electronics box (electronics supply unit). These versions use 1 cable for connecting the electronics supply unit with the scanner unit and 2 USB data cables for connecting the electronics supply unit with the computer. (see ➔ chapter 0).

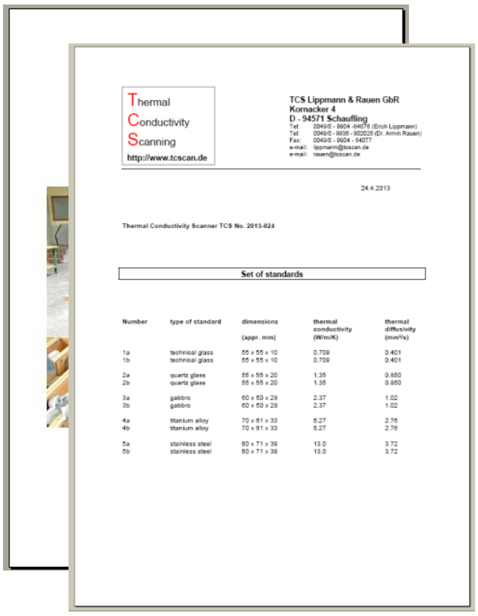
Dust cover for scanner unit.

CD-ROM containing the installation routine for the measurement software TCS, the manual and driver software. See ➔ chapter 1.3.

Case with set of standards. See ➔ chapter 1.2.

Black color and brush. This color is used for painting the standards and samples using the brush. Black color applied to the samples is necessary for absorption of the infrared heat waves emitting from the heat source during the measurement.

The mirror is helpful to have a look at the bottom sides of standards and samples while these are placed on top of the scanner unit.



Thermal
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24.4.2013

Thermal Conductivity Scanner TCS No. 2013-024

Set of standards

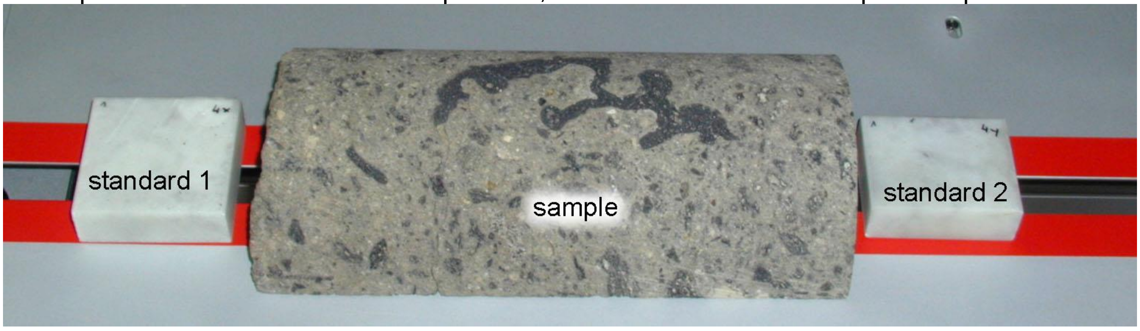
Number	type of standard	dimensions (appr. mm)	thermal conductivity (W/m/K)	thermal diffusivity (mm^2/s)
1a	technical glass	55 x 55 x 10	0.709	0.401
1b	technical glass	55 x 55 x 10	0.709	0.401
2a	quartz glass	55 x 55 x 20	1.35	0.850
2b	quartz glass	55 x 55 x 20	1.35	0.850
3a	gabbro	60 x 60 x 28	2.37	1.02
3b	gabbro	60 x 60 x 28	2.37	1.02
4a	titanium alloy	70 x 61 x 33	6.27	2.76
4b	titanium alloy	70 x 61 x 33	6.27	2.76
5a	stainless steel	80 x 71 x 39	13.0	3.72
5b	stainless steel	80 x 71 x 39	13.0	3.72

Paperwork including the manual and the standards certificate.

1.1 Scanner unit

The flat platform

The top of the scanner unit is the flat platform, where standards and samples are placed.



The optical head

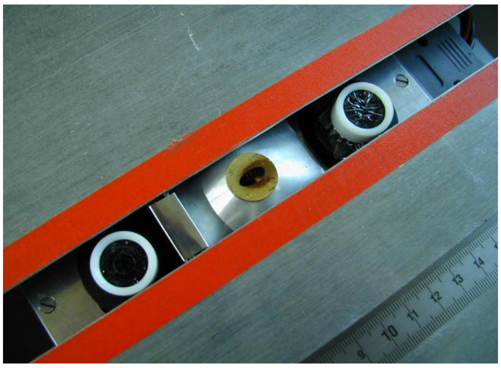
The optical head consists of the infrared emitting heat source and infrared recording sensors. Aditionally, the optical head contains the electronics and the stepper motor for the scanning movement. *Earlier instruments (TCS devices ≤ 24) have a separate electronics box containing the data acquisition and heat source electronics and stepper motor control electrics (➔ chapter 0).*

The positions of the heat source and the sensors are very critical. It is strongly recommended not to change the positions, to avoid any distortions during the measurement.

The optical sensors exist in one of two hardware options (see also ➔ chapter 0).

Thermal conductivity scanner with 1-channel sensor "hot" and 1-channel sensor "cold"

This option contains two 1-channel sensors. This option is able to measure thermal conductivity, but is not able to measure thermal diffusivity. This option was the first, that was realized in 1999 by the manufacturer.

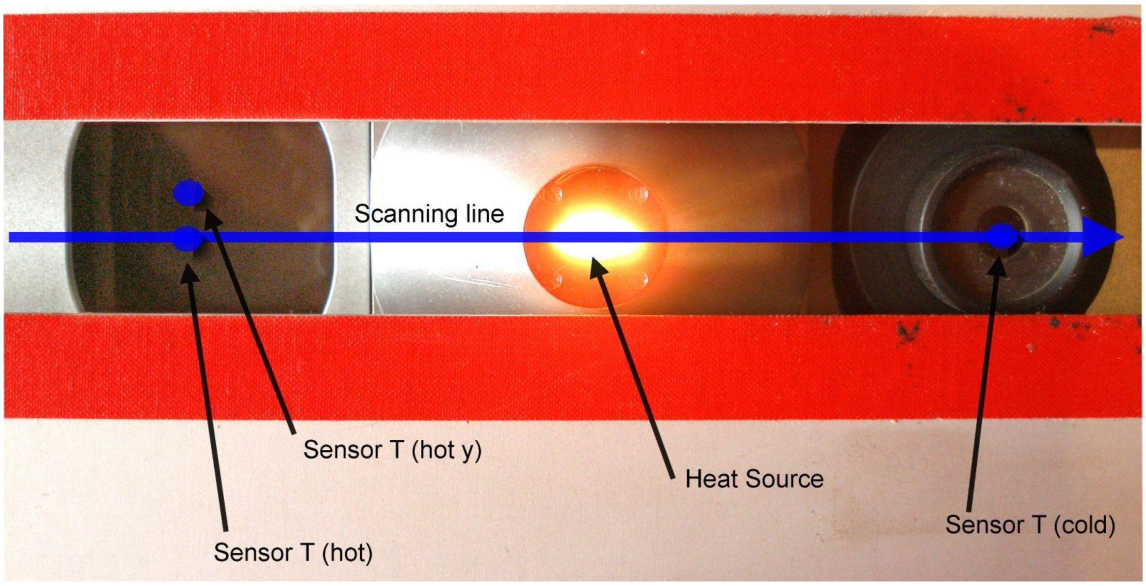


The optical head containing "hot" sensor (left), heat source (middle) and "cold" sensor (right). Movement during measurement conditions from the left to the right.

During moving of the optical head, one temperature channel measures the temperature after heating of the sample and is inline to the heating point (T_{Hot}). The second sensor "Sensor Cold" measures the temperature before heating (T_{Cold}). This measuring mode is called "TC mode" or "TC only mode".

Thermal conductivity scanner with 2-channel sensor "hot" and 1-channel sensor "cold"

This option contains one 1-channel sensor and one 2-channel sensor. This option is able to measure thermal conductivity TC (TC mode) and alternatively to measure thermal conductivity and thermal diffusivity TD simultanously (TC + TD mode). This option was later developped and introduced in 2007.



The optical head containing the 2-channel "hot" sensor (left), heat source (middle) and "cold" sensor (right). Movement during measurement conditions from the left to the right.

The "Sensor Hot" is a two-channel sensor. One temperature channel measures the temperature after heating of the sample and is inline to the heating point (T_{Hot}). The other sensor is appr. 7 mm apart from the heating line and measures T_{Hoty}. The second sensor "Sensor Cold" measures the temperature before heating (T_{Cold}). This measuring mode is called "TC + TD" mode.

1.2. Set of standards

The determination of thermal conductivity (optionally also thermal diffusivity) values is based on the comparison of excessive temperatures of **standard samples / references** (having known thermal properties) with excessive temperatures of one or more **unknown samples** being under heating by the movable concentrated heat source. The thermal properties of unknown samples are calculated as a result of a comparison of the excessive temperatures using the standard thermal conductivity and thermal diffusivity values.

The references consist of different technical glasses, natural rocks (marble or gabbro), titanium alloy and stainless steel. The thermal conductivities and thermal diffusivities are certified in the enclosed "Set of standards" paper.

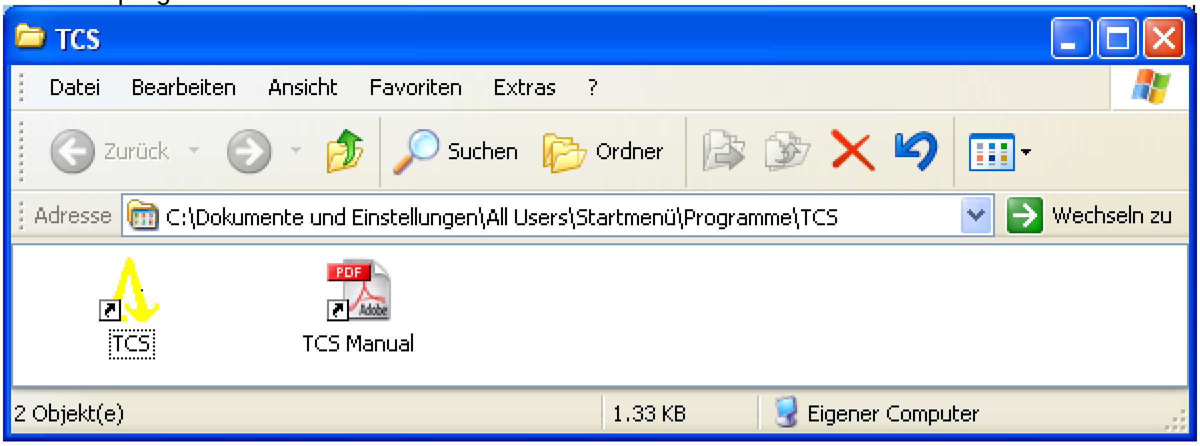
The standards are essential for the optical scanning technology. Each TCS machine is calibrated using the delivered standards. Thefore it is not trivial to change or exchange standards and users are pleased to treat the standards very carefully (➔ chapter 5.1.2).

1.3. Software

After installation of TCS_setup (➔ chapter "2.3 software setup"), a program folder named TCS is created within the Windows programs folder. The TCS program folder contains all necessary files of the software, amongst others, the TCS.EXE program, the TCS.CFG configuration file and the TCS manual.

The TCS.INI file contains all user made settings. This file is not situated in the TCS program folder, but in the Windows user application folder. The reason is the file handling peculiarities of Win 7 and later with restricted user permissions in program folders. The exact location can be seen by using the TCS main menu > setup > files and paths.

The TCS program folder contains two files:



"TCS " is the main software. It is the measurement and processing program. See ➔ chapter "6. TCS software manual" for a detailled description.

"TCS-Manual.pdf" is the TCS manual. This is the same in paper and in electronic form.

Updates

The newest versions of both the TCS data acquisition software and the TCS manual may be downloaded from www.tcscan.de > downloads.

1.3.1. Computer requirements

A standard computer running a Windows operating system (desktop or notebook) is sufficient, few special requirements are necessary.

- one free USB port. (*Older hardware versions use 2 USB ports or 1 USB port + 1 COM port ➔ chapter 0*).
- no local net or internet connection necessary.
- Windows operating system (32 bit and 64 bit) like Windows 95, 98, ME, NT, 2000, XT, Vista , XP, 7,8 or 10. WinXP or later is recommended.
- Main hardware specifications:
  Processor speed and graphics: not critical.
  Recommended RAM: 512 MByte or more.
  Display resolution: 1024 pixels x 768 pixels or more
- Minimum disk space for program installation: 50 MB.
- Minimum disk space for data: 1 GB recommended

1.4. Manuals

"TCS-Manual" is the TCS manual which you read just now. This is the same in paper and in electronic form (pdf document). The newest version of the manual can be downloaded from www.tcscan.de > downloads.

"Set of standards": This paper is a certificate of the delivered standards.

2. First setup of the TCS

2.1. Ambient and measurement conditions

First of all, you should choose a suitable location for the scanner. To obtain the best results, the user should take care of:

- Constant measurement conditions, especially constant room temperature.
- Prevent the complete measurement apparatus especially from direct sunlight. Sunlight would partially increase the temperature of samples, standards and the sensors itself.
- Keep the standards and the samples nearby the TCS instrument in a place with constant temperatures. Standards and samples should have approximately the same temperature. Remove the references from the transport case and let them equalize temperatures before using them for a measurement.
- The instrument, samples and standards should generally be kept away from sunlight, heaters, open windows, ventilators or windy conditions, or changing ambient temperature conditions.
- During measurement, standards and samples should not touch each other to avoid direct heat transfer. Remain a gap of some mm between standards and samples.
- Standards and samples have to be painted by a black color line (see chapters 4.1 and 5.1.1)
- We recommend not to re-paint the standards, unless it gets necessary, because the color stripe is worn out.

The TD measurement is much more sensitive to environmental and other factors than the TC measurement only. Therefore we recommend the following.

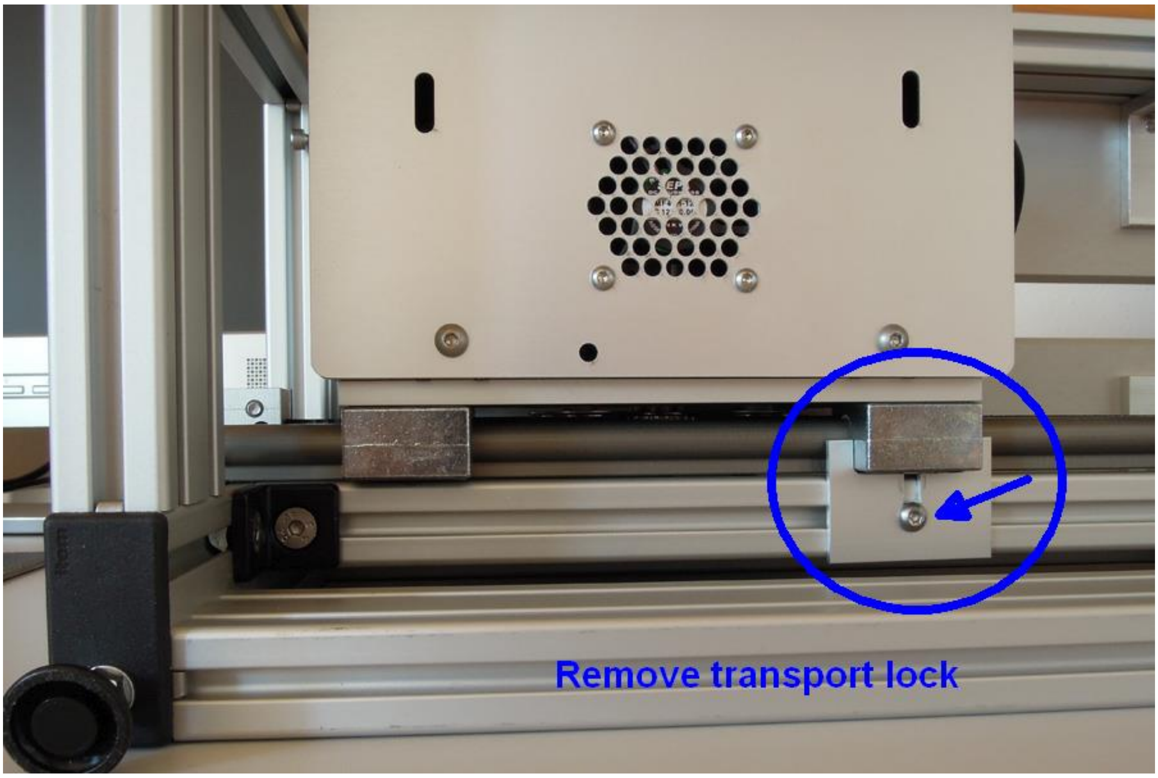
- Take care of correct hardware setup (no direct sunlight, constant ambient temperature, no draught or windy conditions, see above.
- Allow thermal equilibration of the whole apparatus, including standards and samples, before starting of the measurements.
- Store standards and samples near the apparatus in order to have similar (equilibrated) temparatures.
- Take care of correct choice of suitable standards.
- Take care of correct painting of the black color line: the black line must be concolorous (uniformely colored, uniformely thickness with no too thin or too thick areas). The black line must be wide enough to cover both hot sensors. We recommend a wideness of $\approx$ 20 mm.
- Allow the electronics approximately 10 minutes to warm up before starting of the measurements.
- The measured maximum temperature differences should ideally be between 2.0 °C and 4.0 °C. Please avoid too low temperature differences (resulting in greater measurement errors due to decreasing signal/noise ratio), but avoid too high temperatures also (resulting in damaged black color lines and possibly destroyed samples) .
- After extensive measurements, the standards will be heated up (especially the 1st standard with lower TC and TD). With increasing temperature difference between standards and samples, the measurement quality will decrease. In order to avoid further heating of standards, you may:
  (1) wait a certain amount of time for allowing the standards to cool down or
  (2) switch to the other available pair of standards and allow the 1st pair to cool down while continuing the measurements.
- During multiple measurements with the same references: please do not change the positions of the references. If a movement is necessary, let the references cool down first or switch to the other references pair.
- Avoid to measure too long scan lines. Longer scan lines result in higher drift in the temperature readings, this will result in lower measurement quality. The best quaility is provided by short scanning lines containing only the standards and one sample.
- Use only the default data acquisition sampling interval of 2 mm, no other sampling intervals.
- In order to obtain best quality results, use the same type of color for both standards and samples.

2.2. Hardware setup

Scanner unit

- Unpack the scanner unit and remove the dust cover from the scanner unit.

- Remove the transport locking of the sensor head. The transport lock is located at the bottom side of the TCS scanner platform near the sensor head. (*TCS devices no ≤ 24 do not have a transport locking system).*



View of the bottom side of the sensor head.

Unscrew the allen screw (marked by the blue arrow) and remove the small aluminium plate. Be sure to store the transport lock on a safe place for a future use.

- Screw in the four rubber coated feet. Place the scanner unit on your desktop and adjust the heights of the the feet for a stable and horizontal position.

Connecting the scanner unit with the computer

- The scanning apparatus is connected to the computer by an USB cable. Using Windows 7 or later system software, an USB-serial driver will be installed automatically. See the next chapter 2.3 for more details.

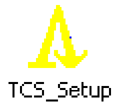
  Earlier versions (≤ 24) are connected by 2 serial interfaces (provided by 2 USB-serial converters) to the computer (➔ chapter 0).

Switching on the scanner unit and the computer

- Connect the scanner unit and the notebook computer to the mains and switch them on. The fan inside the optical head should immediately begin to run.
- Always be certain, that the scanner unit is switched on, when the measurement program TCS.EXE is started.
- Allow the electronics unit approximately 10 minutes to warm up before starting of the measurements.

2.3. Software setup

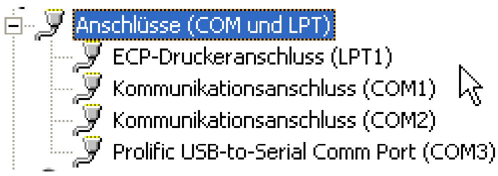
Install the software TCS on the computer using the supplied CD-ROM. Run the "TCS_Setup" for installation.



Plug the USB cable into the scanner unit at one end and into the computer USB port at the other end. Using Windows 7 or 8 system software, an USB-serial driver will be installed automatically. If this driver is not installed automatically, you have to install it manually. The driver software is included in the TCS installation CD-ROM. The USB-serial driver creates a serial port (COM port). This is necessary for communication between the computer and the scanner unit.

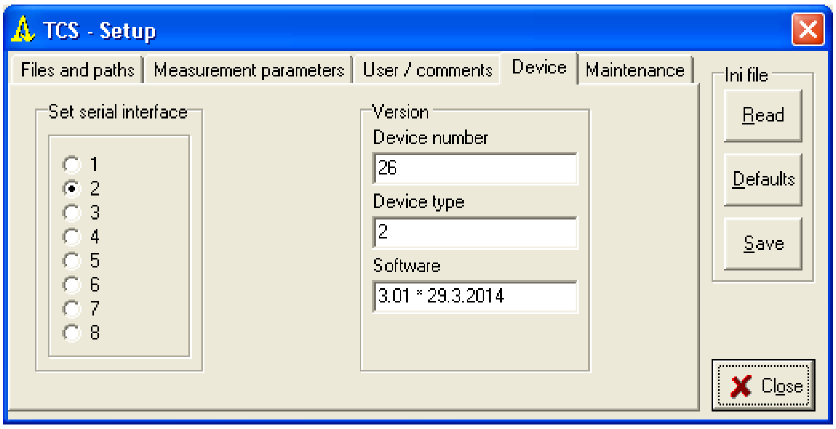
The earlier TCS versions (device numbers ≤ 24) with the separate electronics box (➔ chapter 0) use 2 serial (RS232) interfaces for communication with the computer. In this case, 2 USB-to-serial converters may be used. The driver for these converters have to be installed like described before.

Locate the COM port number which Windows provides after installation of the USB-serial converter. You can check the installed COM port number using the Windows device manager: Press the Windows "Start" button > "Setup" > "System" > "Hardware" > "Device manager". Open "Interfaces (COM and LPT)". Locate the installed COM port number. If the computer has a standard COM port, this will be most probably COM 1. The installed COM port number could be e.g. COM 3 (see example "USB-to-Serial Comm Port").



If you see more than one COM port and you are not sure which is the correct COM port number, you may check following this procedure: Disconnect the scanner unit USB cable. One of the displayed COM ports will disappear. Reconnect the scanner unit USB cable and check which COM port will appear. This is the correct COM port.

Tell the software, which COM port number should be used. Open TCS.EXE. Locate the TCS main menu. Open "Setup" > "Device". Set the correct COM port number. Press "Save" to save the values into the TCS.INI file. (*Older hardware versions use 2 COM ports ➔ chapter 0*).

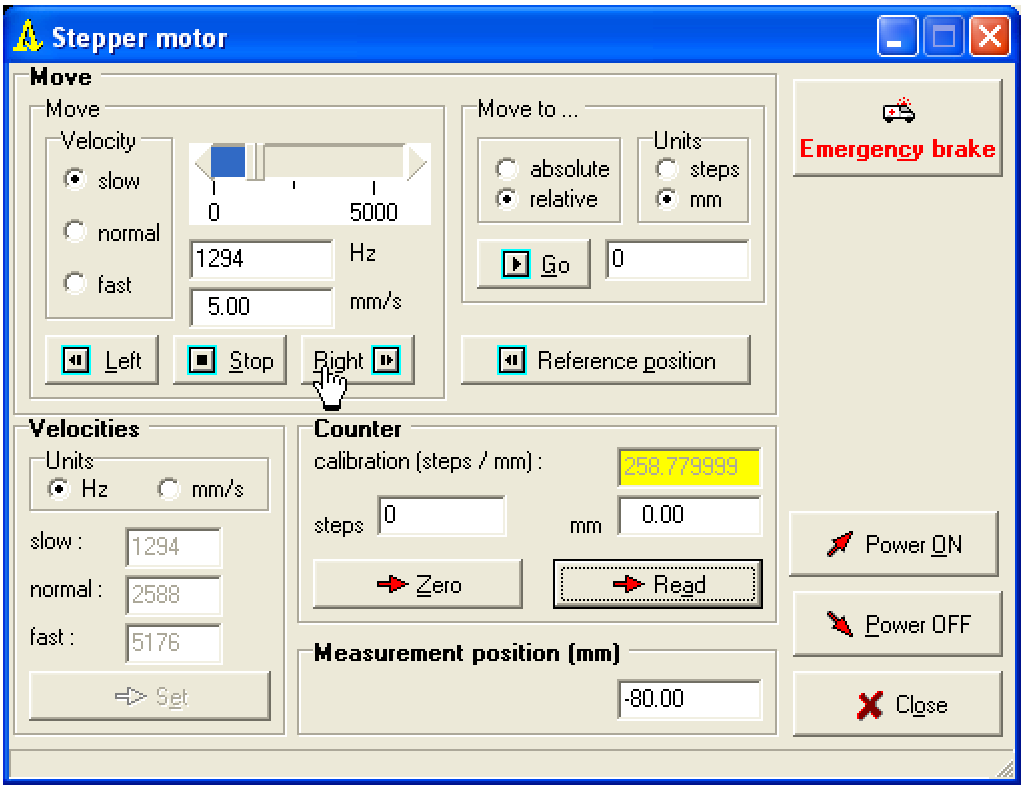


The TCS.INI file is located in the so called user application folder (e.g. "C:\Dokumente und Einstellungen\Armin\Anwendungsdaten\TCS\"). We recommend strongly not to change this file manually, e.g. by an editor.

2.3.1. Communication test

Check the stepper motor

TCS main menu ➔ Setup ➔Test stepper motor.

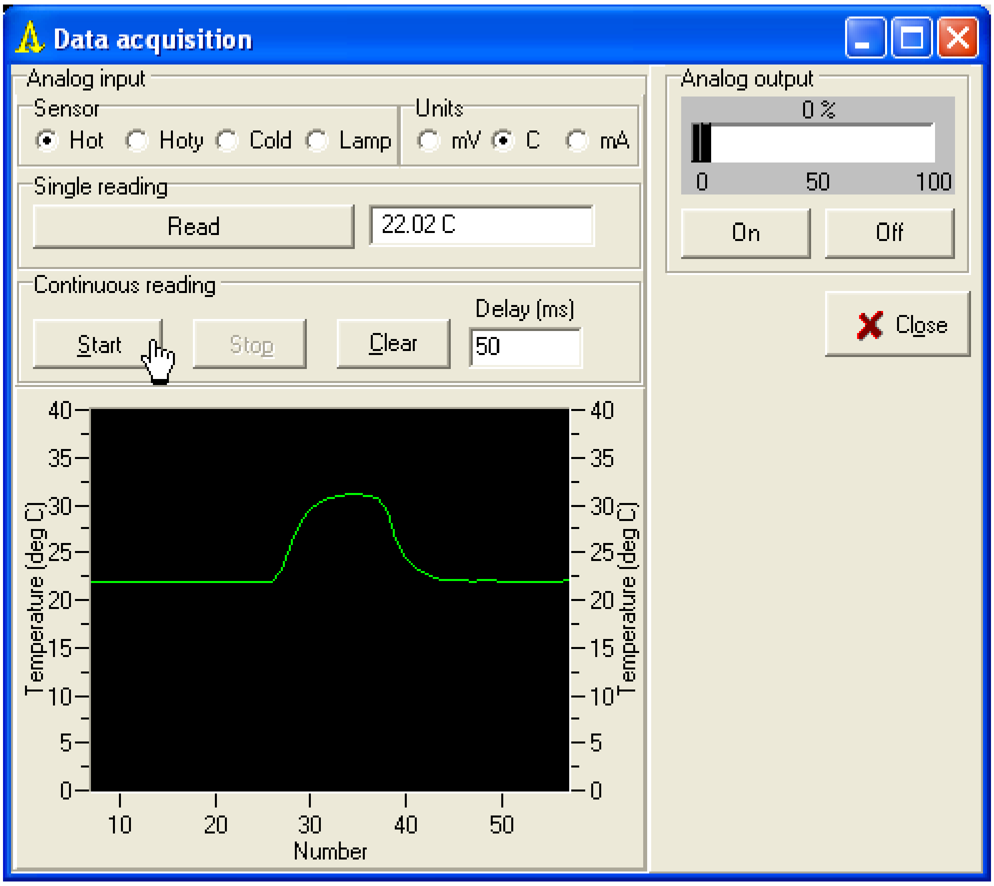


You should be able to move the sensor head manually e.g. by pressing the "Right", "Left" and "Stop" buttons. Let the sensor head move to the very left home position by pressing "Reference position".

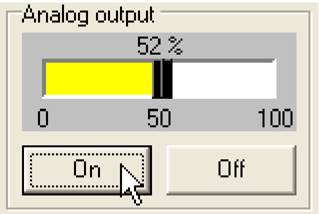
Check the data acquisition communication

TCS main menu ➔ Setup ➔Test DAQ

Choose one of the three sensor outputs "Hot", "Holy" or "Cold" and press the "Start" button. The display should show the respective sensor reading. Check the respective sensor by placing your hand on top of the sensor and by removing your hand. The sensor should display a temperature peak like this:



Check the analog output also by moving the slider to e.g. ≈ 50 % and clicking the "On" button.



The red lamp beam should be visible. Click the "Off" button for switching off the lamp. Be careful not to injure your skin or eyes. Please take care of the safety requirements in the next chapter.

If both communication tests passed without problems, the TCS machine will be ready for the measurements.

3. Safety requirements

Avoid burning of material

The measurement equipment makes use of a special infrared emitting heat source (electrical lamp). The thermal power of this lamp is strong enough to burn paper and other material. Therefore be careful in using the lamp and do never cover the optical head by combustible material like paper if the machine is switched on.

Avoid burning yourself or your eyes

The thermal power of this lamp is strong enough to burn your skin or to injure your eyes. Therefore do not look directly in the lamp beam. Be careful in touching the lamp or moving your hand into the lamp beam.

Avoid injuries of yourself

The moving parts of the machine could squeeze hands of the user or other parts. Therefore, never put your hands or other parts of your body inside the scanning apparatus during the optical head is moving.

Avoid thermal destroying of samples or standards

Be careful in switching the correct output power of the infrared heat source. Strongly increased output power could damage the black color film or even the sample itself. Be sure, that the maximum temperature difference before and after heating does not exceed appr. 4 degrees Celsius (appr. 3 degrees Celsius in case of high conductive material like steel references). In this case, no thermal damage will appear. The "recommended heat power" which may be set automatically during choosing the references will take this into consideration.

Emergency brake

In the possible case of a certain serious problem while the program is running, you should immediately press the **"Emergency brake"** button. Pressing of this button would switch off the lamp and stop the movement of the optical head immediately. Pressing the "Emergency brake" button will result in a sudden stop of the program. The program will not work properly after this sudden stop, so please quit and restart the program.

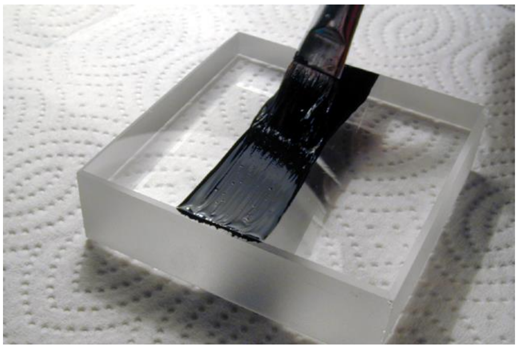
4. Quick start guide - performing the first measurement

4.1. Preparation of standards and samples.

Before the measurements every sample and every reference sample (standard) is to be painted by a black enamel along the scanning line chosen. This is important for a complete absorption of infrared heating. (➔ chapter 5.1.1. for more details).

We recommend to leave the original color on the standards. We recommend not to re-paint the standards unless it gets necessary, because e.g. the color stripe is worn out. The original calibration of the instrument depends on the correct painting.

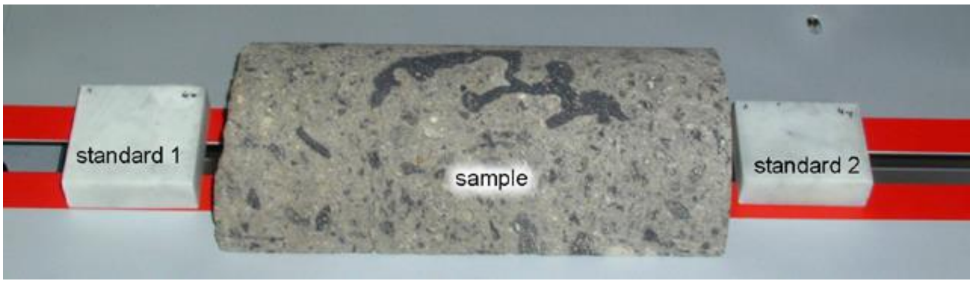
In order to obtain best quality results, use the same type of color for both standards and samples.



TC mode: To measure the thermal conductivity of an unknown sample, it is necessary to use two additional samples (standards) with known thermal conductivity as references for each scanning. The best quality of thermal conductivity measurements is provided when the thermal conductivity of the two standards chosen is as closest as possible to thermal conductivity of the samples studied.

TC + TD mode: If you want to measure in the combined TC+TD mode, you should choose standards with thermal properties in the range of the expected thermal properties of the unknown sample (➔ chapter "5.1.4.Special requirements for the TC+TD mode").

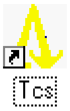
The sample to be measured is placed between the two standards on top of the electrical-mechanical platform. Use the most left side of the area, which is marked by the red tape. The red tape marks the maximum range of measurement positions.



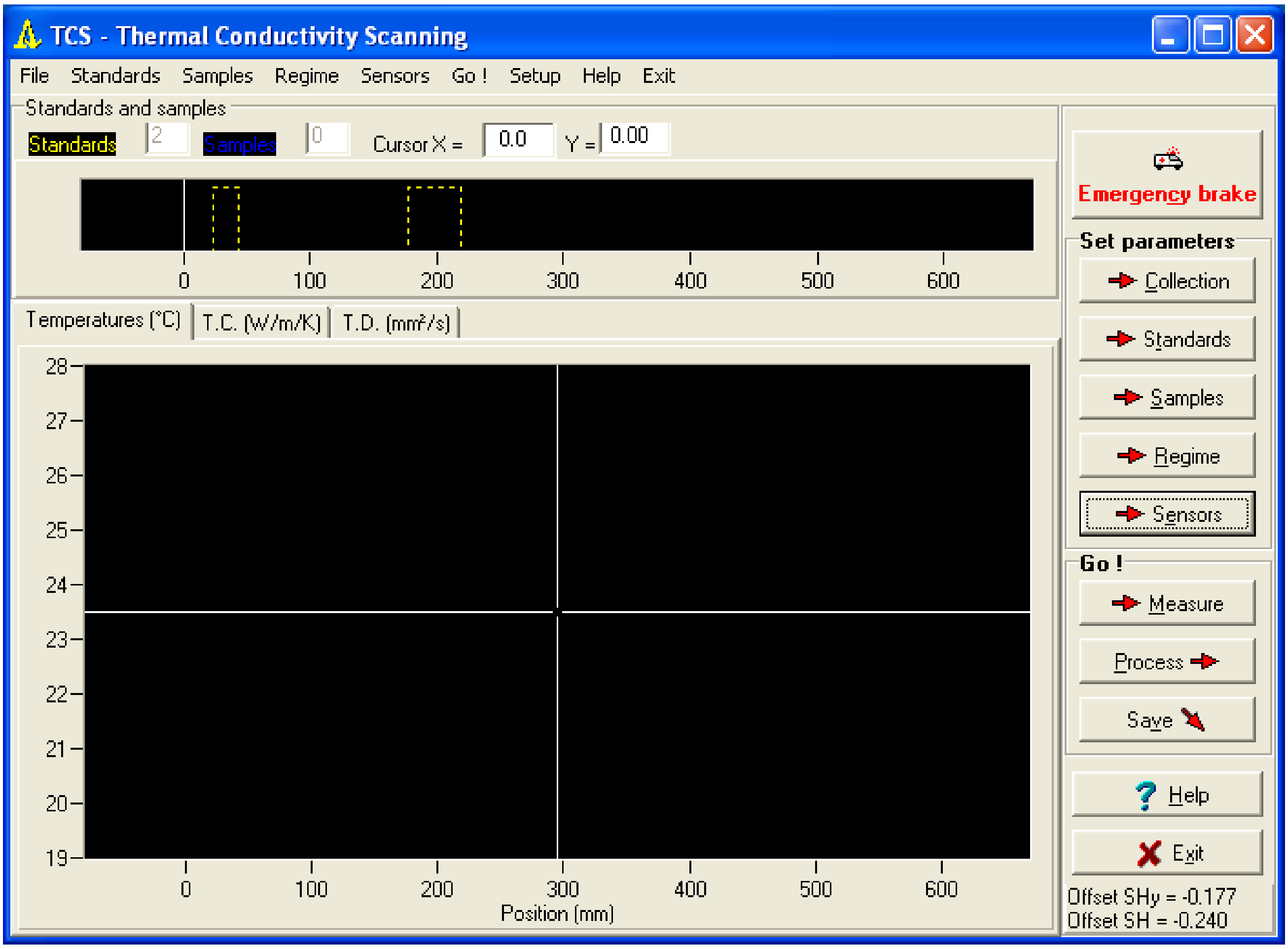
The scanning line requirements are discussed in chapter 5.1.3. in the TCS manual. Standards and samples should not touch one to another. A distance of some mm (≈ 1 to 5 mm) should be provided.

4.2. TCS software quick guide

Be certain, that the computer and the scanner unit are switched on. Take care of the ambient requirements, epecially of the safety requirements (➔ chapters 2.1. and 3).

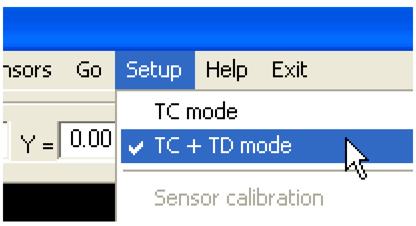


The measurement program TCS is started by clicking the TCS shortcut in the TCS folder or the TCS shortcut on the computer desktop. All essential program options are controlled by the buttons on the right side of the main form. In the case of normal routine measurements, these buttons would be used instead of clicking the main menue on the top of the form. Normal routine work will be done by clicking the buttons in a "top-down" order.



Measurement mode: TC or TC+TD

TCS runs in one of two measurement modes: TC mode or TC+TD mode. In the TC mode, the apparatus measures thermal conductivity (TC) only. In the TC+TD mode, the apparatus measures simultanously thermal conductivity (TC) and thermal diffusisvity (TD). The user may choose the measurement mode by the main menu > setup > TC mode or TC+TD mode:



Collection

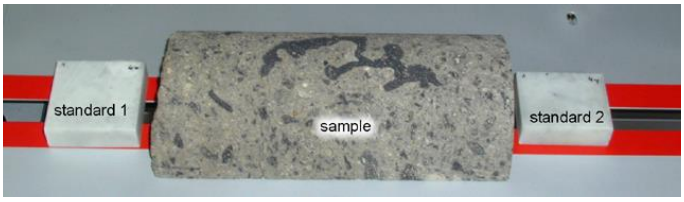
Set the sample collection name. The collection name equals the folder name, which is used for saving the data. All measurements will be stored in the respective folder on the computer harddisk. ➔ chapter "6.2.1. Collection".

Standards

Choose the pair of standards used for the measurement. Choose the standards considering the following topics:

- TC mode: the thermal conductivity of the standards should be close to the expected thermal conductivity of the sample to be measured.
- TC+TD mode: the thermal conductivities of the standard pair should be smaller (standard 1) and greater (standard 2) than the expected thermal conductivity of the sample. See chapter "5.1.4. Special requirements for the TC+TD mode".

The positions of the standards can be given later. When closing the standards window, the user is asked for the default heat source power. Accept the default setting, unless you know better. ➔ chapter "6.2.2. Standards".

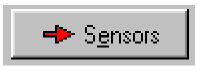


Place standards and samples on top of the scanner unit. Place the sample(s) between the standards. The black color line must be on the bottom of the standards and samples, visible by the infraraed sensors below the platform.

Heat source power

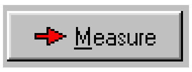
Set the heat source power, if you don't want to use the default value. Set the heat source power considering: the temperature differences after heating should not exceed 4 °C to avoid any damage of the painting or the sample material. If you are not sure about the suitable power, use the recommended power setting after pressing the "Recommended ?" button or even lower values. ➔ chapter "6.2.4. Regime".

Sensor offsets

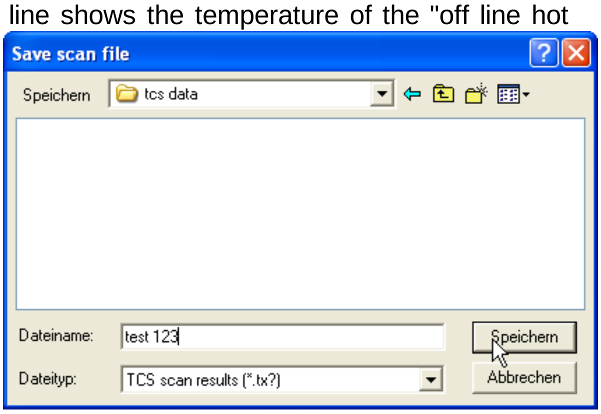


Adjust the sensor offsets. ➔ chapter "6.2.5 Sensors".

Measurement



Start the measurement. The caption of this button switches to "Stop". The observed temperatures will be displayed in the main form. The blue line indicates the temperature measured before heating ("cold sensor"), the red line displays the temperature after heating ("hot sensor"). In case of a 2-channel "hot sensor" (TC + TD mode), an additional orange line shows the temperature of the "off line hot sensor (sensor hoty)". After completing the measurement press the "Stop" button or wait until the scanner reaches its maximum position. In this case, the measurement is stopped automatically. See chapter "6.4.1. Perform one measurement".

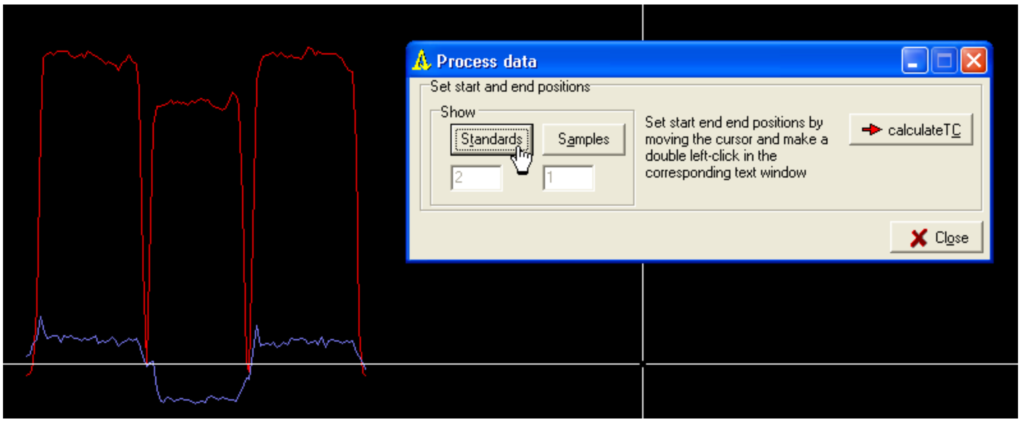


After stopping of the measurement, the optical head will move back until the start position far left. During moving back, the user is asked to save the data.

Now save the scan file. It contains all measured and calculated data. Its file extension will be "*.tx0".

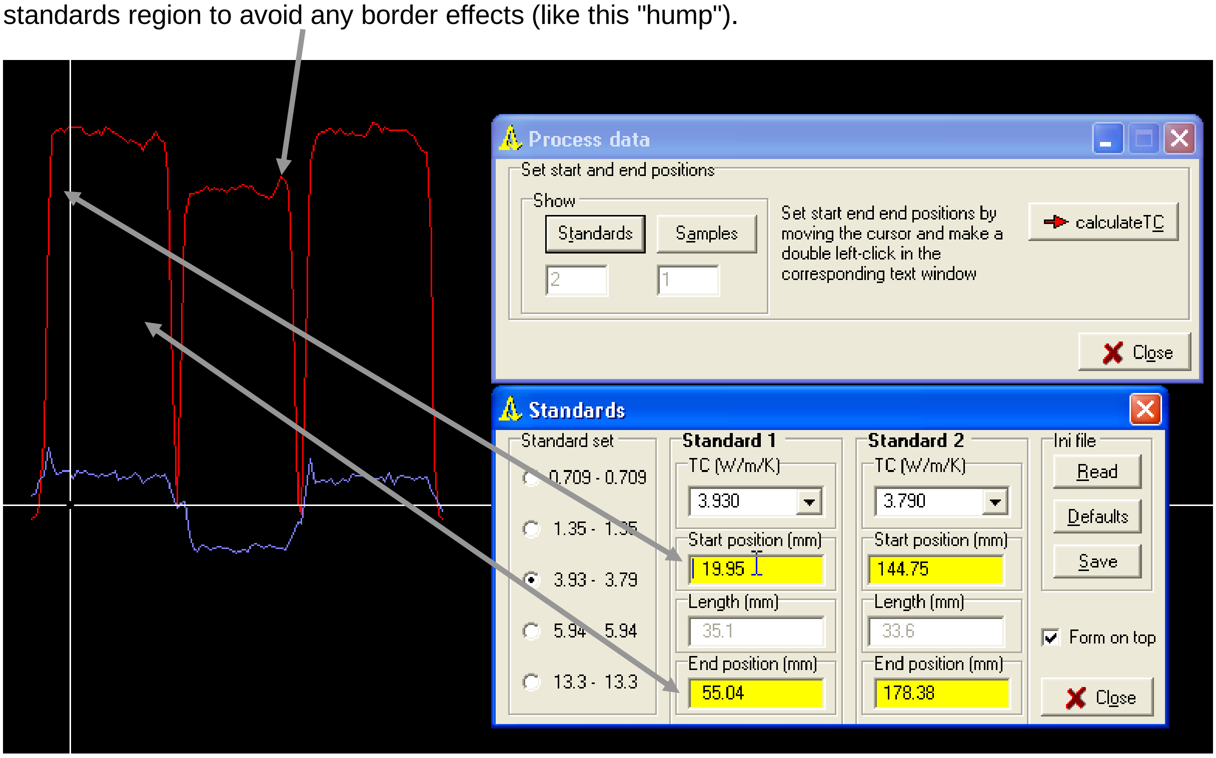
Process the data

Process the observed data.

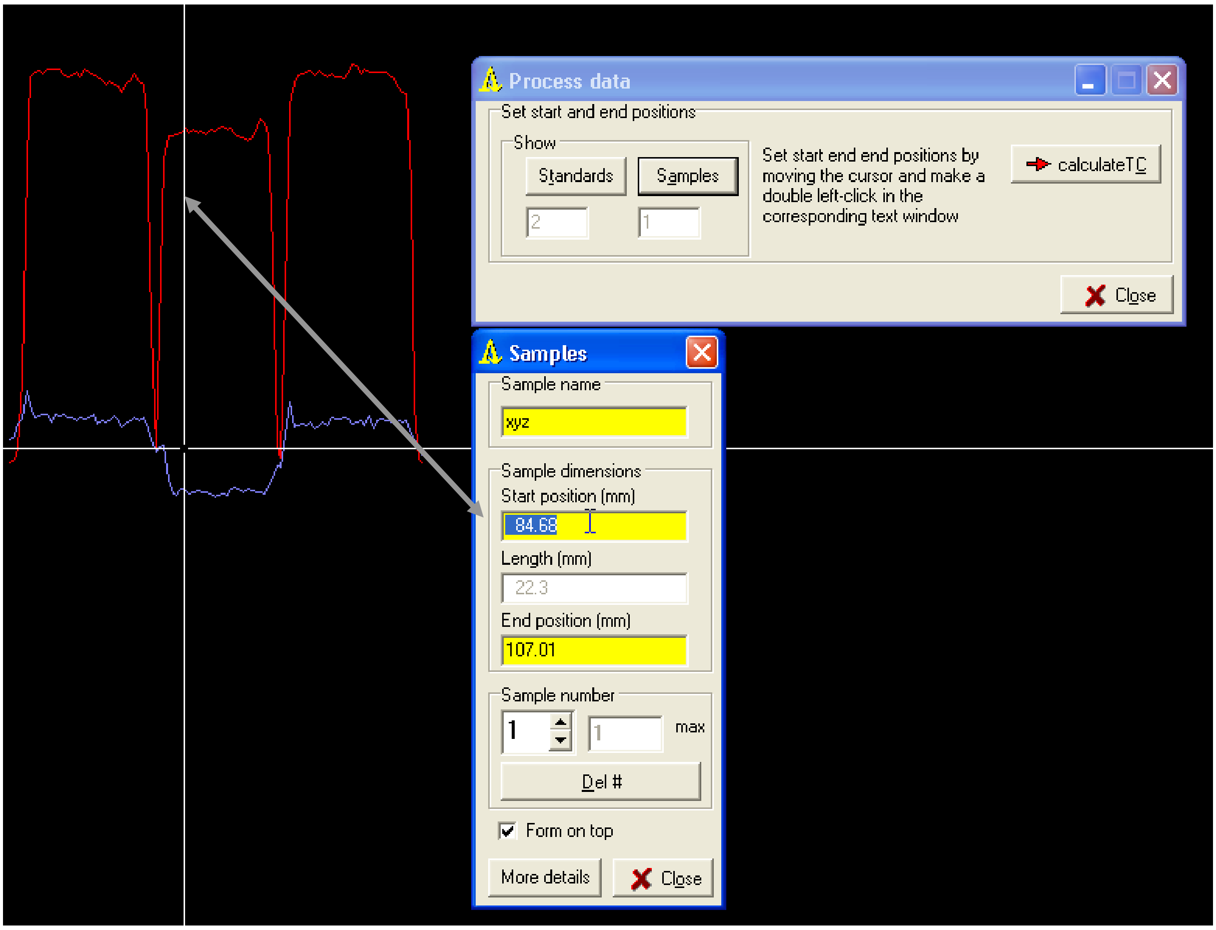


First open the standards window by pressing the respective button. Move the cursor in the temperature window using the left mouse button to the desired start position of the first standard. Then double-click into the yellow start position field. Do the same for the end position and also for the second standard.

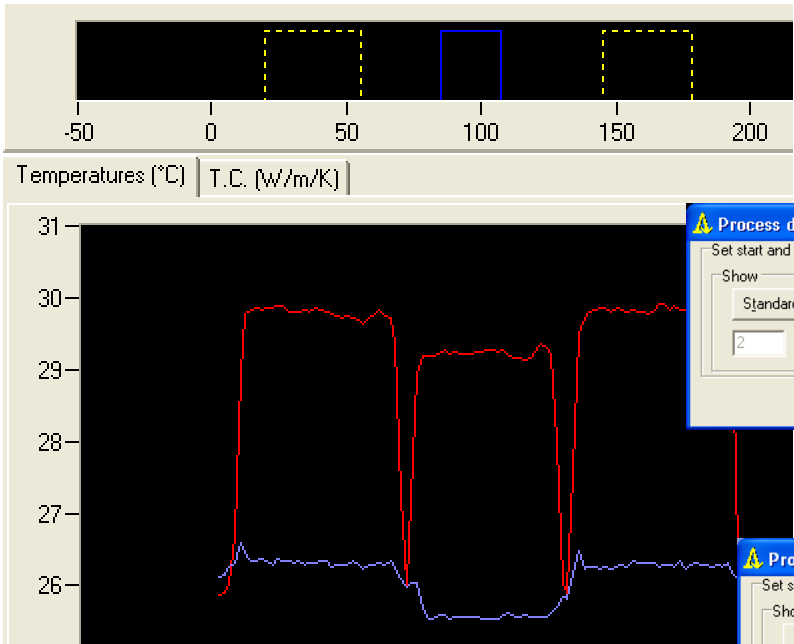
Be sure to select the characteristic temperature interval. Do not use the very beginning or ending part of the standards region to avoid any border effects (like this "hump").



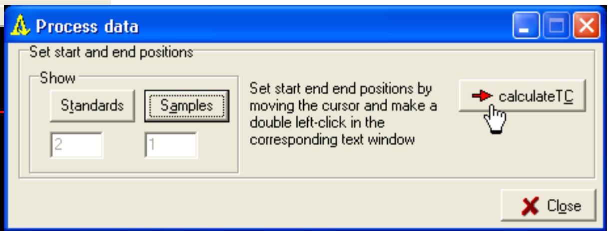
Then open the samples window and do the same for all measured samples. Each sample must be given a name.



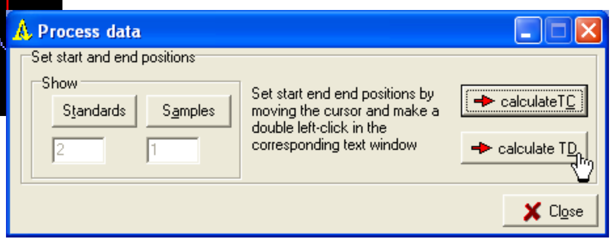
To avoid borderline effects, you should use the inner parts of the standards or samples, respectively. Example: dotted yellow lines = Standards, blue line = sample.



After finishing of the positioning, press the "calculate TC" button to let the computer calculate the thermal conductivity profiles.

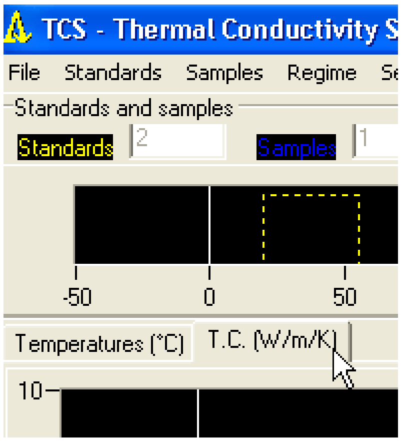


TC+TD mode: The user has to click the "Calculate TD" button also.

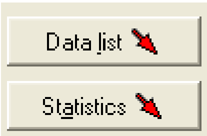


The calculated values will be stored automatically in the scan file. Clicking the "T.C." tabulator on the main program form will display the calculated thermal conductivity profile.

Clicking the "T.D." tabulator on the main program form will display the calculated thermal diffusivity profile.



The Statistics window will appear automatically. It displays the mean, minimum and maximum values of the calculated thermal properties. A new measurement will append the statistics file.



Look at the results. If not done already, save the scan file ("data list" contains the measured temperatures, thermal conductivity and thermal diffusivity profiles) and the statistics file ("statistics").

Each measurement will generate one scan file. It contains all measured and calculated data. Its extension will be "*.tx0". The scan file can be displyed by pressing the button "Data list".

The statistics file with the extension "*.dat" displays a summary of mean, minimum and maximum thermal conductivities and thermal diffusivity values measured (TC+TD mode). Usually, one statistics file will be stored for all measurements belonging to one sample collection. The statistics file can be displayed by pressing the button "Statistics".

Be sure to use different statistics files during using the TC mode or the TC+TD mode, because these two modes use different file formats (data columns).

The TCS file system is explained in the chapters "6.5.1. The data list form" and "6.5.2. The statistics form"..

5. The optical scanning technology

Introduction

The optical scanning technology was developed by Prof. Dr. Yuri Popov and is available in the commercial device named "Thermal Conductivity Scanner" (TCS), produced by TCS - Lippmann and Rauen.

The optical scanning technology is based on the scanning of the plane or cylindrical surface (along the cylinder axis) of a studied sample with a focused, mobile and continuously operated heat source in combination with infrared temperature sensors. The determination of thermal conductivity values is based on the comparison of excessive temperatures of **standard samples** (having a known thermal conductivity k_R) with excessive temperatures of one or more **unknown samples** being under heating by the movable concentrated heat source. The thermal conductivity of unknown samples is calculated as a result of a comparison of the excessive temperatures using the standard thermal conductivity values.

The simultanous measurement of thermal conductivity plus thermal diffusivity uses a 2-channel type of temperature sensor measuring 2 temperatures after heating at spots located some mm apart.

The technology provides:

- nondestructive measurements,
- high-productive measurements,
- recording of the spatial distribution of the thermal conductivity in heterogeneous matters,
- determination of the principal components of thermal conductivity of anisotropic solids at scanning of one or two surfaces
- no strict requirements to the shape, dimensions and quality of the sample surfaces.

The automatic optical scanning instrument includes:

- The flat platform to place standards and unknown samples.
- The electric-mechanical scanner with a stepper motor.
- The optical head including the optical heat source and two or three infrared sensors for the contactless recording of the sample temperatures before and after the heating (initial and excessive temperatures).
- The electronic supply unit.
- The set of standard samples (standards) with known thermal conductivity.
- The portable personal computer with the measurement and processing software TCS to control the instrument work and measurement data processing.

When standards and unknown samples are heated by the movable heat source, electrical signals from the infrared sensors are processed with the computer and transformed in thermal conductivity profiles with data on local and average values of thermal conductivity for unknown samples. It is possible to determine local values of the thermal conductivity in a heterogeneous samples for grains and areas longer than 10 mm. At scanning of a heterogeneous sample a profile of the excessive temperature is fixed which is transformed in the thermal conductivity profile.

The following characteristics are determined from the thermal conductivity profile:

- Equivalent value of thermal conductivity TC (corresponding to heat flow direction in the sample along the scanning line),
- A set of local values of thermal conductivity TC distributed along the scanning line,
- Maximum and minimal values of thermal conductivity TC_{min} and TC_{max} along the scanning line,
- The inhomogeneity factor beta being determined as = 2 $(TC_{max}-TC_{min}) / (TC_{max}+TC_{min})$.

In case of a three channel optical head, the thermal diffusivity is measured simultanously. In this mode, these additional parameters are measured:

- Equivalent value of thermal diffusivity TD,
- A set of local values of thermal diffusivity distributed along the scanning line,
- Maximum and minimal values of thermal diffusivity TD_{min} and TD_{max} along the scanning line.

The metrological characteristics of the optical scanning instrument were compared with characteristics of serial and experimental devices elaborated in:

Russia (instruments IT-k-400, KT-2, KT-3, other experimental devices based on stationary regime methods, etc.), Ukraine (IT-2, IT-3, etc.), Japan (instruments of series QTM, TC-3000), Germany (TK-04, devices based on stationary regime methods), in the USA (divided bar apparatus), in Slovakia (ISOMET), applicable in metrological, industrial and scientific institutions.

The comparisons showed a whole set of significant advantages of the optical scanning method for laboratory measurements under normal conditions (Popov Y.A., Pribnow D.F.C., Sass J.H., Williams C.F. & Burkhardt H., 1999: Characterization of rock thermal conductivity by high-resolution optical scanning. Geothermics, 28, 253-276). Additional information about the optical scanning technology is published by Prof. Dr. Yuri Popov in some scientific articles, see references.

5.1. Preparing procedures

5.1.1. Sample requirements

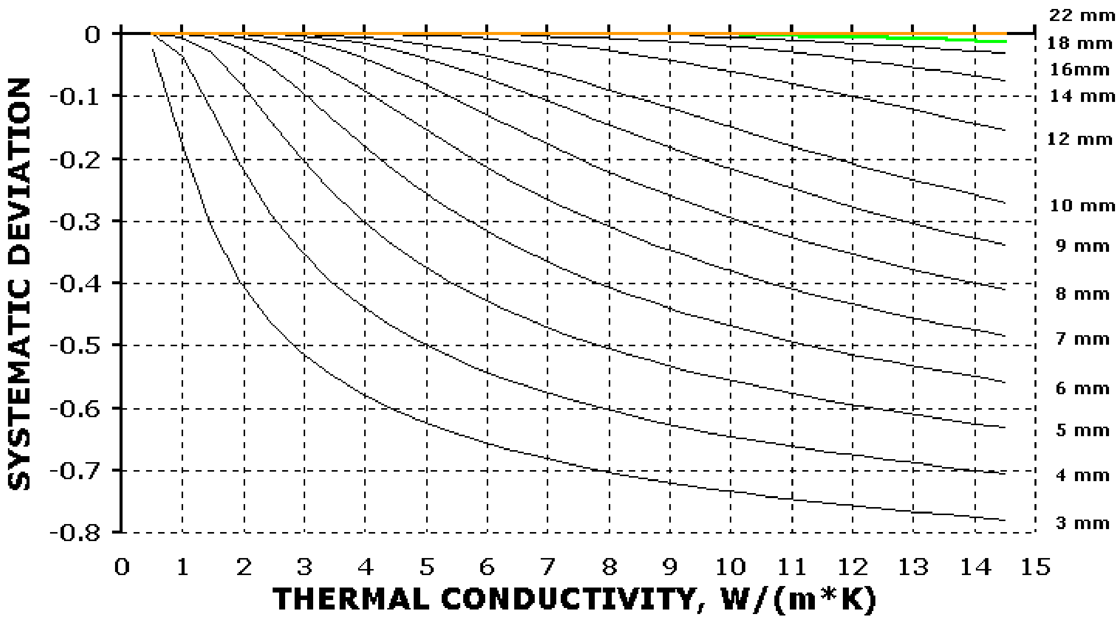
Requirements to the form and dimensions of samples

Measurements can be performed either

- on a flat surface, or
- on a cylindrical surface of an unknown sample (e.g. a drill core). In this case a scanning should be performed along the core axis. It is necessary to provide a coincidence of the scanning line on a cylindrical surface of a core with the upper plane of flat platform. Special plates (not included in the instrument set) should be used to support the cores to fulfill this requirement.

There are no other restrictions in the form of unknown samples. Unconsolidated material will not work.

The **sample length** along the scanning direction must be not less 4 cm and not more than 60 cm. The acceptable **minimum thickness of the sample** studied depends on the sample thermal conductivity and can be determined from the nomograms presented in Fig.6. The acceptable **minimal width of the sample** is equal to the minimum thickness of the sample and can be determined from the nomograms presented in Fig.6. If the sample width is equal or close to the minimum value determined from Fig.6, a scanning line must be chosen in the sample centre. The **acceptable diameter of a core sample** is 60 mm and more.



Dependence of systematic errors of thermal conductivity measurements on thermal conductivity and thickness and width of the samples studied.

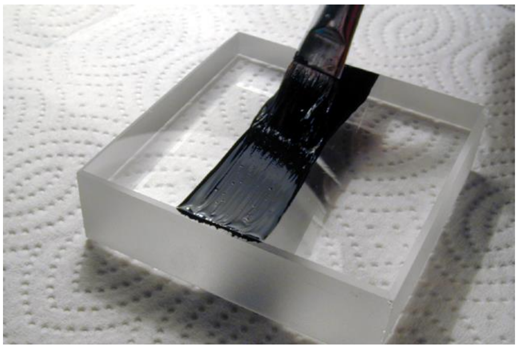
Preparation of samples

Sample surface:

The surface of an unknown sample with a treatment quality corresponding to the diamand sawing is acceptable for the measurements without any additional mechanical treatment (polishing, etc.) of the sample. A rough surface with its spatial deviations not more than +/- 0.5 mm is acceptable for the measurements also. In the case of maximum spatial deviations of the sample surface (+/- 0.5 mm), it is necessary to correct the measurement results increasing them in 5 %.

Painting:

Before the measurements every sample has be painted by a black enamel along every scanning line chosen (recommendations on *Choice of scanning lines* are given below).



Painting of a glass sample

Important for the type of paint:

- non glossy
- deep black (RAL 9005).

The enamel type of *"Acryl-Lack, wasserverdünnbar, seidenmatt, tiefschwarz RAL 9005"* is recommended by the producer for the painting. The painting can be fulfilled with a small brush or in an other way.

A width of the painted strip should be not less than 7 mm (TC mode) or appr. 15 mm (TC + TD mode). We recommend to paint a strip width of appr. 20 mm. This is appr. the width of the gap of the two top plates of the scanning platform.

A strip thickness must be provided in 25-40 µm (µm = micrometer) and is recommended to be close to equal for standards and unknown samples. If the unknown samples are transparent for optic rays within a wave lenght range of 0.37-10 µm or have a mirror surface (the last concerns metals only), double painting must be performed. In such a case, a strip thickness must be provided in 60-80 µm.

No touching by fingers, dirtying and damage of the enamel film are allowed.

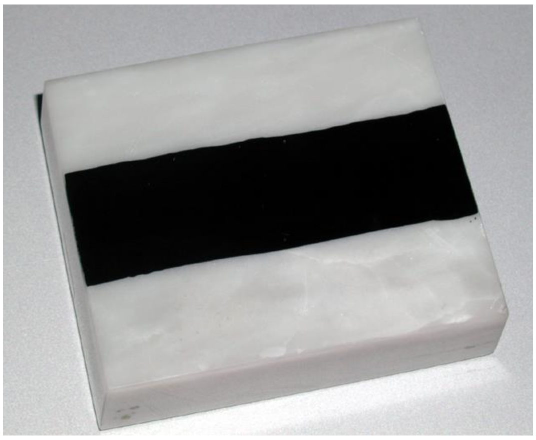
The thermal conductivity measurements must be started after full drying of samples only.

If new painting becomes necessary (for example, because of previous enamel film damage), old enamel film should be removed using the mechanical treatment of the sample surface only.

5.1.2. Standards requirements

The best quality of thermal property measurements is provided when the thermal conductivity of the two standards chosen is as closest as possible to thermal conductivity of the samples studied. Therefore, two necessary standards must be chosen finally after preliminary measurements of thermal conductivity of the unknow samples when a range of thermal conductivity for studying is clarified roughly.

The painting of standards is performed according to the recommendations for the unknow sample painting done above.



Marble reference with black enamel.

To provide more convenient measurements, one surface of a standard can be painted completely (instead of painting along a narrow strip).

5.1.3. Scanning line requirements

5.1.3.1. Choice of scanning lines for isotropic samples

The scanning line should cross the most representative areas of an unknown sample if the sample is inhomogeneous (because of possible variations in mineralogical composition, porosity, fracturing, etc.). If some areas of the sample are especially interesting for the study, the scanning line should cross these areas.

It must be taken into account that heat flow into the sample is directed along the plane perpendicular to the scanning line. It means that empty cracks with the crack plane perpendicular to the scanning line have a minimum influence on the thermal conductivity measurement results. Vice versa, the empty cracks parallel to the scanning line have a maximum influence on the results by reducing the measured thermal conductivity values. If it is wishable to exclude the parallel crack influence, it is necessary to choose the scanning line on the distance from the crack more than 1/2 of the distance determined from the nomograms in Fig. 6.

The minimum allowed distance between the scanning line and one of the boundaries of the sample must be not less than 1/2 of the distance determined from the nomograms in Fig. 6.

The sample zone responsible for the thermal conductivity measurement results is a cylinder with the axis along the scanning line and with a radius value being determined from Fig. 6. Since usually sample dimensions spread more than this zone, it is recommended to use more than one scanning line to study the thermal conductivity distribution within the inhomogeneous sample and to obtain more representative data on thermal conductivity of the infhomogeneous sample.

5.1.3.2. Choice of scanning lines for anisotropic samples

Two-dimensional anisotropy

Two-dimensional thermal anisotropy of the solid corresponds to the situation when thermal conductivity components are $k_x = k_y <> k_z$, where X, Y, Z are the principal axes of thermal conductivity.

The best quality of measurements of thermal conductivity tensor components can be provided if a flat surface of the sample is parallel to the axis Z (in such a case this surface is perpendicular to the axes X and Y). Two scanning directions should be chosen in such a case – parallel and perpendicular to the axis Z. To take into account the inhomogeneity of the sample a few parallel scanning lines can be used for every direction.

If the flat surface of the sample is inclined to the axis Z, one scanning direction must be chosen parallel to the projection of the axis Z on the flat surface of the sample, and the other scanning direction must be chosen perpendicular to the axis Z projection on the flat surface of the sample.

Three-dimensional anisotropy

The best quality of measurements of thermal conductivity tensor components can be provided if the flat surface of the sample is parallel to two principal axes (in such a case this surface is perpendicular to the third principal axis). In such a case two scanning directions should be chosen parallel to these two axes. The third scanning direction must be chosen parallel to the third axis. The third scanning must be performed on other flat (not parallel to the previous flat surface) or cylindrical surface.

If the flat surface is parallel to one principal axis only, two scanning directions - parallel and perpendicular to this axis - must be chosen on the flat surface. The third scanning direction (not parallel to two previous directions) must be chosen on an other sample surface (flat or cylindrical), which is not parallel to the previous flat surface.

To take into account the inhomogeneity of the sample, a few parallel scanning lines can be used for every direction.

5.1.4. Special requirements for the TC+TD mode

General requirements for standards

For measuring of TC only, always one pair of (more or less) equal standards is used. In the TC + TD mode, two different TD standards are necessary. The main general requirements for standards to be used are:

- TD (Standard 1) < TD (Standard 2)
- TD (Standard 2) / TD (Standard (1) < appr. 3.
  The TDs of both standards should not be too different.

General requirements for samples to be measured

The TD of the samples must meet one of the following conditions:

- TD (Standard 1) <= **TD (Sample)** < TD (Standard 2).
  In this case, the TD (Sample) should be closer to TD (Standard 1) than to TD (Standard (2):
  [TD (Sample) - TD (Standard 1)] / [TD (Standard 2) - TD (Standard 1)] < 0.6

- **TD (Sample)** < TD (Standard 1) < TD (Standard 2)
-
- **TD (Sample) must not be > TD (Standard2). This will not work.**

Special requirement = allowed combination of standards and suitable samples to be measured

The following combinations of standards and samples are calibrated:

Standard 1	Standard 2	allowed TD of samples	remarks
glass	**fused quartz**	TD < appr. 0.67 ● 10^{-6} m²/s	
fused quartz	**titanium alloy**	TD < appr. 1.9 ● 10^{-6} m²/s	**This standard setup is strongly recommended for measuring natural materials**
titanium alloy	**steel**	TD < appr. 2.6 ● 10^{-6} m²/s	

Due to the described requirements, the manufacturer strongly recommends the use of the fused quartz and the titanium standards for measuring natural rocks (expected TDs in the range of appr. $1.0 \bullet 10^{-6}$ m²/s to $2.0 \bullet 10^{-6}$ m²/s).

Standard 1
fused quartz

Unknown Sample

Standard 2
titanium alloy

Requirements for the black color line

The Sensors measuring the temperature after heating "off line" is appr. 7 mm apart from the sensor measuring the temperature "in line" after heating. Therefore it is important that the black color line is wide enough to cover both temperature channels. We recommend a color stripe width of appr. 20 mm (15 mm in minimum).

5.2. Measurement and calculation procedures

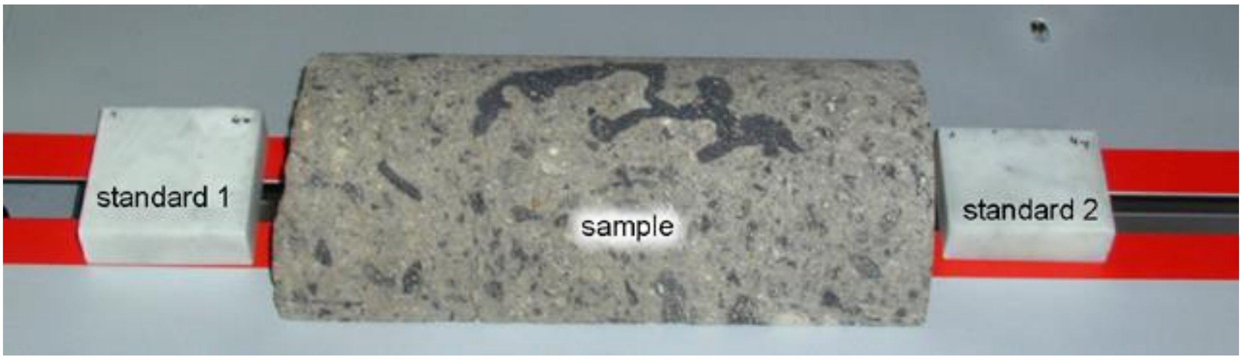
5.2.1. Preparation for measurements

Before the measurements, all unknown samples and chosen standards should be located far from heaters and protected from direct sunlight. The samples and standards should be left in such conditions at least for one hour before starting the measurement. Allow standards and samples temperatures to accomodate.

The optical scanning instrument should not be situated close to heaters, open windows and doors, ventilators, and not in direct sunlight.

First, the user must switch on the scanner unit before he starts the TCS program.

After switching on, two standards are chosen. They are placed left and right of the sample(s) on the Flat Platform.

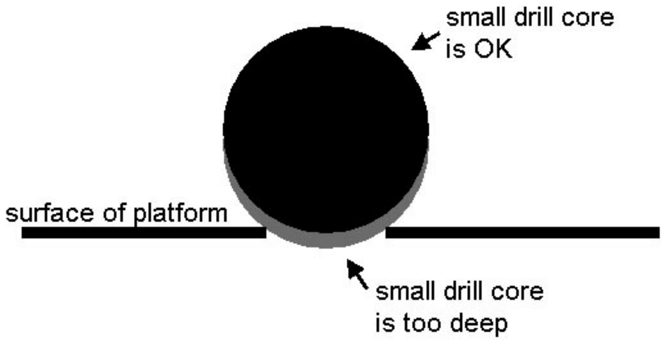


The sample is situated between the two standards.

Necessary information on the measurement regime and rock collection studied must be docked in the computer (see chapter TCS software manual).

5.2.2. Performing the measurements

If the measurements are carried out on cylindrical surfaces of cores, necessary thin flat supports must be placed on the flat platform to provide a coincidence of the vertical level of scanning lines on standards and cores. If the measurements are carried out on a flat surfaces, the supports should not be used and the samples are placed directly on the Flat Platform.



The first set of samples studied must be placed on the Flat Platform between two standards. All samples should not touch one to another and to standards. A distance of 1-2 mm between the samples and between the samples and standards along the scanning line should be provided.

The user starts the measurement procedure (➔ chapter "4. quick start guide" and ➔ chapter "6. TCS - software manual") and observes the temperature profiles on the computer screen. The following information should be taken into account when an observation of standard and sample temperature profiles:

(1) The blue profile corresponds to the initial temperature of the standards and unknown samples (recorded by the "cold" sensor), the red profile corresponds to the standard and sample temperatures after heating ("hot" sensor). In case of TC+TD measurements, an additional bright red color line is visible. This is the temperature of the off line sensor "hoty".

(2) The distribution of unknown sample temperatures recorded by the "hot" sensor and presented in the computer screen during the measurement time is inverse proportional to the thermal conductivity values. The sample temperatures recorded by the 2nd "hoty" sensor presented in the computer screen by bright red color is used additionally for the calculation of the thermal diffusivity values.

(3) The sharp increases of the temperatures at standard and sample boundaries are caused by so-called "boundary thermal effects" and do not represent any useful information about the sample thermal conductivity.

No operations within the software (e.g. replacing standards and samples) are allowed when the measurement procedure started.

5.2.3. Data processing

When the scanning is finished, the user must choose the parts of the temperature profiles of the standards and samples for the thermal conductivity calculation.

For every standard and sample profile it is necessary to save the middle part of the profile ecxluding the left and right parts of the profile corresponding to the boundary effects described above.

A single crack situated in parallel or inclined to the scanning line can reduce the thermal conductivity significantly. If this crack is considered to be not representative for the sample, it is necessary to exclude the profile part corresponding to the crack from the processing and thermal conductivity calculation.

5.2.4. Measurements and data processing for anisotropic samples

Necessary mesurements are carried out for the scanning lines chosen and described above (see *"Choice of scanning lines for anisotropic samples"*). In the general case, thermal conductivity values determined for every scanning line (so-called "apparent thermal conductivity" values) do not present an information about thermal conductivity tensor components and must be used for following calculations of the tensor components on the formulas given below.

Two-dimensional anisotropy ($k_x = k_y <> k_z$)

Situation 1:

The situation when a flat surface of the sample is parallel to the axis Z and two scanning directions were chosen – scanning direction 1 parallel to the axis Z and scanning direction 2 perpendicular to the axis Z.

Apparent thermal conductivity values k_1 and k_2 are determined for scanning directions 1 and 2, respectively. The principal components of thermal conductivity tensor can be determined from the formulas:

$k_x=k_y=k_1$;
$k_z=(k_2)^2/k_1$.

Situation 2:

The situation when a flat surface of the sample is inclined to the axis Z with an angle α, scanning direction 1 was chosen parallel to the projection of the axis Z on the flat surface of the sample studied, and scanning direction 2 was chosen perpendicular to the axis Z projection on the flat surface of the sample.

Apparent thermal conductivity values k_1 and k_2 are determined for scanning directions 1 and 2, respectively. The principal components k_x (k_y) and k_z of thermal conductivity tensor can be easily determined from solution of the equation set:

$k_1=(k_x^2\cos^2\alpha +k_yk_z \sin^2\alpha)^{1/2}$,
$k_2=(k_xk_y)^{1/2}$.

Three-dimensional anisotropy ($k_x <> k_y <> k_z <> k_x$)

Situation 1:

The situation when a flat surface 1 of the sample is parallel to two principal axes X and Y. Two scanning directions 1 and 2 on a flat surface 1 were chosen parallel to the axes X and Y respectively. Scanning direction 3 on an other surface (flat or cylindrical) was chosen parallel to the axis Z.

Apparent thermal conductivity values k_1, k_2 and k_3 are determined for scanning directions 1, 2 and 3, respectively. The principal components k_x, k_y, k_z of the thermal conductivity tensor can be determined from the formulas:

$k_x=k_2k_3/k_1$;
$k_y=k_1k_3/k_2$;
$k_z=k_1k_2/k_3$.

Situation 2:

The situation when a flat surface is parallel to one principal axis (Z) only, two scanning directions 1 and 2- parallel and perpendicular to this axis respectively - were chosen on the flat surface. Scanning direction 3 was chosen on other sample surface (flat or cylindrical) as not parallel to the previous two scanning directions.

Apparent thermal conductivity values k_1, k_2 and k_3 are determined for scanning directions 1, 2 and 3, respectively. The principal components k_x, k_y, k_z of thermal conductivity tensor can be determined from the solution of the equation set:

$k_1=(k_xk_y+k_xk_z\cos^2\beta_1+k_yk_z\cos^2\gamma_1)^{1/2}$
$k_2=(k_xk_z\cos^2\beta_2+k_yk_z\cos^2\gamma_2)^{1/2}$
$k_3=(k_xk_y\cos^2\varphi_3+k_xk_z\cos^2\beta_3+k_yk_z\cos^2\gamma_3)^{1/2}$

where φ_3 is the angle between axis Z and scanning line 3, β_1, β_2, β_3 are the angles between axis Y and scanning lines 1, 2, 3, respectively, γ_1, γ_2, γ_3 are the angles between axis Z and scanning lines 1, 2, 3, respectively.

Situation 3:

The situation when 3 non-parallel scannings along the scanning lines 1, 2, 3 can be performed on two non-coplanar surfaces of the sample.

Apparent thermal conductivity values k_1, k_2 and k_3 are determined for scanning directions 1, 2 and 3, respectively. The principal components k_x, k_y, k_z of thermal conductivity tensor can be determined from the solution of the equation set:

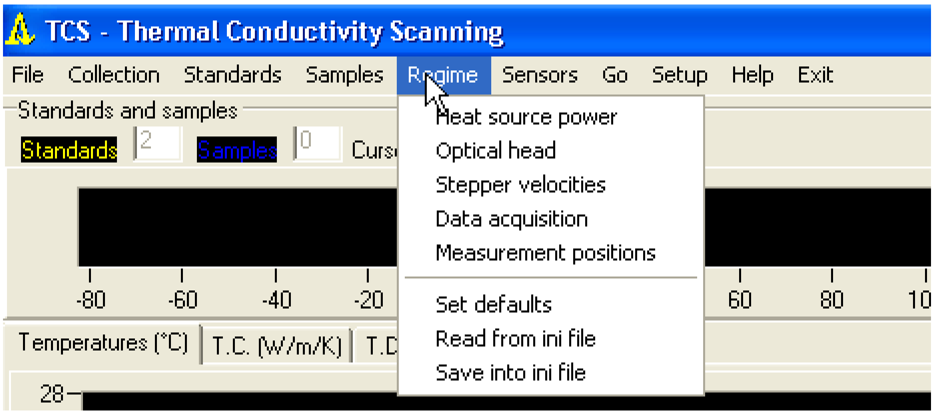
$k_1=(k_xk_y\cos^2\varphi_1+k_xk_z\cos^2\beta_1+k_yk_z\cos^2\gamma_1)^{1/2}$;
$k_2=(k_xk_y\cos^2\varphi_2+k_xk_z\cos^2\beta_2+k_yk_z\cos^2\gamma_2)^{1/2}$;
$k_3=(k_xk_y\cos^2\varphi_3+k_xk_z\cos^2\beta_3+k_yk_z\cos^2\gamma_3)^{1/2}$,
where φ_1, φ_2, φ_3 *are* angles between axis Z and scanning lines 1, 2, 3 respectively, β_1, β_2, β_3 are angles between axis Y and scanning lines 1, 2, 3 respectively, γ_1, γ_2, γ_3 are angles between axis Z and scanning lines 1, 2, 3 respectively.

6. TCS software manual

6.1. General program features

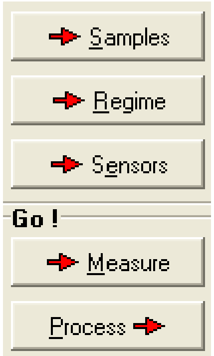
The file "TCS.EXE" contains the program code. After starting the program, the main form appears. It contents the main menue in the upper part, the list of buttons in the right part and the data displays in the central part of the screen.

The main menue:



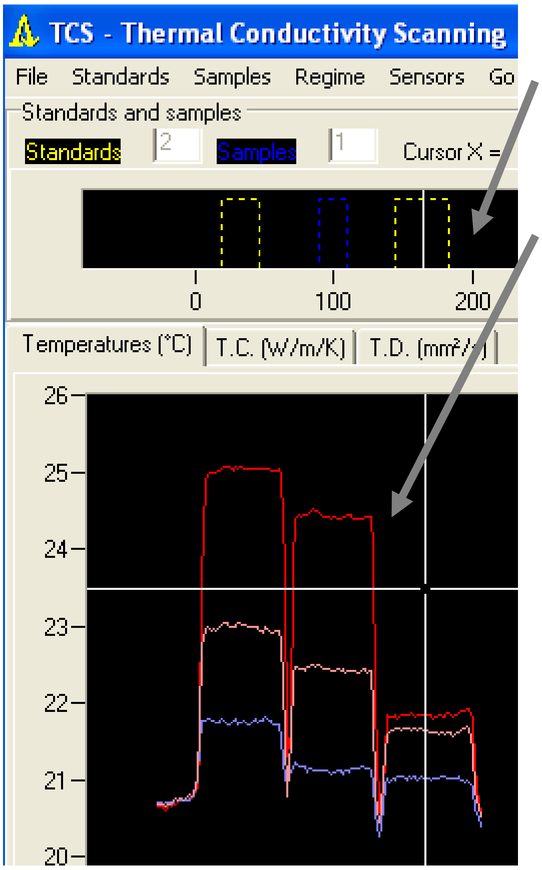
The main menue gives access to all options. Some details, like program setup properties, are available only by the main menue. Most of the other details are available by pressing one of the buttons as well. Setup and other properties can be saved into the initializing file and can be read from this file. By pressing "Set defaults", the default values, which are contained in the program code, are restored.

The buttons:



All necessary options are controlled by clicking one of the buttons. In the case of normal routine measurements, these buttons would be used instead of clicking the main menue. Normal routine work will be done by clicking the buttons in a "top-down" order, ➔ chapter "3. Short course: How to perform a measurement". The buttons can be activated by left-clicking with the mouse or by pressing the underlined character on the keybord or by pressing the "return" key (only in the case, when the button is highlighted).

The displays:



Three different data displays are available.

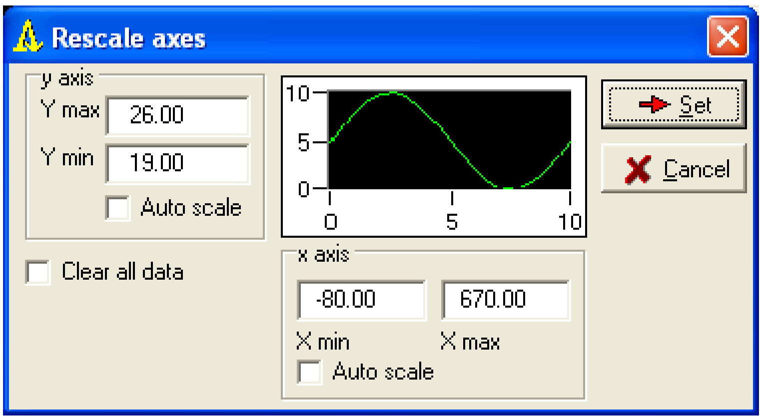
(a) The narrow display in the top contains information as box plots about the standards (yellow dashed lines) and samples (solid blue lines) which are used at the moment.

(b) The masured temperatures are displayed in the "Temperatures" display. The red line corresponds to the temperature of the "hot sensor", i.e. the sensor which measured the temperature after heating.The blue line corresponds to the "cold sensor", i.e. the sensor measuring the initial temperatures before heating. In the TC+TD mode, an additional orange line is visible. This corresponds to the data of the "off line" sensor hoty.

(c) Clicking the "T.C." tabulator opens the thermal conductivity display, where the calculated thermal conductivity values are plotted. Clicking the "Temperature" tabulator re-opens the display of temperatures.

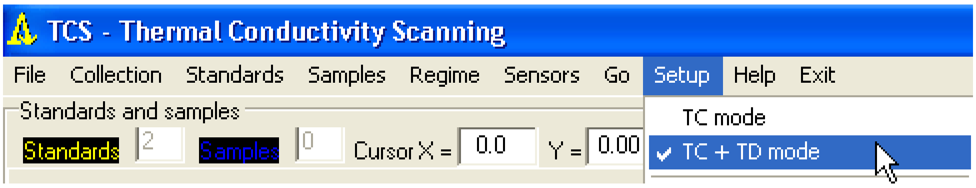
(d) The "T.D." tabulator opens the thermal diffusivity display (TC+TD mode only).

These and all other displays appearing during the run of the program can easily be rescaled: The user has to double-left click in the respective display window and the appearing "Rescale axes" form allows any rescaling, including automatic rescaling and clearing.



6.1.1. TC mode and TC + TD mode

Depending on the infrared sensor equipped, the TCS machine is able to measure in two different modes (➔ chapter "6.3.2 Program setup" for switching the modes).



TC mode

The apparatur measures thermal conductivity only. No measurement of thermal diffusivity is possible. Each TCS apparatus is able to measure in the TC mode.

TC + TD mode

The apparatus measures in the combined mode, that means thermal conductivity and thermal diffusivity are measured simultanously. Only a TCS apparatus equipped with the 2-channel infrared sensor is able to measure in the TC + TD mode.

6.1.2. File management

The file "TCS.INI" contains information about the general program settings. It is located in the Windows user application directory and is read automatically during starting of the program. This file can be edited by the "Setup" options in the program. It is strongly recommended not to edit this file by an external editor (e.g. "Notepad") to avoid any problems in reading this file.

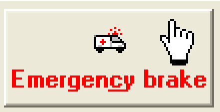
The file "TCS.CFG" contains information about the hardware and all calibrations. It is located in the program directory (same as for the main program "TCS.EXE") and is read automatically during starting of the program. This file MUST NOT BE CHANGED manually by the user. **Since TCS software version 4.00, the user is able to edit standards and calculate own calbrations,** which will update the TCS.CFG configuration file. See ➔ chapter "6.3.2. Standards edit / calibration" and ➔ chapter "6.3.2.1. How to perform own calibrations".

The sample collection name is given in the program. All data and statistics files are stored in the directory, which equals the sample collection name. Different sample collections are stored in different directories.

The scan files are stored with names like e.g. "MARBLE01.TX0". All scan files have the same extension "*.TX0". The scan files contain the used program settings, the original measured temperatures as well as the calculated thermal conductivities. Formerly saved scan files can be re-read and re-calculated if it is necessary.

For each sample collection, a statistics file is saved. It is named e.g. "MARBLES.DAT" with the extension "*.DAT" and contains the calculated mean values and other properties. The statistics file will be appended by each new measurement.

6.1.3. Emergency brake



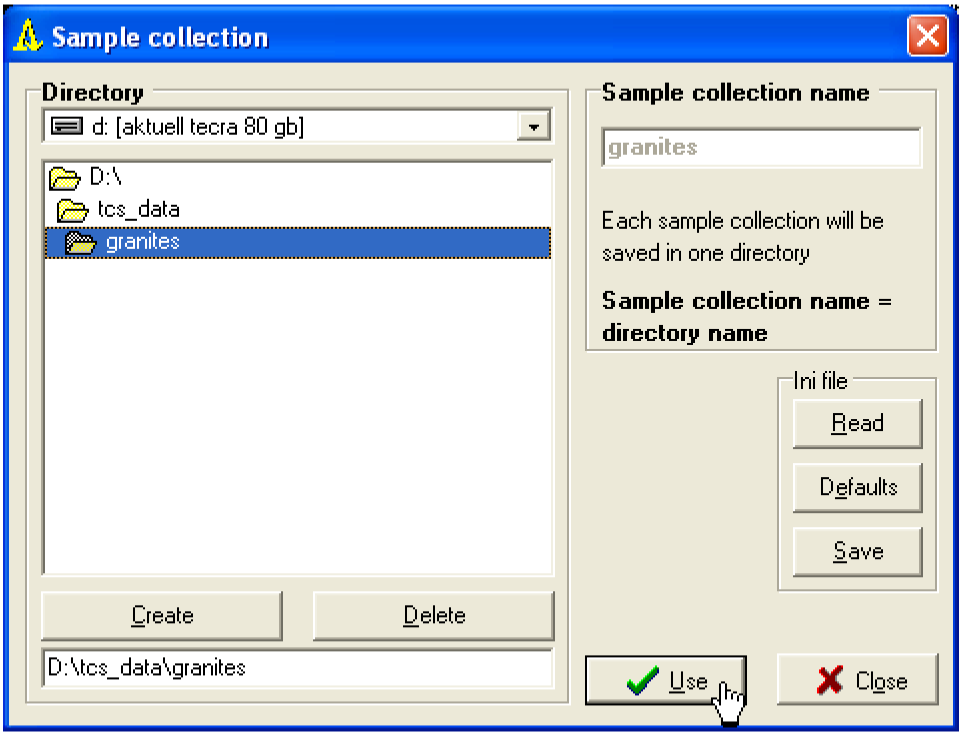
Pressing this button immediately stops heating as well as moving. This option can be very useful, if the user notices some serious problem. A serious problem could be e.g. to high heating power, which can result in burning of some material like paper (➔ chapter "3. Safety requirements").

Pressing of this button leads to a hard break in the software. Some parts of the software may not function properly after this emergency brake. Therefore, it is strongly recommended to exit and re-start the program.

6.2. Set parameters

6.2.1. Collection

Clicking this button opens the sample collection form:



The name of the sample collection is asked. The sample collection equals the "last path" of the directory, where the scan files and the statistics files will be saved later. In the above example: the collection is "granites". The folder with the same name is located in the "tcs_data" folder.

The sample collection name will be saved in the "TCS.INI" initialization file and used after the next program start.

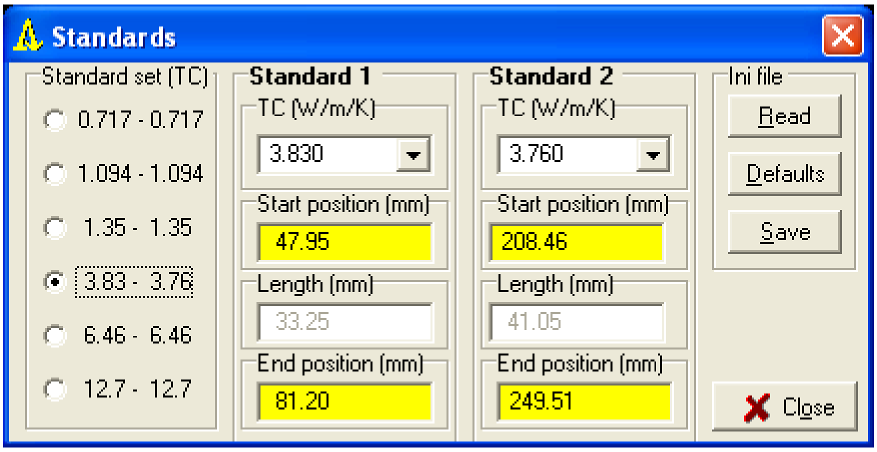
By clicking the button "Use directory", the sample collection name is set to the used directory. Afterwards, the user is asked to open the statistics file. The statistics file name is set to the sample collection name + extension ".dat" by default, but can be changed by the user.

It is recommended to create one statistics file for each sample collection.

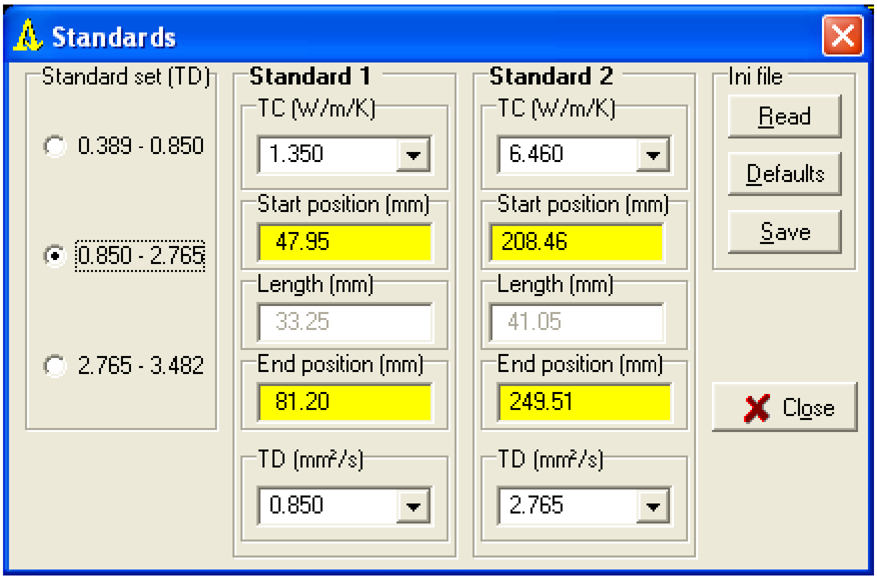
6.2.2. Standards

This button opens the form with the main standard properties:

TC mode: The user chooses one of the displayed pairs of standards. Other combinations than the mentioned ones are not possible. **Please notice:** if there are two different values of thermal conductivity within a pair of standards (e.g. 3.83 and 3.72 in the example), it is very important to place the standards in this suggested sequence. The displayed example means to place first the standard (3.83), then the sample(s), and then the standard (3.76).



TC+TD mode: The user chooses two standards, which are not a pair. The respective thermal diffusivities of the standards are shown too. If the user chooses standards which are not allowed, a message will appear.



The yellow text boxes contain information about the standard positions. These positions can be edited by two ways:

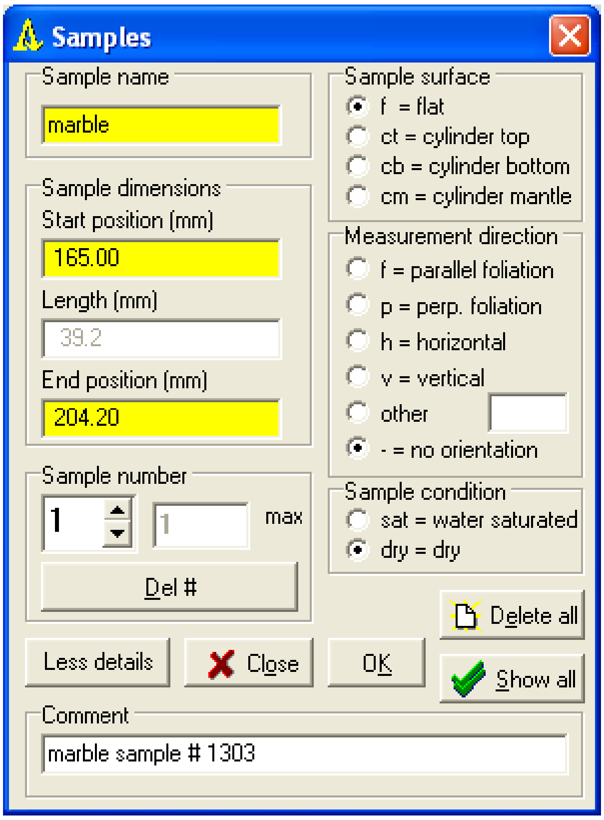
(a) by clicking the respective text box and rewriting the start and end positions, or

(b) by moving the cursor in the central temperature display up to the desired position. Catch the cursor by press the left mouse botton and move the mouse. Double-left clicking the suitable yellow text box will take the cursor position from the central temperature display.

The standard properties can be read from or saved saved into the initialization file by clicking "Read" or "Save", respectively. Clicking "Defaults" will resore default values. After closing of this form, the "Samples and standards" display is updated.

6.2.3. Samples

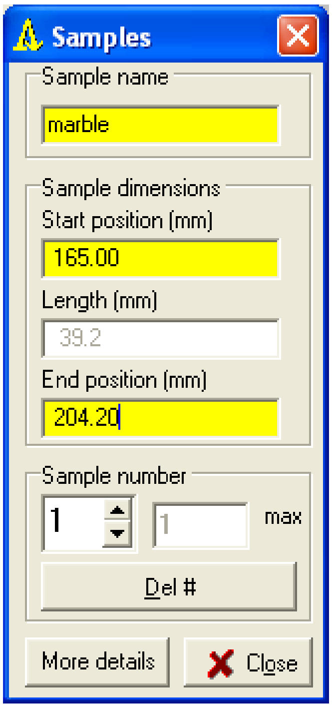
This button opens the samples form.



This form displays all sample information. The yellow text boxes must be filled out, the other properties are not necessary. The start and end positions can be edited - like in the standards case - using two ways:

- by clicking the respective text box and overwriting the positions or
- by moving the cursor in the central temperature display (in the main form) up to the desired position and then by double-left clicking the suitable yellow text box.

The button "OK" accepts all changes. The button "Del #" deletes the information about the actual sample, the button "Delete all" will delete all samples. Clicking "Show all" will open a new form containing a table with all sample information.



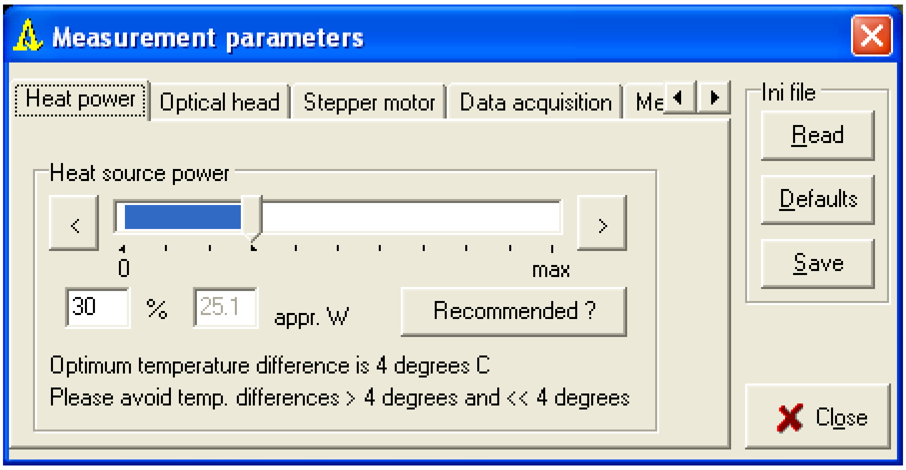
Clicking the "Less details" button will reduce the size of the form. The reduced form gives access to the most important properties.

After closing of this form, the "Samples and standards" display in the main form is updated.

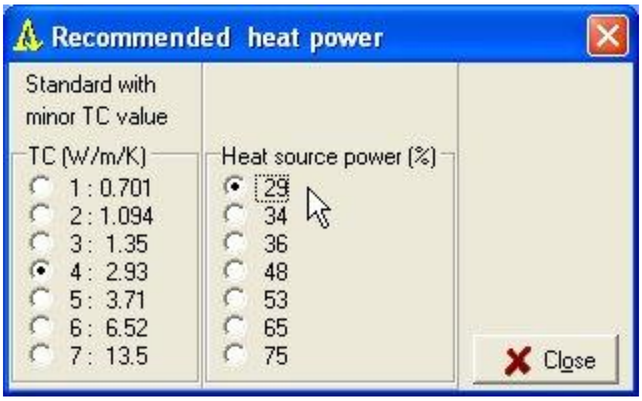
6.2.4. Regime

This button opens the form, which contains information about all measurement properties. The following two properties are the most important:

(a) Setting of the proper heat source power (Tabulator "Heat power").



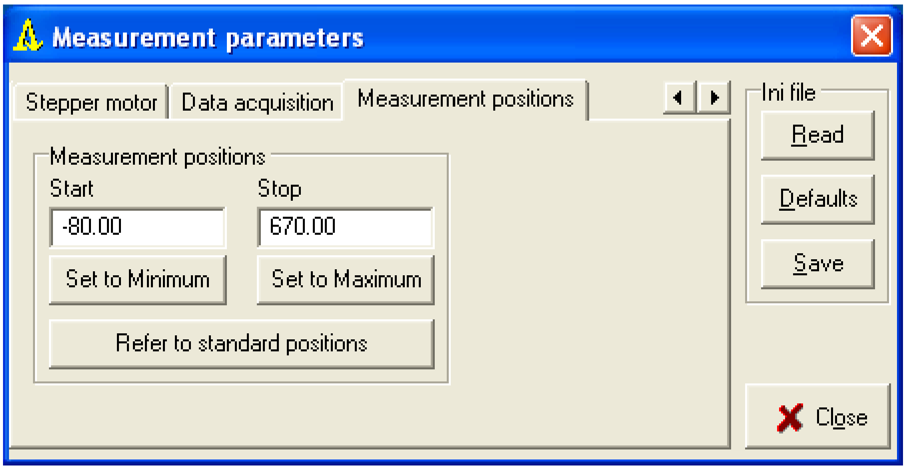
The slider in the "Heat source power" box gives the power in per cent. This value is calculated into the approximate electrical power in Watts and is displayed also. Clicking the button "Recommended ?" opens a form with default values depending on the used standards. This heat source value will be correct for most cases, when the sample thermal conductivity is in the same order (not less) than the standard conductivities. It is strongly recommended, that the user carefully sets the proper heat source power. Too high heat source power (> 4 °C) could result in damaging of the black painting and even in thermal damaging of sensitive samples (see chapter "3. Safety requirements").



For complete unknown thermal properties of the samples, the following approach is recommended: Use the standards with the lowest thermal conductivities and set the respective heat source power. Measure the samples. Change, if necessary, the used standards and heat source power and re-measure the samples until the measured temperature differences are appr. 3 to 4 °C, not more than 5 °C. Then the results will be best.

Adjustements in this form can be stored in the initializing file.

(b) Setting of start and stop positions of the moving line of the optical head (Tabulator "Measurement positions").



The positions are given with respect to the heat source position. That means, if the heat source is located at position = 0 mm, the "hot sensor" will be located at -50 mm and the "cold sensor" at +50 mm, depending on the mechanical separations between the sensors and the heat source.

The maximum and minimum of the possible positions can be chosen by clicking the respective buttons "Set to minimum" and "Set to maximum". If the standard positions are set already, the button "Refer to standard positions" will calculate the suitable positions. If the user gives own positions, he should take care of the distances of the sensors to the heat source, e.g. if the 1st standard begins at 0 mm, the measurement should start at -50 mm to cover the complete distance range.

For routine measurements, it is recommended not to change these parameters. These are set by default to minimum and maximum values. After starting of the measurement scan, the user will look at the central temperature display and will be able to stop the measurement by pressing the "Stop" button at the appropriate position.

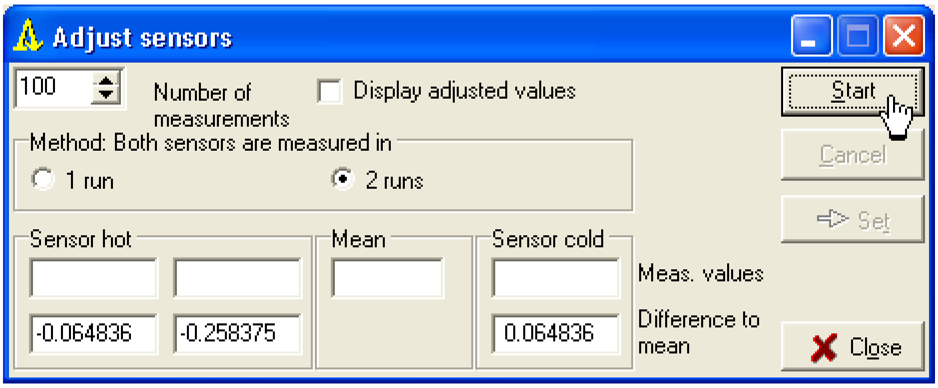
Parameters in this form can be stored in the tcs.ini file.

6.2.5. Sensors

Before each starting of a scanning line, the sensors should be adjusted carefully. During this adjustment, an offset in the two sensor readings is measured and taken into account for the following measurements. The sensors adjustment procedure can be done manually or automatically (➔ chapter 6.3.2).

The program offers a more sophisticated sensor calibration procedure as well. This detailed sensor calibration takes into account the offsets in the sensor readings and in the sensor sensitivities as well. The complete sensor calibration was done by the manufacturer already and will be necessary only after changes in the sensor setup, e.g. by replacing one of the sensors (➔ chapter 6.3.1. sensor calibration).

The adjustment procedure works as follow: The sensors are covered by a sample (e.g. a standard sample). It is important to use a sample with constant and homogeneous temperature. Do not use a sample which was heated during a standard measurement before. Clicking the button "Start" will start the adjustment procedure. During the adjustement, the sensor output temperatures are read, mean values are calculated and a third, adjusted, mean is calculated from the two sensor mean values. The differences to the adjusted mean will automatically be taken into account during the following scan.



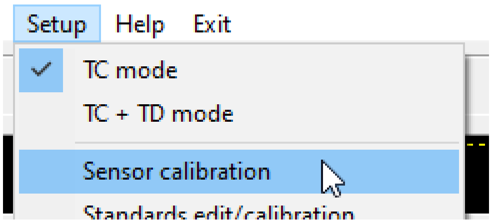
The adjustment values can be measured using two different methods:

- The method "1 measurement" observes the two temperatures at the same time. In this case, the sample used must cover both sensors. The option ″automatic adjustment″ uses this ″1 measurement″ method, where the sensors are covered by a metal sample.
  It is also possible to remain the sensors looking to the room ceiling, without any covering with a sample. In this case, the ceiling temperature is measured. Depending on the diverging measuring angle, huge volumes and areas are measured, which could increase errors. This is not recommended.
- In method 2, a reference sample is placed onto one sensor after another and the adjustment measurements are done in the same order. **The method "2 measurements" is recommended.**

It is recommended to do the adjustment procedure before each measuring scan.

6.3. Setup

6.3.1. Sensor calibration



The sensor calibration procedure is part of the program setup and accessed by the main menue only (➔ chapter "6.1. General program features"). This detailed sensor calibration takes into account:

- the offsets in the sensor readings and
- in the sensor sensitivities as well.

The **offsets** in the sensor readings should be adjusted before each measurement by the "*Sensors: Adjust the sensors"* procedure (➔ chapter 6.2.5). The calibration of the sensor **sensitivities** was done by the manufacturer already and will be necessary only after changes in the sensor setup, e.g. by replacing one of the sensors.

The calibration principle

If the combined mode TC+TD is available, this combined mode must be active during the sensor calibration. This is important for calibrating both sensors "hot" and "hot y".

The calibration is done using two samples with different temperatures: a "cold" sample and a "warm" sample. For both sensors calibration values at these two temperatures, referring to these two samples, are determined. This calibration procedure is repeated several times. During cooling of the "warm" sample and heating up of the "cold sample", different temperatures are realized.

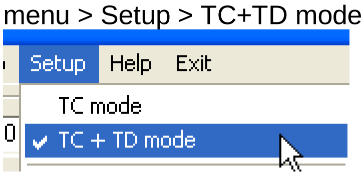
This way, several sensor calibration values for different temperatures are measured. A regression analysis of these values is performed. From the regression line, three values for each sensor are computed and used for further calibrations:

- the "cold" temperature
- the calibration value at this temperature. The calibration values of both sensors have the same amount, but different signs.
- the slope of the regression line. Also the slopes referring to the two sensors have the amount, but different signs.

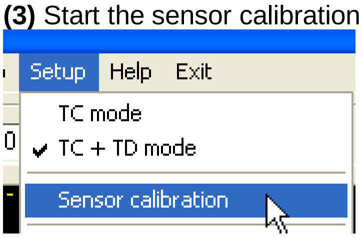
Performing the calibration procedure

(1) Choose two homogeneous samples with not too low specific heat capacity. These may be two references, e.g. the two titanium samples. Place one of the samples into an oven at appr. 40 degrees C (this will be later the "warm" sample), the other in a refrigerator at about 10 degress C (this will be later the "cold" sample) for approximately one hour.

(2) Start the TCS program and make sure that the combined TC+TD mode is active (if available). TCS main menu > Setup > TC+TD mode.



(3) Start the sensor calibration form by TCS main menu > Setup > Sensor calibration.

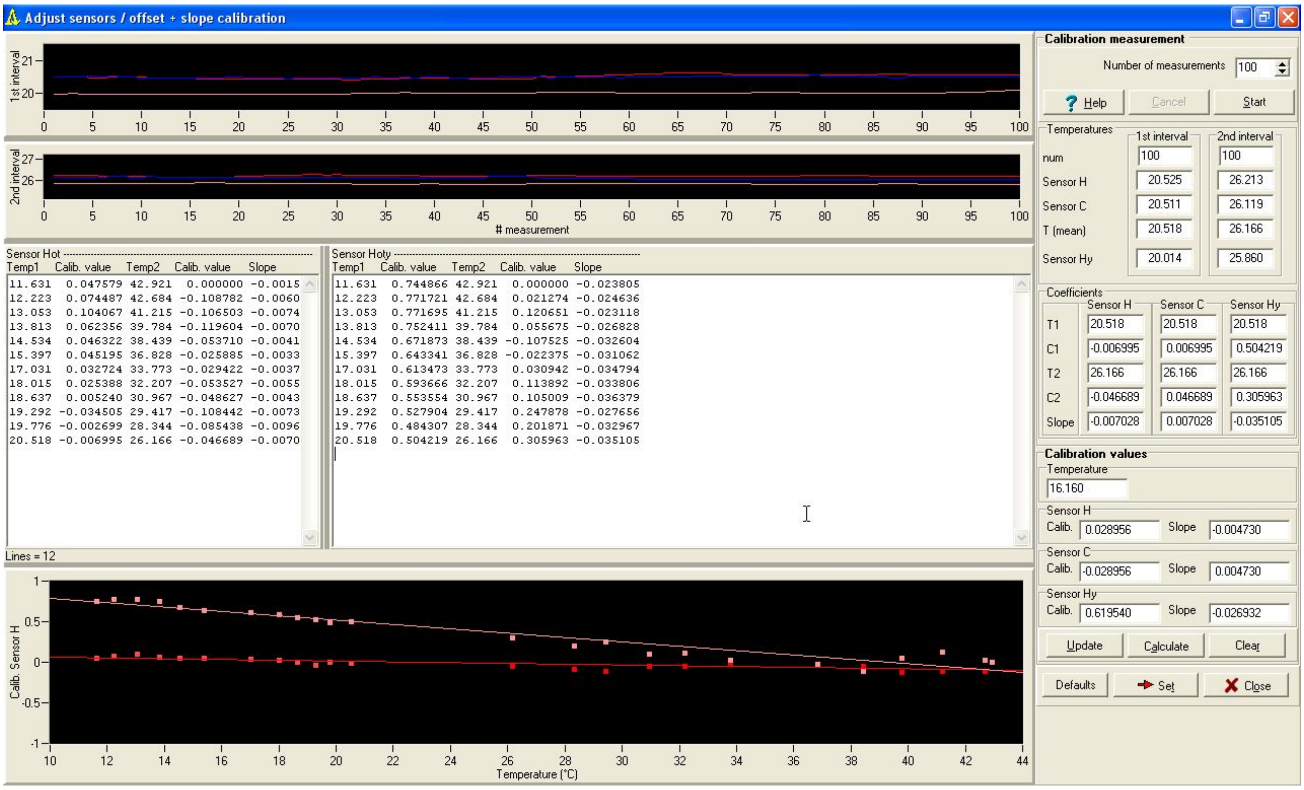


(4) Take the two samples from the oven (= "warm" sample) and the refrigerator (= "cold" sample) and bring them near the TCS instrument.

(5) Press the "Start" button. The user is adviced to perform three steps:

- "Cold" sample on "Sensor Hot", "warm" sample on "Sensor Cold",
- " warm" sample on "Sensor Hot", "cold" sample on "Sensor Cold"
- and again "cold" sample on "Sensor Hot", "warm" sample on "Sensor Cold".

After completing this cycle, the measured temperatures are written in the text memo and displayed in the graphics. The calibration values of the sensor Hot are displayed (the respective values of sensor cold have the same amount, but the opposite sign). In case of the TC+TD mode, the calibration values of the 2nd sensor hoty are displayed too.



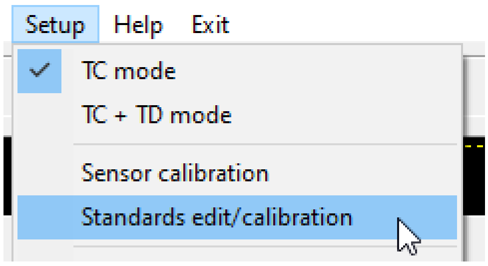
(6) These calibrations are performed several times to get several calibration temperatures. The program uses a regression line calculation from the measured temperatures for best fits automatically.

The user is able to edit the memo box, e.g. to delete outliers. Pressing the "Calculate" button updates the regression line and calculates the new calibration values.

This calibration cycle should be repeated some times. The user should take care of the correct positioning of the samples to measure as exactly as possible the same points of the samples in case of the both sensors. In order to get good statistics, maybe 10 cycles are sufficient.

(7) The calculated calibration values will be used by pressing the "Set" button. The values are not saved automatically. To save the values in the initializing file (TCS.INI), it is necessary to click the "Save" button in the program setup menue.

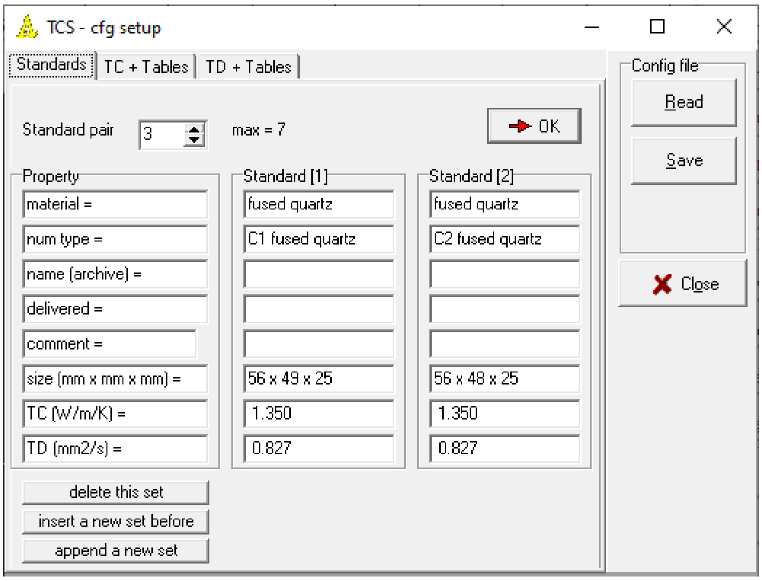
6.3.2. Standards edit / calibration



This menue gives access to all features related to the standards. The user is able to:

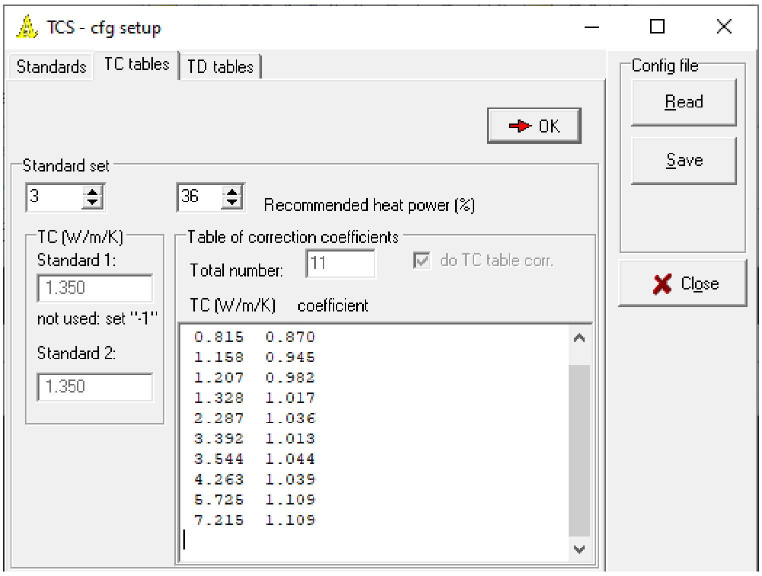
- edit standards parameters, delete standards or add new standards
- edit calibration tables for TC or TD
- make own calibration measurements for TC or TD

Tabsheet "Standards"



This tab gives access to standards parameters, like names, thermal conductivity, thermal diffusivity, comments.

Tabsheet "TC tables"

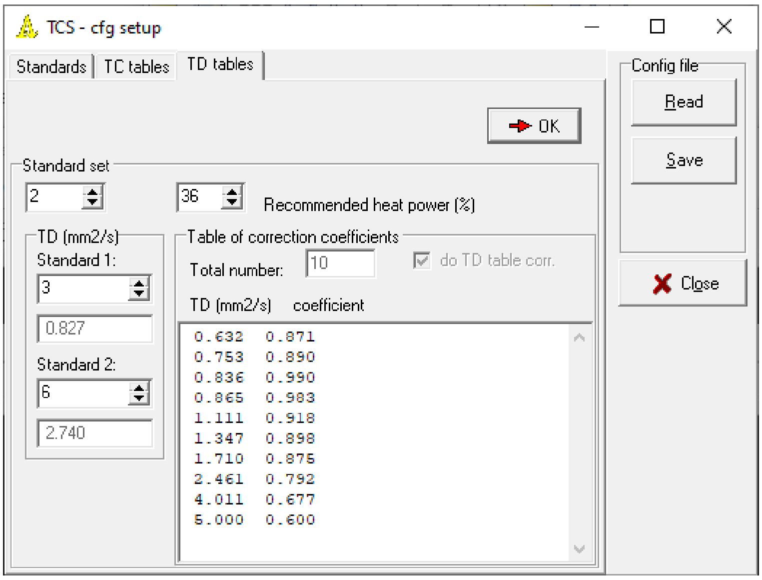


This tab shows the recommended heat power setting (in %) and the thermal conductivity correction table settings. The correction will be calculated like this:

TC (corrected) = TC (measured) * coefficient

TC (measured) and the coefficient will be interpolated between the given values.

Tabsheet "TD tables"



This tab shows the thermal diffusivity correction table settings. The correction will be calculated like this:

TD (corrected) = TD (measured) * coefficient

TD (measured) and the coefficient will be interpolated between the given values.

6.3.2.1 How to perform own calibrations

The TCS machine is calibrated yet by the manufacturer. A new calibration is not necessary under normal circumstances. A new calibration may be necessary by following facts:

- adding new standards by the user
- replacement of sensor hot. The sensor cold is not as critical.
- replacement of heat source / lamp
- re-adjustment of sensors or heat source

User calibrations are possible using the TCS software version 4.00 and later.

The calibration principle

- a set of samples with known thermal properties is provided
- a set of standards is choosen
- the user has to perform measurements of the samples, using the set of standards. During these measurements, the calibration tables are switched off.
- the program calculates the respective correction coefficients from the measuremets
- the respective correction coefficients have to written into the TCSD.CFG configuration file

There are 2 calibration modes:

TC calibration mode: The TC calibration table is switched off. All measurements will be performed without the usage of the TC calibration table. The respective TC correction values are calculated. The TD calibration table is not used.

TD calibration mode: The TC calibration table is switched on and the TD calibration table is switched off. All measurements will be performed with the usage of the TC calibration table and without the usage of the TD calibration table. That implies, that in case of a complete user calibration, the TC calibration has always to be done first and the TD calibration later.

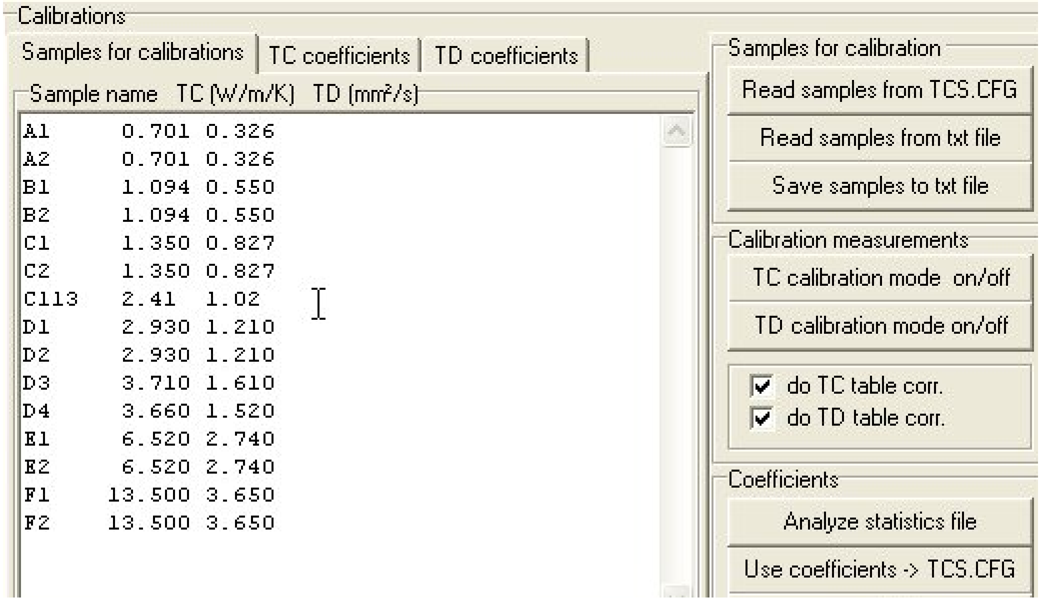
The principle steps explain to perform a complete own calibration:

(1) Optimum ambient conditions

Be sure to have optimum ambient conditions ➔ chapter ″2.1. Ambient and measurement condition″.
Be also sure that the sensors are calibrated well ➔ chapter ″6.3.1. Sensor calibration″.

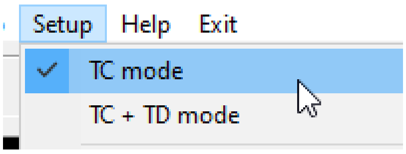
(2) Set of samples with known thermal properties

Prepare a set of samples with known thermal properties (thermal conductivity and thermal diffusivity). This set may be the standards set delivered by the manufacturer. Clicking ″Read samples from TCS.CFG″ will read the references and set these as samples.



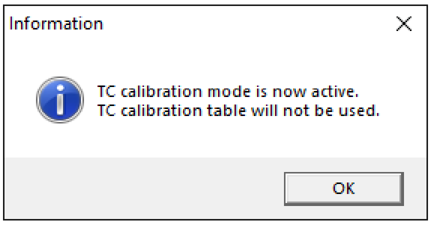
This set may be completed by own samples, if available. The more samples are used for calibration measureemnts, the better. In the above example the references A1, A2, .. F1, F2 are read and completed by the additional sample C113.

(3.1.) Switch on the TC mode



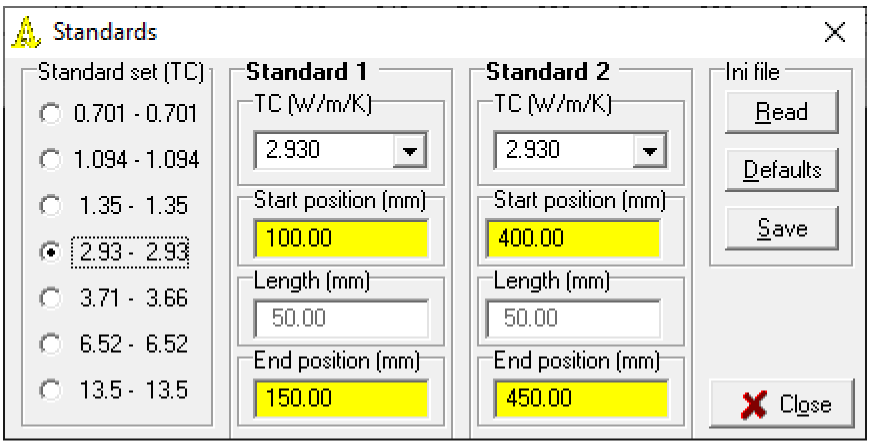
➔ chapter "6.1.1. TC mode and TC+TD mode".

(3.2) Switch on the TC calibration measurement mode



Now the TC calibration mode is active (TC calibration table will not be used). The user may now close the "TCS - cfg setup" window.

(3.3.1) Choose the TC standard set, which should be calibrated

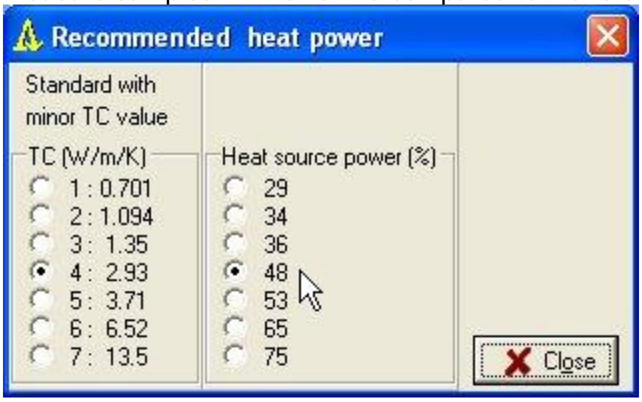


➔ chapter "6.2.2. Standards".

(3.3.2) Perform all TC calibration measurements for the respective standard set

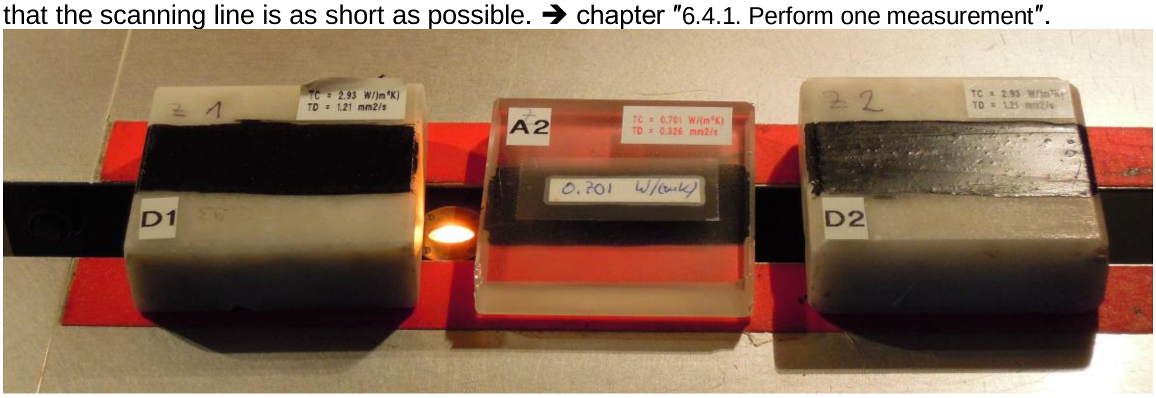
Be sure to adjust the sensors before each measurement. ➔ chapter ″6.2.5. Sensors″.

Set the heating power to a value that allows a maximum temperature difference of not more than 4 deg C. If you measure a sample with higher TC compared to the TC of the references, the recommended heat power would be ok, because the resulting temperature difference will be lower. If you measure samples with lower TC compared to the reference TC, you have to reduce the heating power.

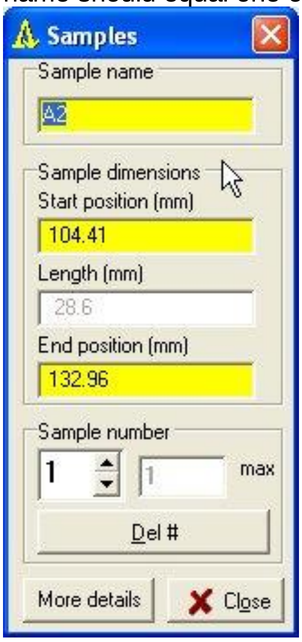


➔ chapter ″6.2.4. Regime″.

Place the standards on top of the measurement platform. Set in between the sample to be measured. Be sure that the scanning line is as short as possible. ➔ chapter ″6.4.1. Perform one measurement″.



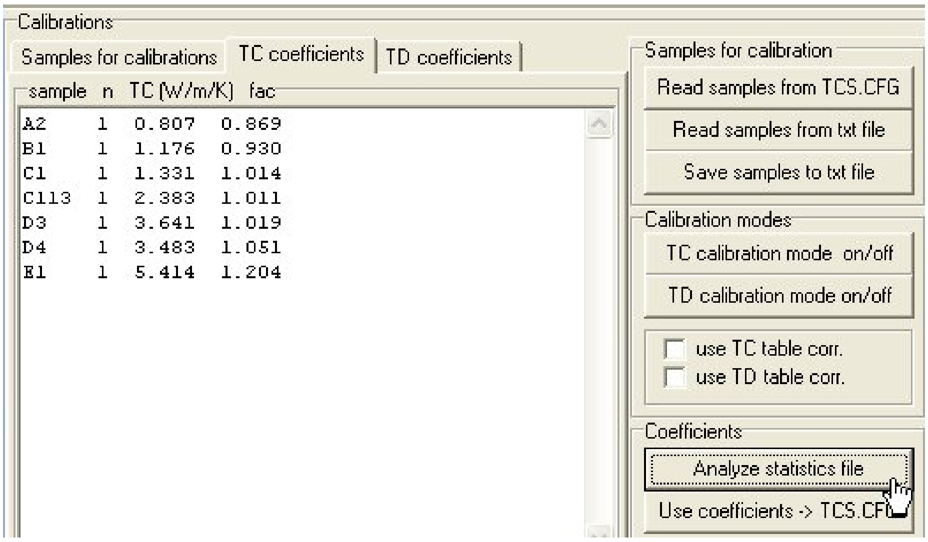
After completing the measurement, process the data. ➔ chapter ″6.4.2. Process measured data″.The sample name should equal one of the sample names in the set of samples table.



➔ chapter ″6.2.3. Samples″.

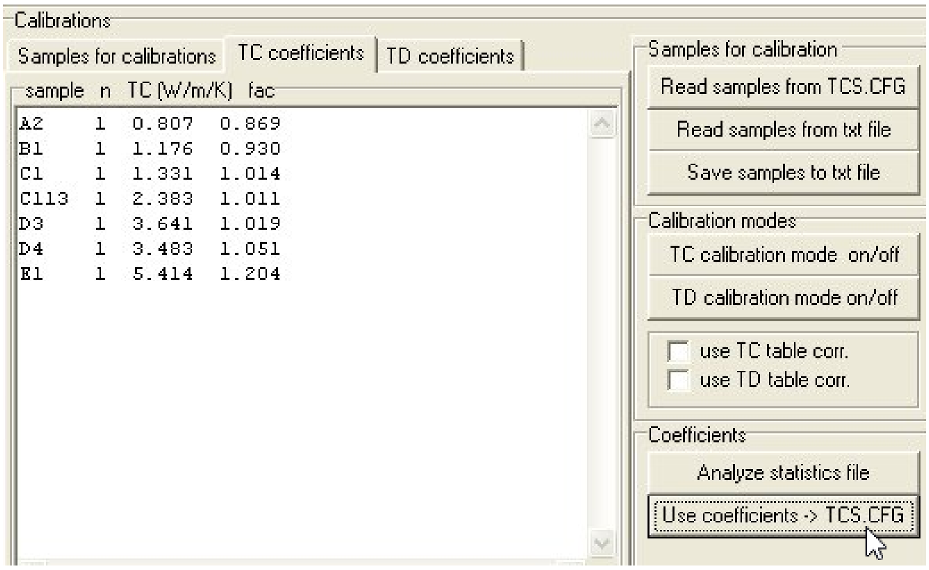
Repeat measurements and processing for all available samples. All measurements will be saved into the statistics file *.DAT. ➔ chapter ″6.5.2. The Statistics form″.

(3.3.3) Calculate TC correction coefficients



Pressing the button ″Analyze statistics file″ will calculate the correction coefficients using the TC values stored in the statistics file. In case of repeated measurements, the mean values will be calculated.

(3.3.4) Update TC table in TCS.CFG configuration file

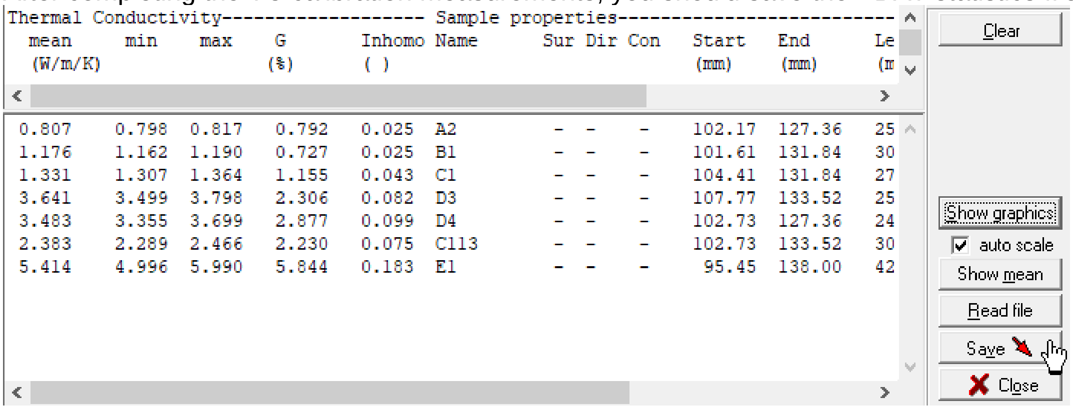


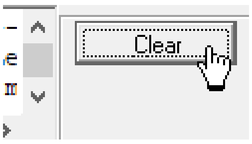
(3.3.5) Set configuration file

The correction table my be edited by the user, e.g. by calculating mean values. Press ″OK″ and ″Save″.

(3.3.6) Close statistics file containing the TC calibration measurements for this TC standard set

After completing the TC calibration measurements, you should save the *.DAT statistics file.

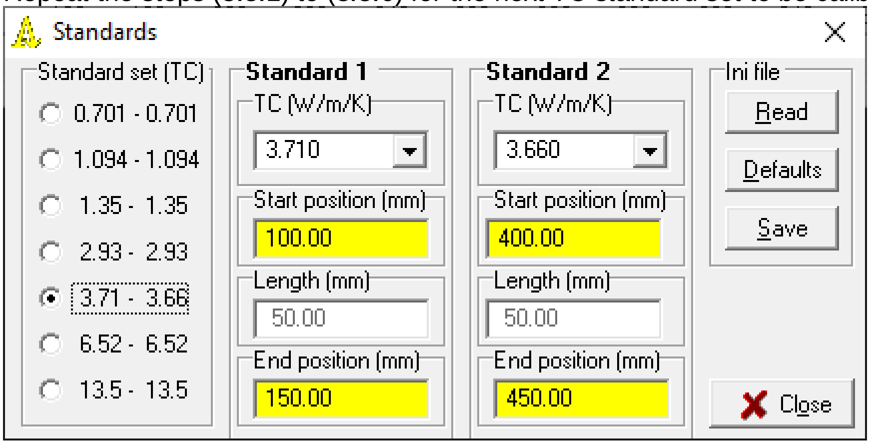




➔ chapter "6.5.2. The Statistics form".

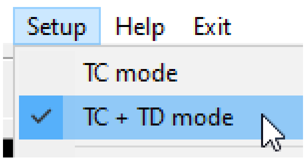
(3.4) Repeat for the next TC standard set

Repeat the steps (3.3.1) to (3.3.6) for the next TC standard set to be calibrated.

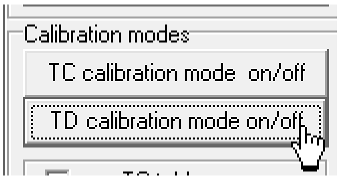


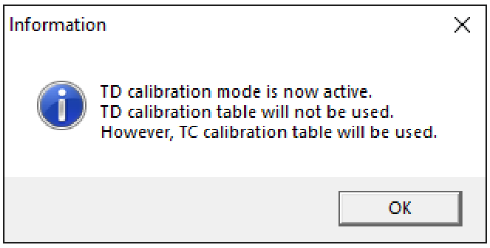
(4) Proceed with the TD calibrations in a similar way ...

(4.1) Switch on the TC+TD mode

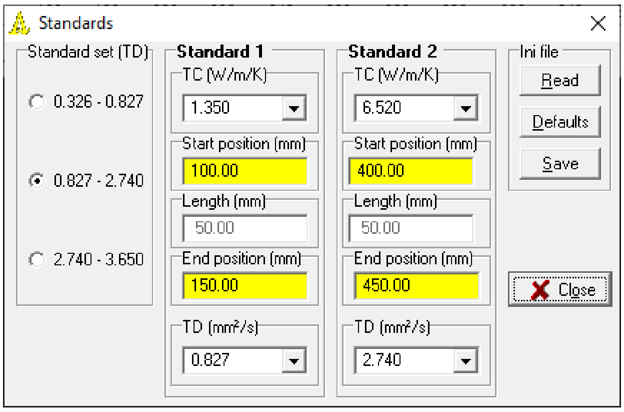


(4.2) Switch on the TD calibration measurement mode





(4.3.1) Choose the TD standard set, which should be calibrated



(4.3.2) Perform all TD calibration measurements for the respective standard set

(4.3.3) Calculate TD correction coefficients

(4.3.4) Update TD table in TCS.CFG configuration file

(4.3.5) Set configuration file

(4.3.6) Close statistics file containing TD calibration measurements for this TD standard set

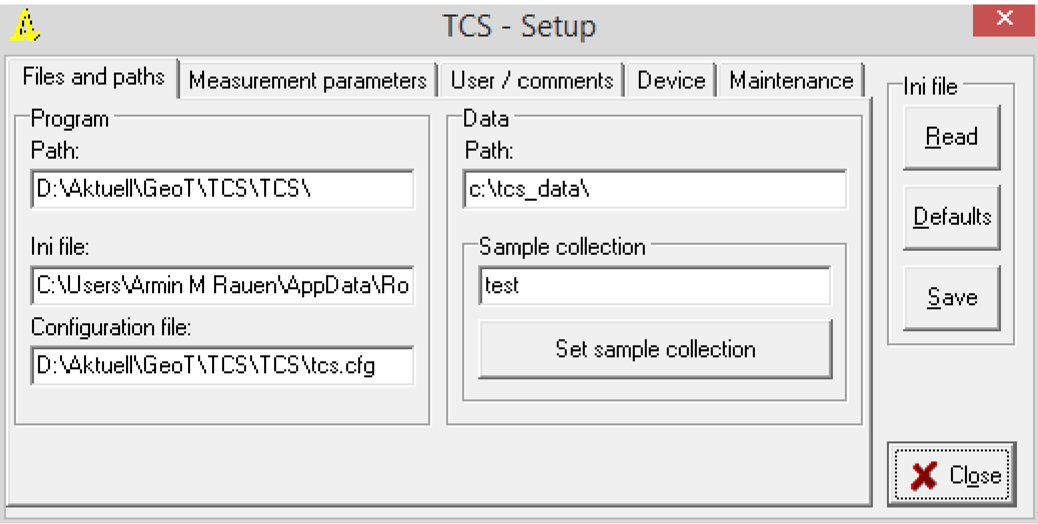
(4.4) Repeat for the next TD standard set

...

unitil all available standards sets are calibrated.

6.3.3. Program setup

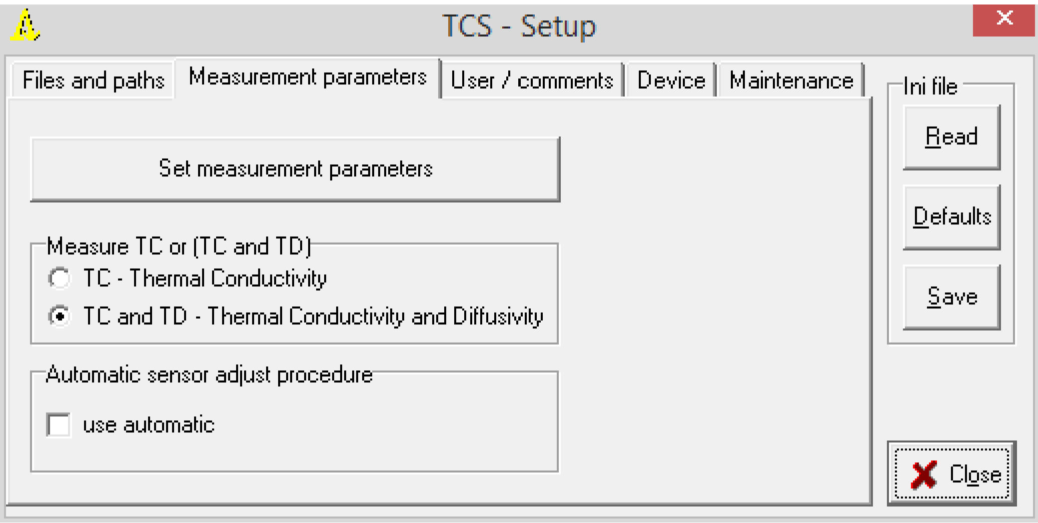
The program setup is accessed by the main menue only (➔ chapter "6.1. General program features").



Using the buttons "Read", "Defaults" and "Save", the setup properties can be read from the initializing file, changed to the default values or saved to the initializing file.

"Files and paths": To avoid any problems, the user should not change the "Drive", "Program", "Stepper driver", "Website offline" or "Manuals" paths. Setting the sample collection will result in creating a directory within the "Data" path.

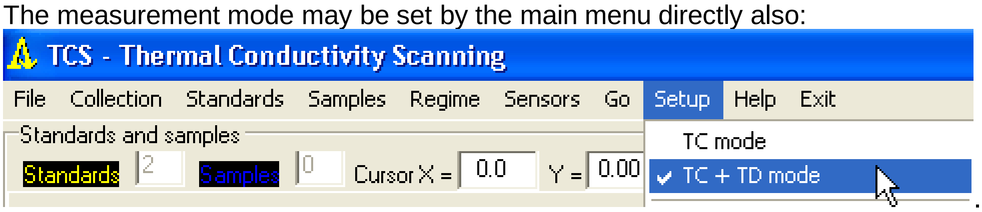
"Measurement parameters" will give access to the measurement properties discussed in chapter "2.1.4. Regime: Set measurement properties".



"TC only" and "TC+TD" mode:

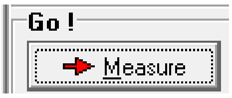
- TC - Thermal Conductivity: The apparatus measures in the "TC mode". No measurement of thermal diffusivity is possible.
- TC and TD - Thermal Conductivity and Diffusivity: The apparatus measures in the combined "TC + TD mode". Thermal conductivity and thermal diffusivity are measured simultanously

The measurement mode may be set by the main menu directly also:



Automatic sensor adjustment procedure

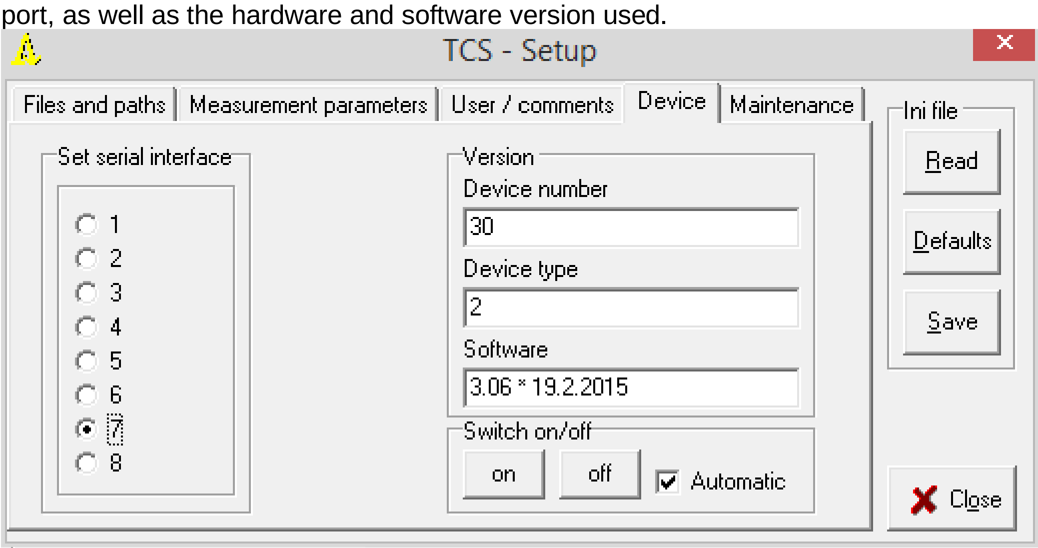
If ″use automatic″ is checked, the following procedures are used:

- Both sensors are covered by a sample with homogeneous thermal conductivity and temperature.
- 

The measurement is started (➔ chapter 6.4.1)
- The sensor offset calibration is done automatically using the ″1 measurement″ option (➔ chapter 6.2.5)
- After completing the sensor offset calibration, the sensor head moves appr. 96 mm to the right and stops at this position.
- The lamp is heated.
- After some heating time (appr. 10 s), the measurement begins as usual.

"User / comments" can be used to give some general information like the name of the user or general remarks. These informations will be saved in the scan file as well.

"Device" gives some information about the hardware setup of the equipment, e.g. the number of the COM port, as well as the hardware and software version used.



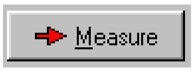
These 2 buttons switch can switch the TCS apparatus on or off. Actually, ″off″ switches into the standby mode ″on″) switched back from the standby mode into the working mode.
If the ″automatic″ checkbox is checked, the TCS apparatus will be switched into the standby mode by exiting the TCS program and will be switched on automatically by starting the TCS program.
These modes are available for TCS machines number 30 or higher only.

"Maintenance" gives access to the maintenance mode. This mode is not available for the user. It is determined only for the manufacturer for program maintanance.

6.4. Program actions

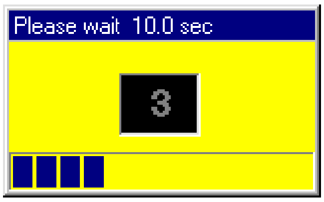
This part of the program summarizes all actions. The order of the buttons from the top to the bottom displays the sequence of actions necessary to perform a complete measurement: Measuring, processing, saving (➔ chapter "4.2. TCS software quick guide ").

6.4.1. Perform one measurement



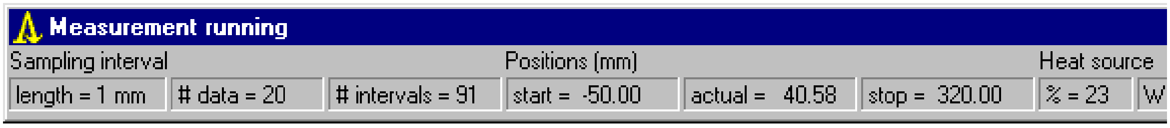
After the completing of measurement parameters (➔ chapter "6.2.4. Regime ") and the adjustment of sensors (➔ chapter "6.2.5. Sensors ") the program is ready to measure a sample scan. It is useful to set collection and file names before the starting of the measurement, but not necessary.

The user places standards at the start and end of the scanning line und the unknown samples in between. Then he clicks the "Measure" button. The caption of this button changes to "Stop".



First, the user is forced to wait a certain time after beginning of heating the heat source. In the meantime the heat source should reach a stable output. The waiting time can be changed using the "Regime" button (tabulator "Optical head", box "Delay time"), but changing is not recommended.

Afterwards, the "Measurement running" form appears in minimized state. The user can leave it in this minimized state or can maximize it. After maximizing ...



... it gives information about the actual sampling properties like number of sampling interval, actual and start/stop positions.

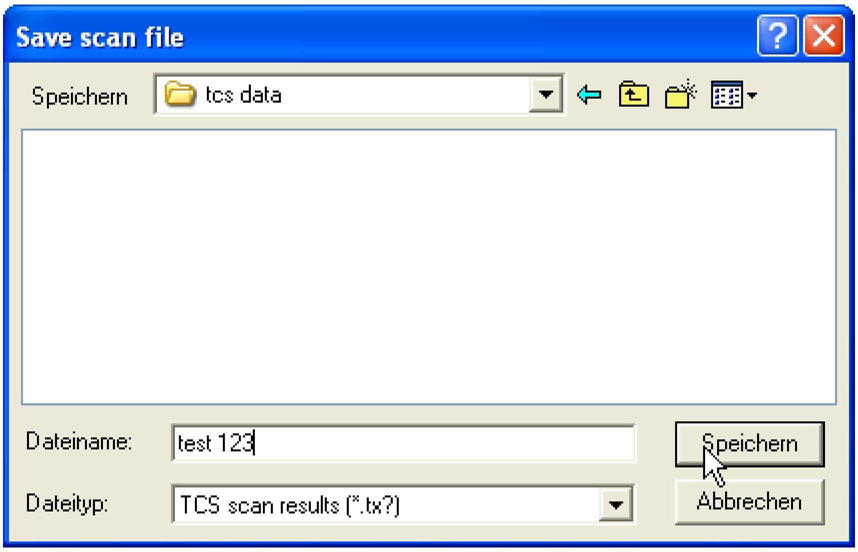
The measured temperatures are displayed in the main display as blue, bright red and red lines. The blue line corresponds to the initial temperatures measured by the first sensor ("sensor cold"), the bright red line corresponds to the "off line" hot temperature ("sensor Hoty" in the TC+TD mode) and the red line corresponds to the temperaures after heating ("sensor hot"). The user should take care, that the temperature differences do not exceed appr. 4 degrees C to avoid any damage of paintings, samples or standards.

It is strongly recommended not to make any actions during the measurement, especially not to move the cursor nor to rescale the main display. In these cases, some of the measurements could be skipped. These values would be lost.

When the scanning unit reaches the stop position, the measurement is automatically stopped. By pressing the "Stop" button (this is the former "Measure" button, which changed its caption) the user can stop the measurement manually.

After finishing of the measurement, the user is asked to save the scan into a file.

Saving a scan file:

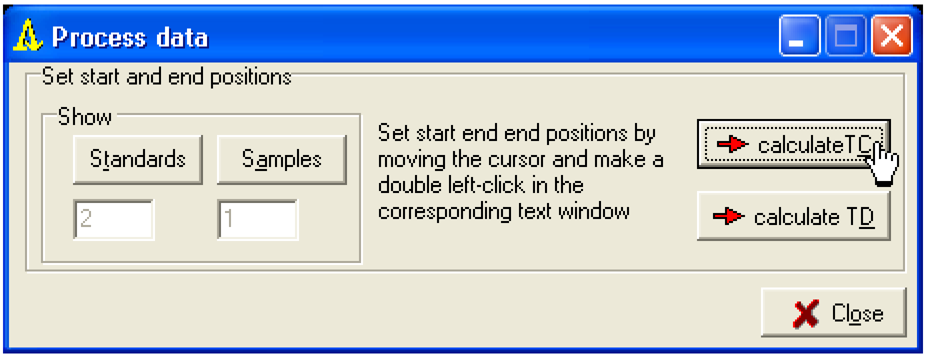


Clicking the "Save / Speichern" button will save the scan data into the displayed file name. Closing this window without pressing the button will not immediately delete the measured data. The user can save this data later by entering the "Data list" form. This form appears after pressing the "Save" button on the main form.

This form allows not to change the collection name. This can be done by clicking the button "Collection" in the main form.

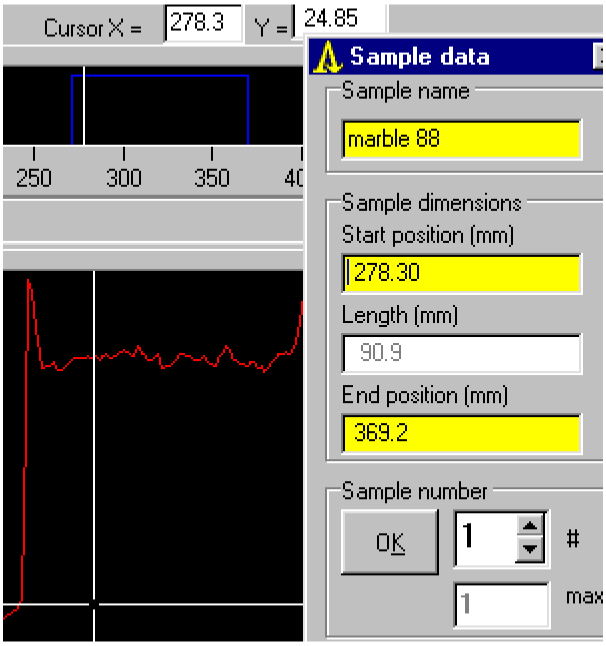
6.4.2. Process measured data

Clicking the "Process" button opens the "Process data" form:



The user is asked to pick the parts of the measured profile, which are assumed to be representative for the standards and the samples, respectively. The user should exclude profile parts near the standard/sample boundaries to exclude any boundary effects. The botton "Standards" opens the standards form (➔ chapter "6.2.2. Standards: Set standards properties"). After editing of start and stop positions of the both standards, the user clicks the "Samples" button to open the samples form (➔ chapter "6.2.3. Samples: Set samples properties"). As it is described in the both mentioned chapters, the user can either

- write the positions directly in the respective yellow text boxes or,
- more comfortable, change the cursor position in the main temperature display and double-left click into the respective yellow text box. The cursor position is taken automatically.



After completing of standards and samples positions, the user clicks the "Calculate TC" button. Then the program calculates the thermal conductivity profiles and the respective mean values automatically. The profile of thermal conductivity is displayed in the main display. It can be seen by clicking the "T.C." tabulator of the main display in the main program form.

In case of the "TC+TD" mode, the user has to click the second button "Calculate TD" also to let the program calculate the thermal diffusivity values.

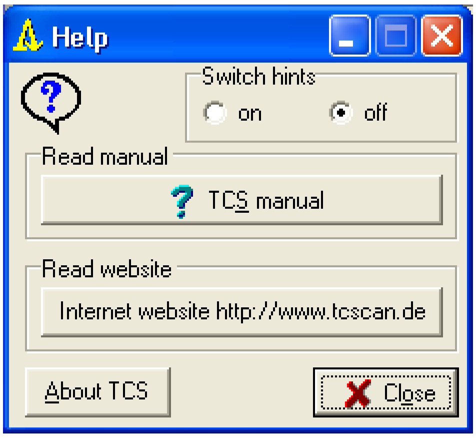
6.4.3. Save scan and statistics files

Clicking of the "Data list" button gives access to procedures, which save the scan file ("Data list" form).

Clicking the "Statistics" button leads to the statistics file ("Statistics" form).

6.4.4. Help

Clicking the "Help" button opens a form with access to different assistance functions:



The "Switch hints" box enables or disables the display of small help texts (so called hints) when the mouse is positioned on a button.

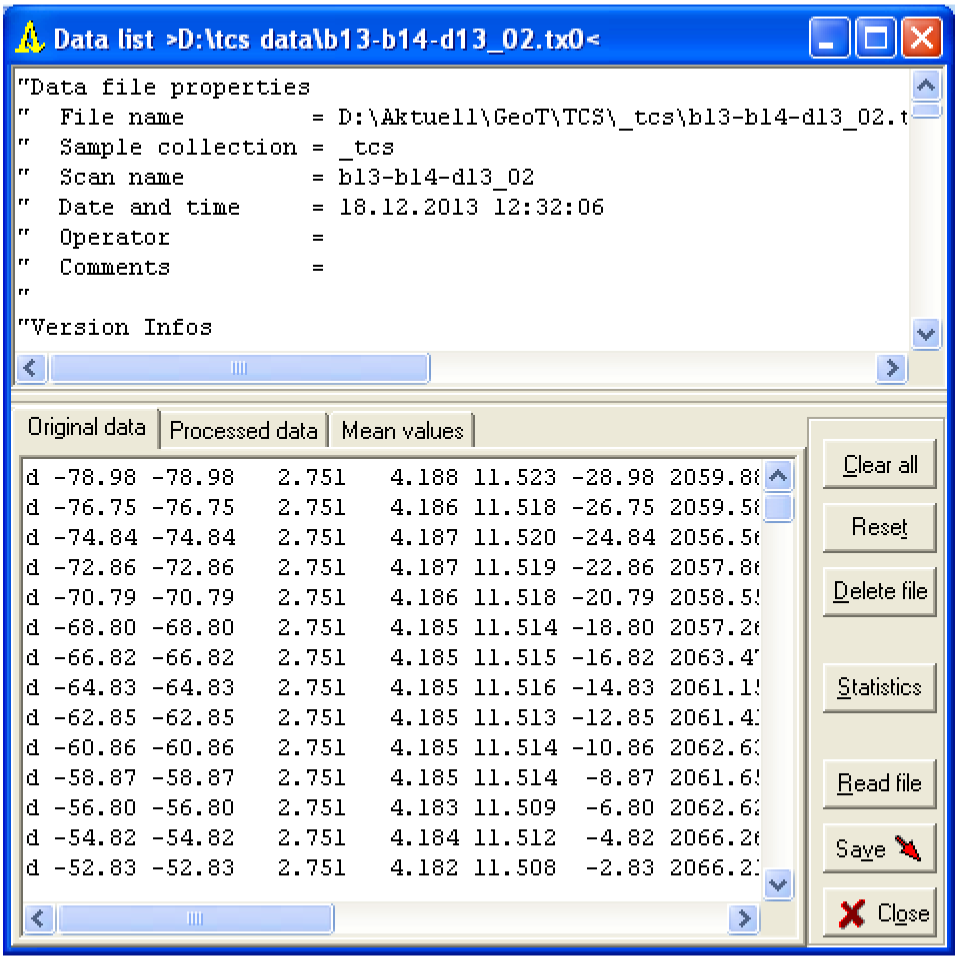
The button "TCS manual" will open the TCS pdf manual. The pdf manual is the same as the delivered printed manual.

The "Internet website..." button will connect to the internet (if connectivity is possible) and launch the actual online website.

The "About" button opens a new window displaying actual versions of the program.

6.5. Data format

6.5.1. The Data list form

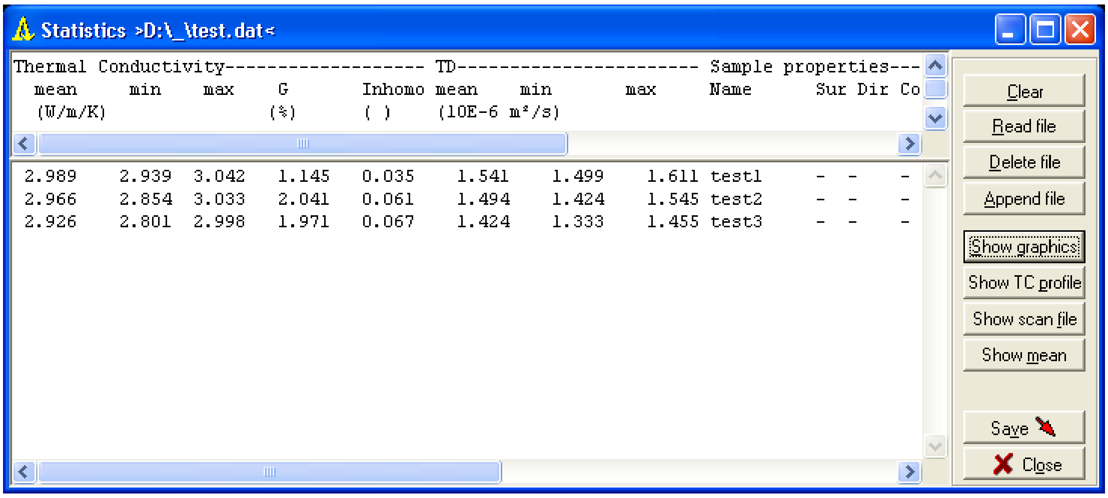


The memo in top of the form contains all header information, like measurement or sample properties and data format. The data is shown in three different tabulators at the bottom of the form.

- "Original data" displays the measured data.
- "Processed data" contains the processed thermal conductivity profile and
- "Mean values" contains the calculated thermal conductivity values.
  TC mode: the maximum, minimum and mean of thermal conductivity, the factor G = standard deviation / mean value and the inhomogeneity coefficient = (maximum-minimum) / mean.
  TC+TD mode: the maximum, minimum and mean of thermal conductivity, the factor G = standard deviation / mean value and the inhomogeneity coefficient = (maximum-minimum) / mean. Additionally the maximum, minimum and mean of thermal diffusivity.

The data formats are explained in the header part. The memos are automatically updated after completing of one processing. The mentioned mean values are added as a new line in the "Statistics" form too (➔ chapter "6.5.2. The 'Statistics' form"). The button list at the right side give the user the possibility to save, to delete, or to read formerly mesured scan files. Clicking the "Save" button will save the contents of the memos in the mentioned file (if the user made some changes in the memos, theses changes are saved also). The button "Statistics" opens the "Statistics" form (➔ chapter "6.5.2. The 'Statistics' form").

6.5.2. The Statistics form

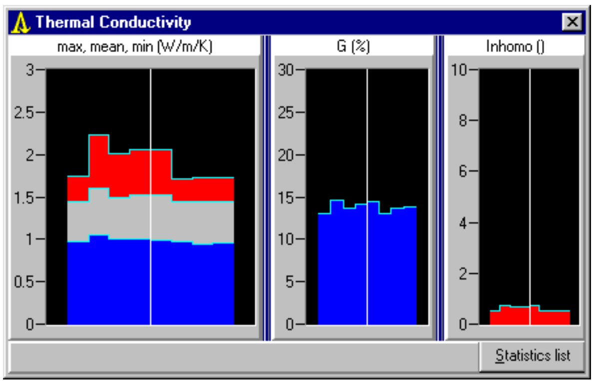


This form summarizes as an overview all calculated mean values and sample properties in one file (the statistics file). The top memo contains the header information which explains the data shown in the bottom memo. Clicking the "Show profile" button will display the thermal conductivity profile of the actual scan. The actual scan is the scan, where the mouse pointer is (e.g. the last line in the above figure). The memo is automatically updated after completing of one processing. The mean values can be displayed as histograms using the "Show graphics" button.

Please be sure, not to mix up statistics files for the TC only and the TC+TD mode. The respective statistics files contain different amounts of columns and therefore are not compatible.

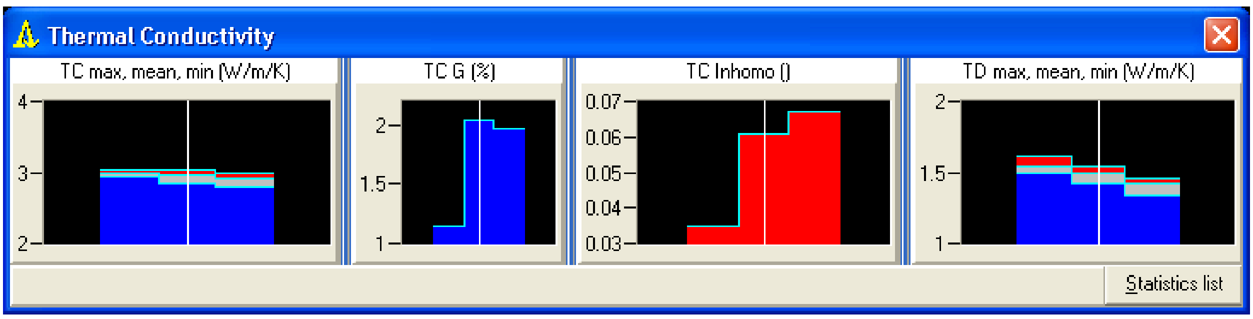
The complete contents of the actual displayed statistics file is shown as histograms

TC mode



From the left to the right: The maximum, mean and minimum values of thermal conductivity, the factor G = standard deviation / mean value and the inhomogeneity coefficient = (maximum-minimum) / mean.

TC+TD mode



From the left to the right: The maximum, mean and minimum values of thermal conductivity, the factor G = standard deviation / mean value and the inhomogeneity coefficient = (maximum-minimum) / mean, the maximum, mean and minimum of thermal diffusivity.

6.6. Licence agreement, guarantee and liability

Licence agreement

The user of TCS and all other related program components (=software) accepts the following conditions:

The user is allowed:
1. To install and use the software on one single computer.
2. To make one copy of the program as a safety copy.
3. To give the software to a third person only after a written consent of the producer.

The user is not allowed:
4. To give under-licences or to sale or to lend the software or parts of the software to third persons.
5. To try to get access to the source code of the program by reverse engineering, decompiling or other methods.
6. To use a former version of the software, in the case of getting an upgrade of the software.

Extended licence agreement:
The user has the duty to comply with additional licence agreements, which are valid for the delivered additional software products: Windows NT$^{(TM)}$ and the stepper motor driver.

Guarantee terms

SchwaRTech - Schwab Research Technology guarantees, that the software is developped carefully. The software is very complex, therefore we cannot guarantee the absolute absence of errors. Errors and bugs are corrected as complete as possible in the guarantee time interval, which is valid for the complete Thermal Conductivity Scanner, without costs.

Liability

There is no liability of *SchwaRTech - Schwab Research Technology* for any possible consequences of this software.

7. References

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Popov Y., Bayuk I., Parshin A., Miklashevskiy D., Novikov S & Chekhonin E. (2012): New methods and instruments for determination of reservoir thermal properties. Proceedings, 37th workshop on Geothermal Reservoir Engineering, Standford University, Stanford, California, Jan 30 - Feb 1, 2012. SGP-TR-194.

Popov Y., Beardsmore G., Clauser C & Roy S. (2016): ISRM suggested methods for determining thermal properties of rocks from laboratory tests at atmospheric pressure. Rock Mech Rock Eng DOI 10.1007/s00603-016-1070-5

8. Specifications

Measurement range:	TC: 0.2 to 25 W m^{-1} K^{-1} TD: 0.6 * 10^{-6} to 3.0 * 10^{-6} m^2 s^{-1}
Accuracy & precision:	TC: 3 % (for a confidential probability of 0.95) TD: 10 %
Productivity:	up to 60 samples per hour (depending on sample length)
Sample dimensions:	40 to ≈ 500 mm length with any given shape.
Maximum scanning length:	620 mm *earlier versions may differ*
Sample preparation:	no polishing or sawing necessity, preliminary painting (a paint strip with 25-40 micrometer thickness and width of appr. 20 mm) along the scanning line on flat or cylindrical surface is necessary.
Computer:	Notebook or desktop computer with Windows NT (TM), Windows 2000 (TM), Windows XP (TM) Windows 7 (TM) to Windows 10 (TM) system software. 1 free USB port needed. *Earlier versions need 2 free USB ports.*
TCS software:	Controlling software with intuitive user interface and pdf manual.
Scanning speed:	5 mm/s
Weight:	appr. 15 kg *earlier versions may differ*
Dimensions:	length = 100.0 cm height = 21.4 cm width = 20.0 cm *Earlier versions may differ*

9. Authors

The Optical Scanning Technology was developed by Prof. Dr. Yuri Popov. The TCS (Thermal Conductivity Scanner) based on the Optical Scanning Technology was developed by Dr. Armin Rauen and Erich Lippmann. The TCS (Thermal Conductivity Scanner) is produced by:

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