PromLegion Ltd.

Z-METER DX4190

USER GUIDE

Moscow, 2016

version 1.11

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WARRANTY

PROMLEGION LLC warrants that the Z-Meter, if properly used and installed, will be free from defects in material and workmanship and will substantially conform to PROMLEGION's publicly available specification for a period of one (1) year after date of the Z-Meter was purchased.

PROMLEGION LLC also provides a 3-month warranty for the following parts and components included in the standard delivery set of the product: the cables, program disks and documentation

If the Z-Meter fails during the warranty period PROMLEGION will repair the Z-Meter or replace it or its parts.

For the warranty support a Consumer can address to the office of the company PROMLEGION or its sales representative.

The product repaired or replaced in whole or in part, will have the warranty period counted as one (1) year from initial shipment but not less than 3 months upon shipping of repair or replacement.

TECHNICAL SUPPORT

For the technical support and repair within and after the warranty period, please, address:

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CONTENTS

1. INTRODUCTION

The ten channel Z-Meter provides measurement of the following parameters of thermoelectric (TE) modules (also TE coolers, TECs) - the measurement of up to 10 TE modules at a time.

- AC Resistance (R)
- Figure-of-Merit (Z)
- Time Constant (τ)
- Maximum Temperature Difference[1] (ΔT_{max})

Using the Z-Meter it is possible to perform testing of various types of single- and two-stage TE modules.

It is also possible to evaluate quality of more-stage TE modules by the measurement of electrical resistance.

The parameters are measured at the ambient temperature T_a. The Z-Meter provides recalculation of R and ΔT_{max} to another temperature value from the T_a vicinity.

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[1] *For thermoelectric coolers (TECs) the measured Figure-of-Merit allow to calculate performance parameter - maximum temperature difference ΔT_{max}. The calculation is valid for single-stage TECs. Measured Z for multistage TECs correlates with the cooling capacity, but no possibility for simple calculation of it.*

The Z-Meter is operated by computer under the operating system Windows 98/2000/XP/Vista/7.

ADVANTAGES

- ✓ *Express testing performance of single stage and multi-stage thermoelectric modules*
- ✓ *Testing performance of TE modules integrated into optoelectronic devices (photodetectors, lasers etc.)*
- ✓ *Time constant measurement*
- ✓ *Compatible with other Z-Meters of PromLegion Devices Family.*

FEATURES

- ✓ *Ten Channels*
- ✓ *Current adjustable in a range 0...80 mA*
- ✓ *Measurement at direct and reversed current*
- ✓ *Results normalization to standard temperatures*
- ✓ *Correction coefficients to Z value*
- ✓ *Low power consumption*

2. TECHNICAL CHARACTERISTICS

2.1. Specifications

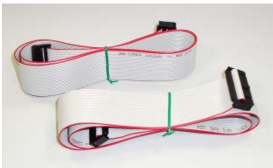
Parameters	Units	Values
Electrical Resistance R		
Range	Ohm	0.1...100
Accuracy	%	0.6 (but>0.01Ohm)
Repeatability	%	0.3
Figure-of-Merit Z		
Range	10^{-3}/K	1...3
Accuracy	%	1.5
Repeatability	%	0.4
Time Constant τ		
Range	s	1...100
Accuracy	%	1.5
Repeatability	%	1
Power Supply		
AC Voltage	V	85...264
Frequency	Hz	47...63
Voltage DC	V	120...370
Power (max)	W	15
Operational Conditions		
Temperature range	°C	+15...+35
Humidity	%	0...95
Storage		
Temperatures range	°C	-20…+60
Humidity	%	5…95
Mechanical Parameters		
Measuring Unit		
Dimensions	mm	235x180x90
Mass	kg	1.1

Parameters	Units	Values
Testing Unit		
Dimensions	mm	388x180x44
Mass	kg	1.6

2.2. Delivery Kit

Measuring unit
1 pc.

Testing unit
1 pc.



Connection cable
2 pcs.

Temperature sensor
1 pc.

Measuring terminal*
10 pcs.

	Power supply cable 1 pc.
	USB cable 1 pc.
	* Measuring terminals can be made on the basis of Kelvin clips of various designs.

2.3. Features

- Z-meter consists of two units that allow using either the testing unit (supplied) for a TEC connection or any other means providing the 4-wire connection.
- Measurement of up to 10 TE modules (ten channel device) of the same type at a time.

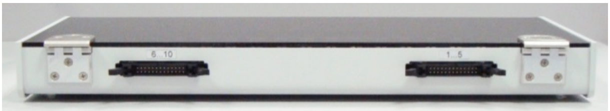
2.4. Design overview

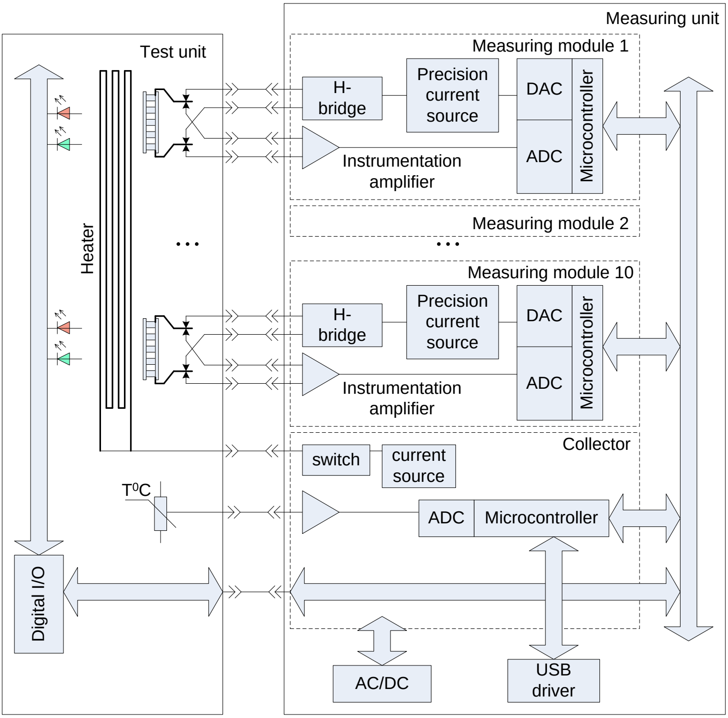
The device consists of two units:

- Measuring unit,
- Testing unit.

The measuring unit is designed for generating testing current, voltage measurement, temperature measurement, measurement mode signaling, for the control of light signals of the testing unit, and heater control. The measuring unit has a plastic housing with connectors for the power switch on the end panels.

The testing unit is a passive thermostat, providing TEC constant temperature during the measuring procedure and is equipped with terminals for an easy connection of the measured TEC. There is a sensor, and a LED indicating the measurement results. In addition, there is a testing unit heater checking the TE module polarity.





Z-meter functional scheme

The description of the measurement processes is in Section 9 Measuring Processes.

2.5. System Requirements

The Z-Meter works under the control of the program "Z-Meter". The program "Z-Meter" provides all possible operational modes of the Z-Meter. It has a simple interface and does not demand a User's special knowledge.

The Z-Meter is operated by computer under the operating system Windows 98/2000/XP/Vista/7.

The software is delivered with the Z-Meter. The requirements are:

- Free USB port,
- 20 MB free hard drive space (additional space may be required later to store database for various types of coolers),
- Mouse or compatible pointing device.

3. WORKING WITH Z-METER

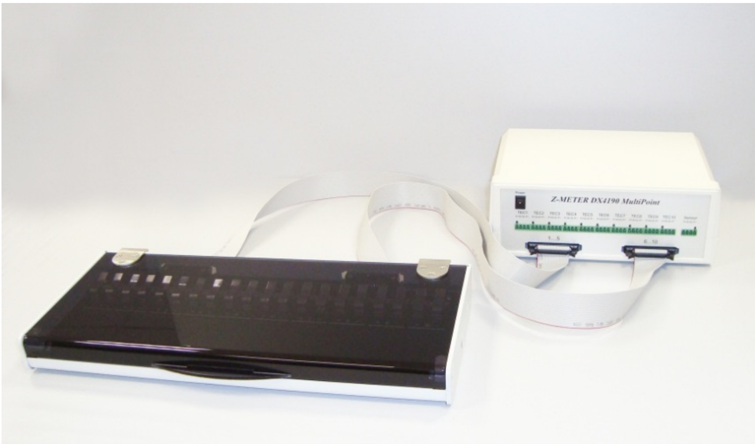
3.1. Getting Ready

Make sure that the switch on the front of the measuring unit is turned off. Using the power cable, plug in the measuring unit to the supply voltage.

Using a USB cable, connect the measuring unit to a computer free USB port.

If you intend to use the measurement terminals, connect them to the connectors TEC1 ... TEC10 of the measuring unit, and connect the sensor to the connector "Sensor".

If you want to use the testing unit, connect the appropriate connectors of the measuring unit and the testing one by the flat measuring cables. The corresponding connectors are marked similarly: "1…5" and "6…10".



3.2. Drivers Installation

For the device operation, a driver should be installed.

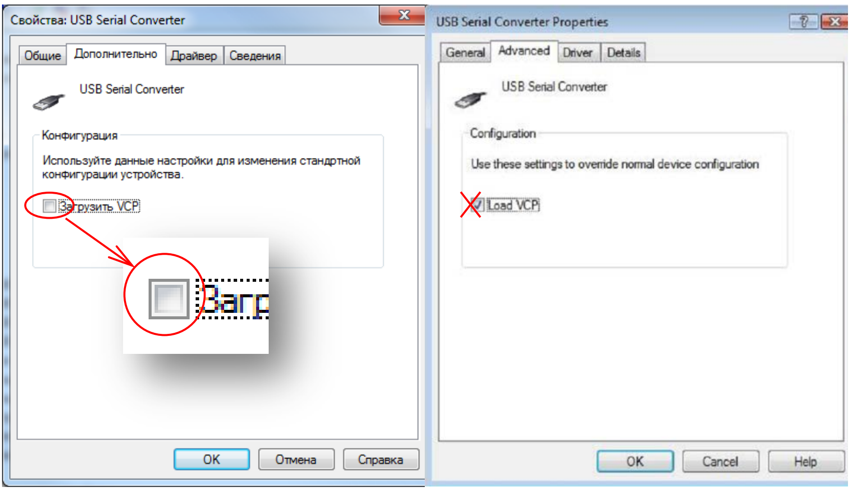
The latest driver, depending on the Windows version of the operating system can be found at http://www.ftdichip.com: http://www.ftdichip.com/Drivers/D2XX.htm.

You can see the installation procedure for a specific version of Windows in the documents linked to the following webpage http://www.ftdichip.com/Support/Documents/InstallGuides.htm.

After installing the driver, turn the power of the measuring unit on by the switch "Power" on the front panel.

There should appear USB Serial Converter in the Windows Device Manager.

Important! *For the proper operation of the program tick off the virtual COM port in the properties of USB Serial Converter in the tab "Advanced*".



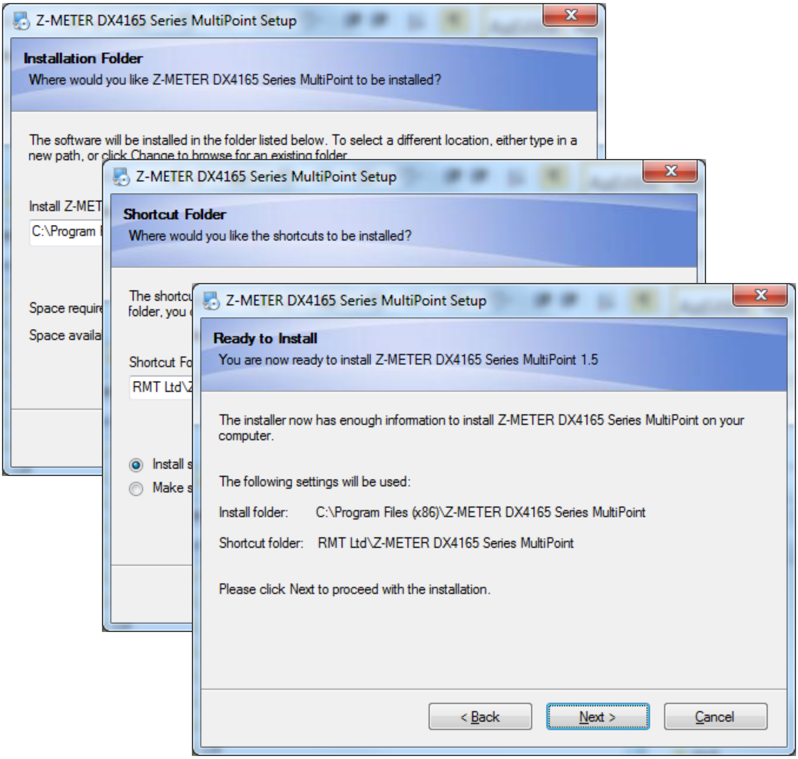
3.3. Software Installation

The program is distributed in the form of the installation file ZMeterXsetup.exe.

As the program is designed to control multichanel Z-meters of different types, the name of the device may be "DX4165".

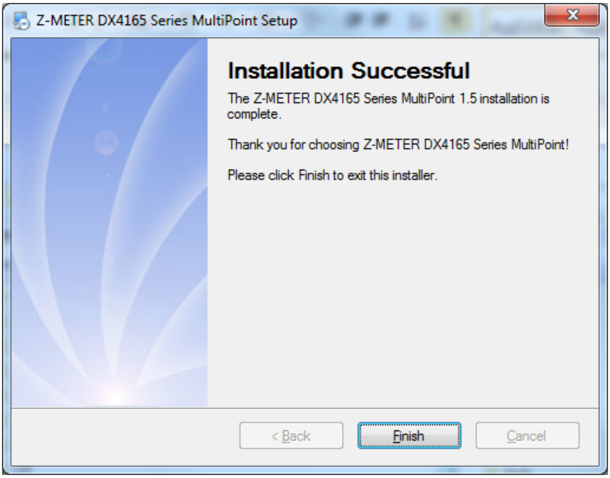
The latest version of the program can be downloaded from the company PromLegion website http://www.promln.ru/downloads/.

To install the program you should run the file (as administrator) and follow the instructions that appear during the installation process.



During the installation you will be offered options of direction that can be changed according to your preferences.

When choosing the disk, bear in mind that the program requires 20 MB free hard drive space (additional space may be required later as your database is growing.



3.4. TE Modules handling

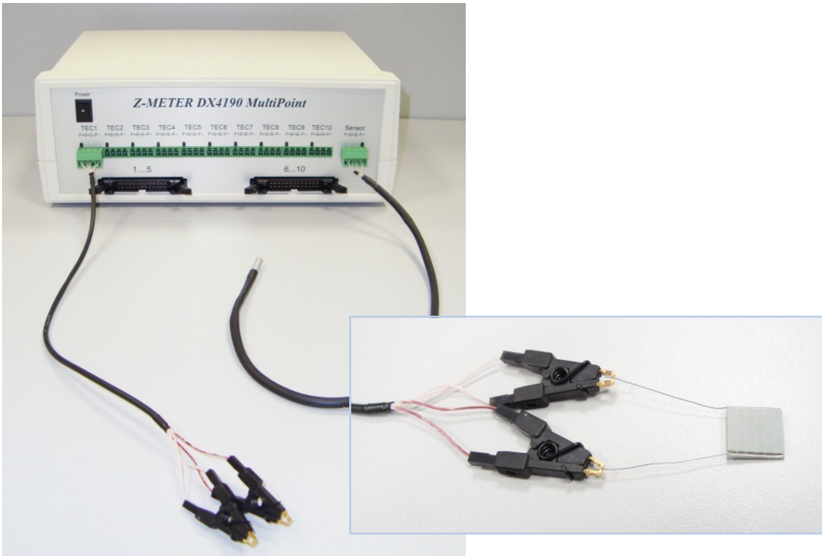
3.4.1. Preparations

Before measuring, it is necessary to keep the Z-Meter and tested TE modules during one hour at room temperature.

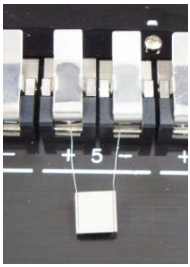
Attention! *If Z-Meter was outdoors at low temperature for a long time (temperature below +10°C), it is necessary to keep Z-Meter at room temperature for not less than 2 hours.*

3.4.2. TE Modules Connection

If the measuring terminals are used, connect your TEC. If possible, eliminate air convection in the area of measurement. Place the temperature sensor close to the measured module.



If the testing unit is used, open the cover and connect your TEC to the terminals. Mind the correct polarity.



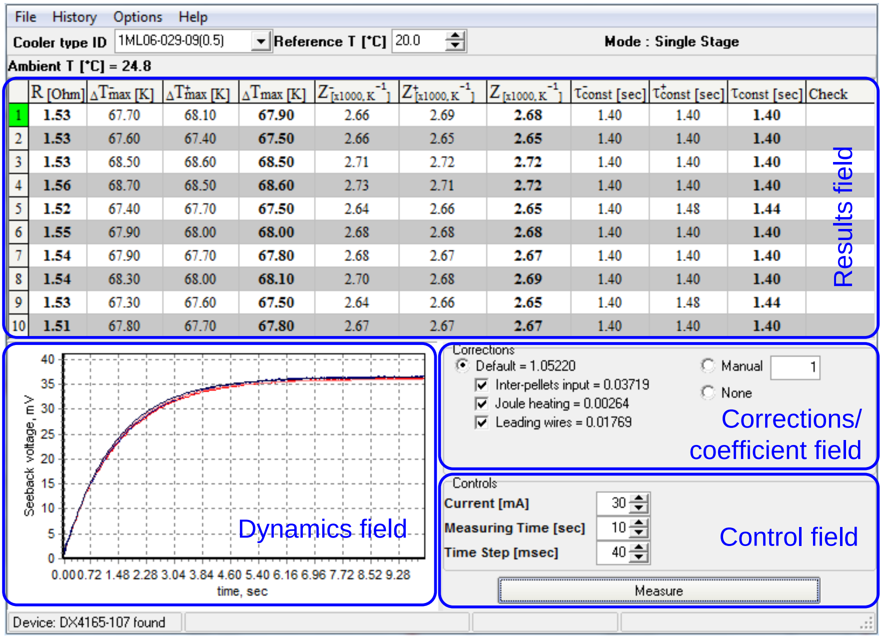
Close the cover.

4. SOFTWARE

4.1. Introduction

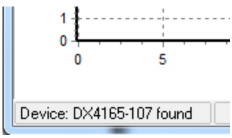
Before running the Program, the device should be switched on.

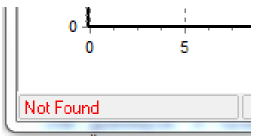
Run the program "Z-Meter".



Program main window and its structure

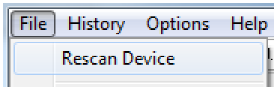
If the device is properly plugged in and the program has found it, the status bar will show the device ID:





If for some reason the program failed to discover the device, in the status bar the information "Not found" will appear.

In this case make sure the device is rightly powered and plugging into the PC is correct. Check if the USB drivers have been properly installed and rescan the device (File->Rescan Device):



4.2. Main Window

The main program window is shown above. Its functional structure is common for three Z-Meter measurement options for:

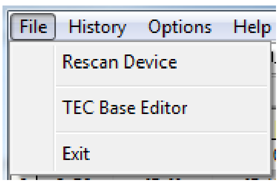
- Single-stage TE module;
- Single-stage TE sub-mount;
- Two-stage TE module.

The main window includes the following:

4.2.1. Menu

There are four items in the Menu bar.

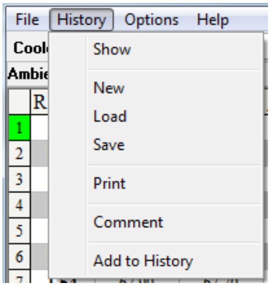
- ***"File"***



Rescan Device. Rescan Device allows repeating search of the device. It is applied if the program’s first attempt to find the device failed.

__TEC Base Editor.__ TEC Base Editor allows editing the TE modules data banks (see “Database Update”).

- ***"History"***



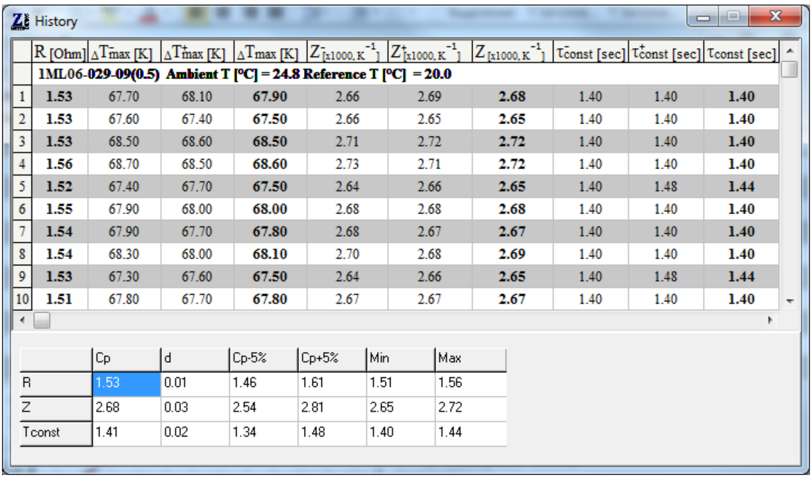
__Show__ - displays or hide the History window.

__New__ - creates a new history.

__Load__ - downloads the history from the history file.

__Print__ - allows printing the history.

__Add to history__ - allows inputting the results manually.



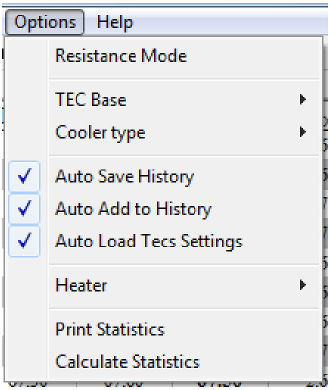
History

	R [Ohm]	ΔT^-_{max} [K]	ΔT^+_{max} [K]	ΔT_{max} [K]	$Z^-_{[x1000, K^{-1}]}$	$Z^+_{[x1000, K^{-1}]}$	$Z_{[x1000, K^{-1}]}$	τ^-_{const} [sec]	τ^+_{const} [sec]	τ_{const} [sec]
	1ML06-029-09(0.5) Ambient T [ºC] = 24.8 Reference T [ºC] = 20.0									
1	**1.53**	67.70	68.10	**67.90**	2.66	2.69	**2.68**	1.40	1.40	**1.40**
2	**1.53**	67.60	67.40	**67.50**	2.66	2.65	**2.65**	1.40	1.40	**1.40**
3	**1.53**	68.50	68.60	**68.50**	2.71	2.72	**2.72**	1.40	1.40	**1.40**
4	**1.56**	68.70	68.50	**68.60**	2.73	2.71	**2.72**	1.40	1.40	**1.40**
5	**1.52**	67.40	67.70	**67.50**	2.64	2.66	**2.65**	1.40	1.48	**1.44**
6	**1.55**	67.90	68.00	**68.00**	2.68	2.68	**2.68**	1.40	1.40	**1.40**
7	**1.54**	67.90	67.70	**67.80**	2.68	2.67	**2.67**	1.40	1.40	**1.40**
8	**1.54**	68.30	68.00	**68.10**	2.70	2.68	**2.69**	1.40	1.40	**1.40**
9	**1.53**	67.30	67.60	**67.50**	2.64	2.66	**2.65**	1.40	1.48	**1.44**
10	**1.51**	67.80	67.70	**67.80**	2.67	2.67	**2.67**	1.40	1.40	**1.40**

	Cp	d	Cp-5%	Cp+5%	Min	Max
R	1.53	0.01	1.46	1.61	1.51	1.56
Z	2.68	0.03	2.54	2.81	2.65	2.72
Tconst	1.41	0.02	1.34	1.48	1.40	1.44

History window

- ***"Options"***



Resistance mode - allows measuring TE module resistance only.

TEC base allows selecting a TE modules data base of a manufacturing company.

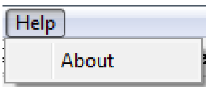
Cooler type allows selecting a system type to be measured (a single-stage TE module; a single-stage TE module in a housing (on a header) - TE sub-mount; a two-stage TE module).

Auto Save History allows saving a TE module's measurement history automatically. After your exiting the program, the history is automatically saved in the directory \History. The file name is formed by the current date and time.

Auto Add to History automatically adds the measurement results to the history.

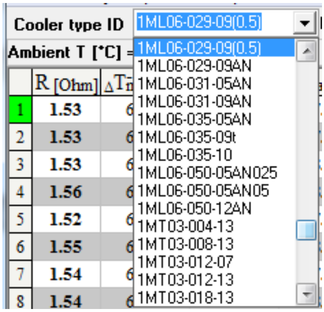
Auto Load TECs settings automatically loads/saves the measurement settings (electric current, frequency and measurement time) for each TE module measured.

- ***"Help"*** gives information concerning the software "Z-Meter".



4.2.2. "Reference" Bar

There are two fields in the Reference bar.

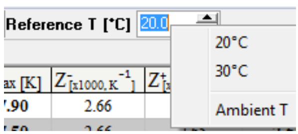


The field "Cooler type ID" gives a list box for selecting a TE module type to be tested.

The field "Reference T" serves for the reference temperature input. The values R and ΔT_{max} are recalculated to this temperature. The temperature step is 0.1 K.

Besides that, you can click the right mouse button in the "Reference T" input field.

The following list is to fall down:

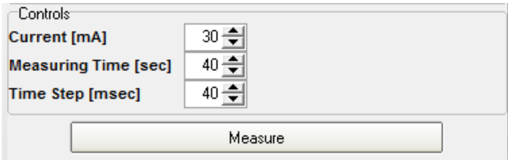


You may choose a value from standard reference temperatures (20 and 30°C) or use the measured ambient temperature $T_{ambient}$ as a reference.

4.2.3. Functional Fields

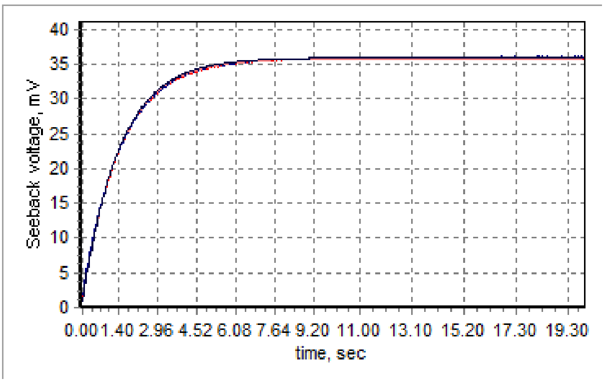
There are four functional fields in the main window (Section 4.1):

- ***"Control Field"*** presents the following measuring parameters: electric current, total time of measurement, time step.



The button "Measure" starts the measuring procedure.

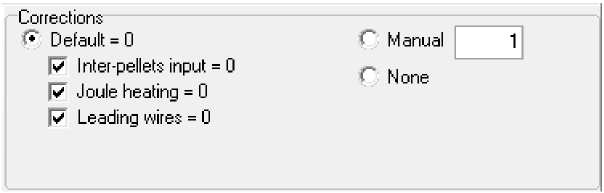
- ***"Dynamics Field"*** depicts the chart window of the Seebeck voltage $U_{\alpha}(t)$ temporal behavior telemetry: measured and interpolated at two current directions.



To see the Seebeck voltage $U_{\alpha}(t)$ dynamics of a selected TE module, one should choose it in the Results field. The selected TEC number is then identified by the green color.

- ***"Corrections Field"*** contains calculated corrections values (see Chapter 6.3).

  It allows switching a certain correction ON or OFF. As an alternative it provides a general coefficient A (see Section 6.3.3).



  For this coefficient calculation it is possible to choose one of the three following approaches:

  1) Default - using the corrections calculated in the corrections field (only for the TE modules fully described in the database);
  2) Manual - using a User's own coefficient value A, manually inputted;
  3) None - using neither corrections nor coefficients at all.

- ***"Results Field"*** contains the following measured/calculated results for all the 10 channels:

  1) Electrical resistance R of the TE module;
  2) Ambient temperature $T_{ambient}$;
  3) Figure-of-Merit Z of the TE module (for two polarities and averaged);

4) Maximum temperature difference ΔT_{max} of the TE module (for two polarities and averaged);

5) Time constant τ of the TE module (for two polarities and averaged).

Ambient T [°C] = 20											
	R [Ohm]	ΔT^{-}_{max} [K]	ΔT^{+}_{max} [K]	ΔT_{max} [K]	Z^{-} [x1000, K^{-1}]	Z^{+} [x1000, K^{-1}]	Z [x1000, K^{-1}]	τ^{-}const [sec]	τ^{+}const [sec]	τconst [sec]	Check
1	**1.54**	65.90	66.30	**66.10**	2.55	2.58	**2.57**	1.40	1.40	**1.40**	
2	**1.53**	65.70	65.80	**65.70**	2.54	2.54	**2.54**	1.40	1.40	**1.40**	
3	**1.55**	66.70	66.90	**66.80**	2.60	2.61	**2.60**	1.40	1.40	**1.40**	
4	**1.56**	66.80	66.80	**66.80**	2.61	2.60	**2.61**	1.40	1.40	**1.40**	
5	**1.53**	65.70	65.80	**65.80**	2.54	2.55	**2.54**	1.40	1.48	**1.44**	
6	**1.56**	66.00	66.20	**66.10**	2.56	2.57	**2.56**	1.33	1.40	**1.37**	
7	**1.55**	65.80	65.90	**65.80**	2.55	2.55	**2.55**	1.33	1.40	**1.37**	
8	**1.55**	66.30	66.40	**66.30**	2.57	2.58	**2.58**	1.33	1.40	**1.37**	
9	**1.54**	65.60	65.60	**65.60**	2.53	2.54	**2.53**	1.40	1.40	**1.40**	
10	**1.52**	66.10	66.00	**66.00**	2.56	2.56	**2.56**	1.40	1.40	**1.40**	

While TE modules are being tested there can be a situation when a TE module line in the Results field is colored red. It occurs in two cases:

1) The measured TE module has a break in a circuit or a bad contact in its terminals (see TE module 3 in the figure below). In this case check the contacts and redo the measurement.

1	**1.53**	65.80	66.20	**66.00**	2.54	2.57	**2.56**	1.40	1.40	**1.40**	
2	**1.52**	65.60	65.50	**65.50**	2.53	2.53	**2.53**	1.40	1.40	**1.40**	
3											
4	**1.56**	66.70	66.50	**66.60**	2.60	2.59	**2.59**	1.40	1.40	**1.40**	
5	**1.52**	65.60	65.60	**65.60**	2.53	2.53	**2.53**	1.48	1.48	**1.48**	

2) For large powerful TE modules at a high current the electric voltage applied to the module exceeds the device constraint. In this case there only appears a measured resistance value and the TEC line is red colored (see TE module #8 in the figure below).

6	**1.55**	65.70	66.10	**65.90**	2.54	2.56	**2.55**	1.33	1.40	**1.37**	
7	**1.54**	65.60	65.90	**65.80**	2.54	2.55	**2.54**	1.33	1.40	**1.37**	
8	**1.54**										

Make your measuring electric current lower and retry the test.

4.3. AC Resistance Measurement

For measuring AC electrical resistance only (of a TE module or a resistor) it is necessary to choose Resistance Mode in the menu "Options". The results are offered in the main window:

	R [Ohm]	ΔT^{-}_{max} [K]	ΔT^{+}_{max} [K]	ΔT_{max} [K]	$Z^{-}_{[x1000, K^{-1}]}$	$Z^{+}_{[x1000, K^{-1}]}$	$Z_{[x1000, K^{-1}]}$	τ^{-}_{const} [sec]	τ^{+}_{const} [sec]	τcons
1	**1.53**									
2	**1.53**									
3	**1.55**									

4.4. Measurement Presets

4.4.1. Temperature Setting

The parameters of TE modules (R, ΔT_{max}) can be recalculated to various temperatures (see Chapter 6.3 as well as Section 4.2.3).

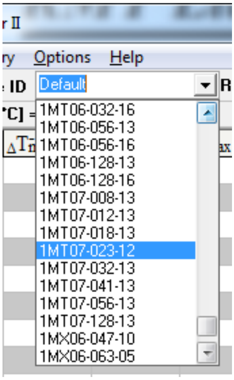
Attention! *The standard temperature is 27°C, other manufacturers may apply their own values.*

Select the proper temperature value from those suggested in the list "Reference T".

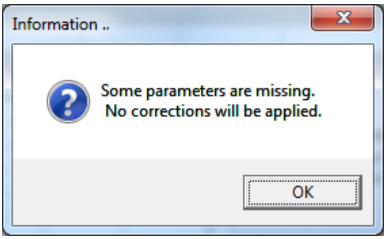
If there is no required reference temperature in the list, enter it manually.

4.4.2. TE Module Type

Choose a type of a TE module to be tested from the "Cooler type ID" list. The list represents TE modules data base selected via the command "File"-"TEC Base Editor". RMT is the default TE modules base.



The following window reports that one or more parameters of the TE module selected is/are absent:



If a necessary TEC type is absent in the list, you should introduce the TE module parameters to the database manually (see Chapter "Database Update").

Attention! *If no information on parameters of a tested TE module, you may choose the corrections/coefficient default mode and the TE module test results will exclude any corrections (in this case in the line "TE Cooler Type" the* *module type is "Default").*

4.4.3. Correction Coefficients

With all TEC parameters available, the corrections as well as their equivalent coefficient A are taken into account by default (see Equation 6.3.3.1).

It is possible to switch this or that correction on/off with the help of corresponding radio button pairs on the "Corrections" field. The Results window fits the changes automatically.

Corrections for Z-metering

Symbol	Description	Notes
b_T	Allows for the inequality of the ambient temperature and the average temperature of a TE module	For single-stage modules only
b_{th}	Allows for additional heat fluxes between pellets	For single-and two-stage modules
b_a	Allows for external heat fluxes	For two-stage modules
b_r	Allows for additional electrical resistance of leading wires	For single-and two-stage modules

Therefore, a User is given an opportunity either of taking into account the corrections via the calculated values selected by a User and their equivalent coefficient A (by default) or using one's own value of A, or refusing all the corrections.

4.4.4. Package Thermal Resistance

For taking into account a header thermal resistance for measuring a TE module sub-assembly Figure-of-Merit Z it is necessary to input the average values of the following parameters of the package header:

1) material thermal conductivity

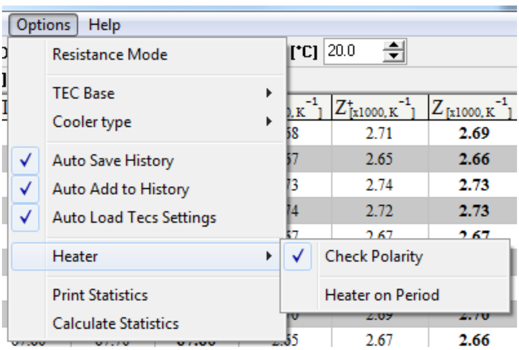
2) average thickness

3) area of the TE module - header contact.

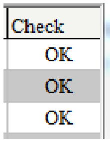
Attention! *The temperature of a TE module changes slightly owing to hands touching. Besides, the measuring procedure induces a slight TE module average temperature increasing. So maintain a pause of about this test 3 time constants before the next one. This time should be enough for the TEC to achieve heat equilibrium with the ambience.*

4.5. TE Module Polarity Verification

To use this function mark "Check Polarity" in the sub-menu "Option-Heater".

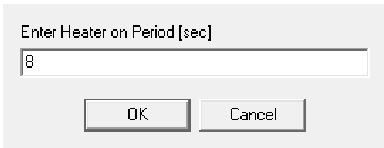


The polarity checking is made automatically for the direct polarity measuring. The procedure involves comparison of the average voltage values before and after the heater switching on. The verification data is displayed for all the 10 channels. For the right polarity the result is "OK", otherwise - "NOK".



The time of the heating can be set manually. To do that it is necessary to select the menu item "Option->Heater->Heating Period".

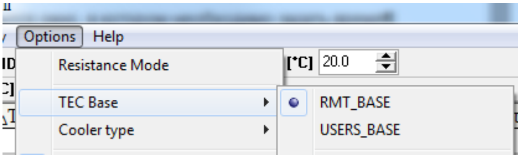
The following window pops up. One can set the heating period in it (in seconds).



4.6. TE Modules Database Update

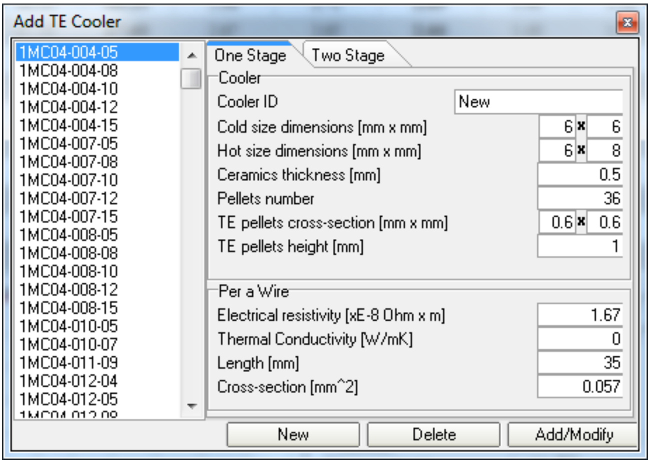
If the parameters of a TE module you are going to deal with are not introduced in the database, you can add them yourself. To do that, you should know the following parameters of the TE module:

1) TE module cold and hot sides dimensions
2) Pellets number (for a two-stage TE module the pellets numbers ratio)
3) Pellet cross-section
4) Pellet height
5) Leading wires material
6) Leading wires length
7) Leading wires cross-section.



Choose a database you want to edit (see the figure above). Select the "File" - "TEC Base Editor" command from the "Main" menu. The window titled "Add TE cooler" will appear as shown below.

There are two logic fields in the window: "Cooler" and "Leads", as well as a control line.



When you add a new TEC, press the button "New" in the control line. Enter the necessary parameters and click "Add/Modify".

You can also edit or delete a TE module existing in the database. To do it just select the TE module, make appropriate changes in the data and click on the "Add/Modify" button.

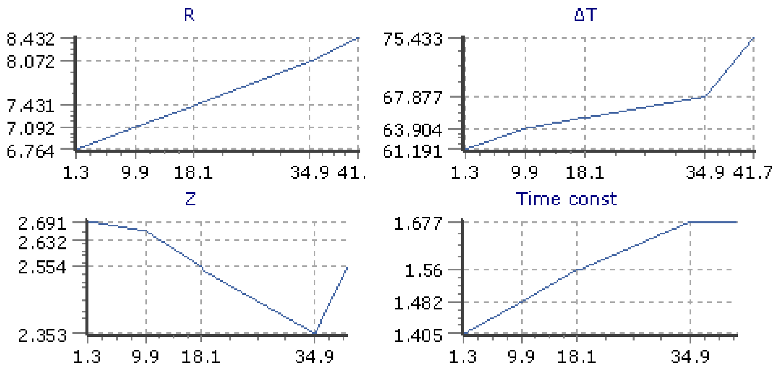
To remove the TE module from the database, select it and click on the "Delete".

5. MEASURING IN TEMPERATURE RANGE

Using the Z-meter DX4190 with the thermostat DX2100 (an option) allows you to obtain the dependence of the measured values on the temperature. These are $R = f(T°C)$; $Z = f(T°C)$; $\Delta T = f(T°C)$; $\tau = f(T°C)$. In this procedure a special thermostat chamber cover should be used.

Attention! *The thermostat DX2100 in an optional. Should be ordered separately.*

The measurements of thermoelectric modules at different ambient temperatures yield temperature dependences of the form:



To set up and maintain the necessary temperature the thermostat DX2100 is used.

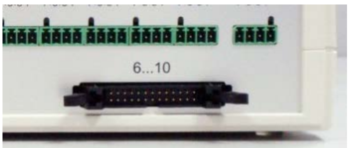
The process is automated and described below.

To connect to a PC, there should be two free ports USB.

5.1. Thermostat Connection

1. The thermostat is connected to a computer by a standard cable USB.

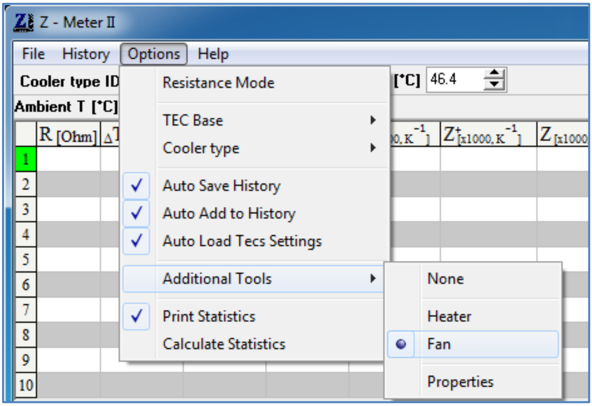
2. For the connection to Z-meter, use the thermostat chamber cover with probes:
3. Connect the ribbon cable from the cover to the Z-Meter terminal with channels **6…10**.



4. Switch on the Z-meter and thermostat.

5.2. Additional Tools

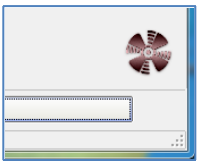
1. Select the item **"Fan"** in the menu **"Options"-"Additional Tools".**



In the thermostat cover there is a cooling fan. This option serves to activate it.

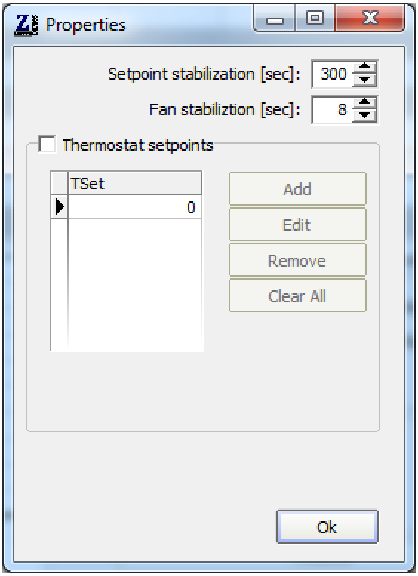
While the thermostat is achieving the set point, the fan driven by the Z-Meter DX4190 works in the chamber (in the cover). It makes convection more effective and temperature distribution even. Before starting the measurement of thermoelectric coolers the fan is turned off.

"FAN stabilization" is the time during which the program will wait after the fan turning off before the start of the measurements. The default time is 8 seconds.



It is recommended to choose the setpoint stabilization parameter at least 300 seconds ("**Setpoint stabilization**").

2. Enter the settings menu **"Options"-"Additional Tools"-"Properties"** or click on the fan icon in the lower right-hand part in the program main window.



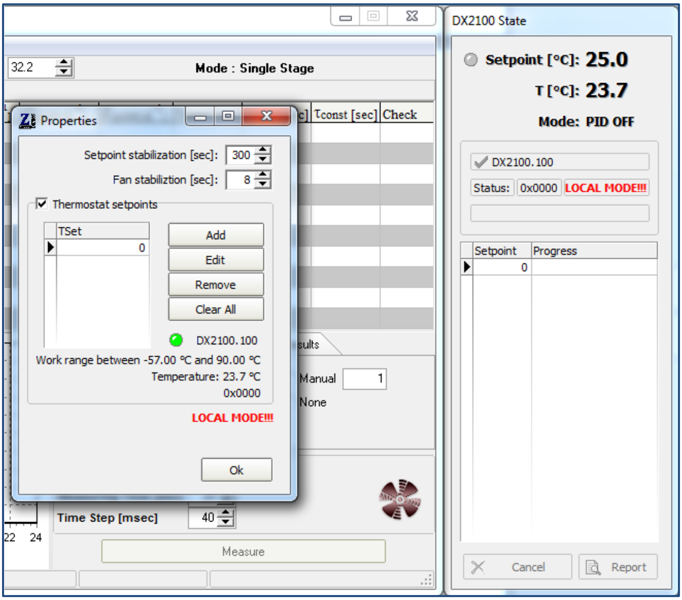
Set the desired values of stabilization time:

"Setpoint stabilization" is the time to wait after the thermostat set point achieved to start the measurement. It ensures minimum fluctuations of air temperature in the chamber after the start of measurements.

"Fan stabilization" is the time during which the program will wait after the fan turning off before the start of the measurements;

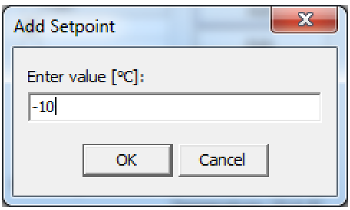
The default values are shown in the figure below.

3. Tick off **"Thermostat setpoints"**. The program tries to connect to the thermostat **DX2100**, as a result the thermostat status additional window is open. The window **"Properties"** displays current values of the temperature range, status, operational mode and temperature set point.

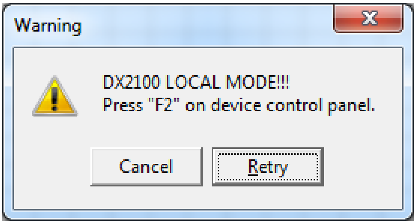


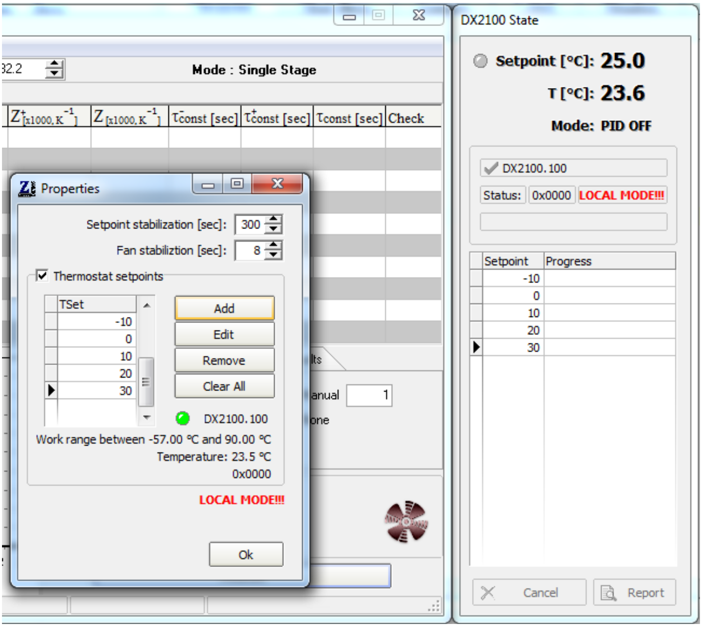
Adding and editing a number of set points at which it is supposed to perform measurements is carried out using the buttons "Add", "Edit", "Remove", and "Clear All".

Add necessary measurement points:

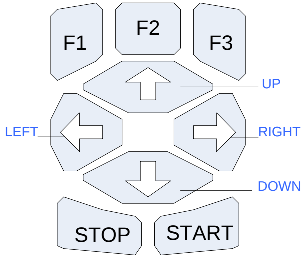


If the thermostat is in the local mode, press the button **"Ok".** The warning will pop up:



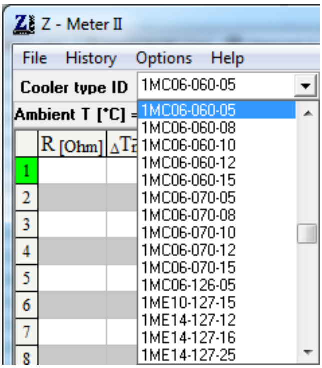


To switch the thermostat to the operational mode under the PC control, press the function key **"F2"** on the DX2100 control panel.

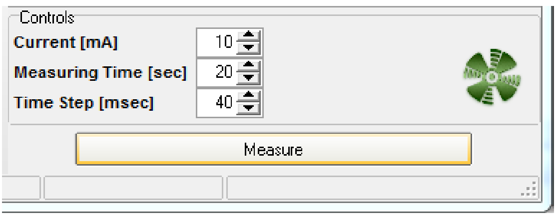


5.3. Measurement

Select an appropriate type of modules and correct the measurement parameters, if necessary (current, measuring time and telemetry period – time step):

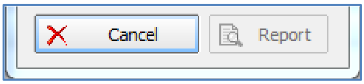


Press the button **"Measure"**:



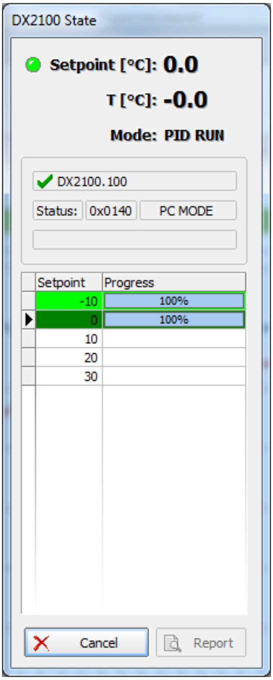
The thermostat starts temperature control:

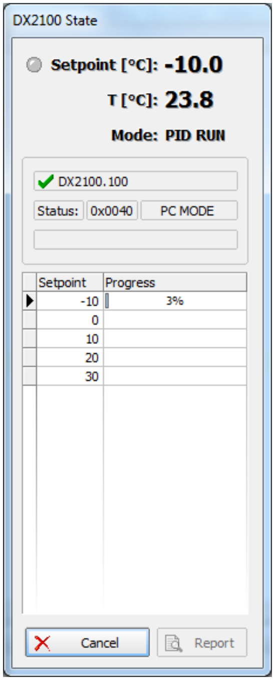
- From the lower set point;
- Indication is displayed in the field "Progress";
- When the set point is settled, thermoelectric module measurement is started;
- Entire measurement cycle is automated;
- If necessary, the measuring procedure can be interrupted:

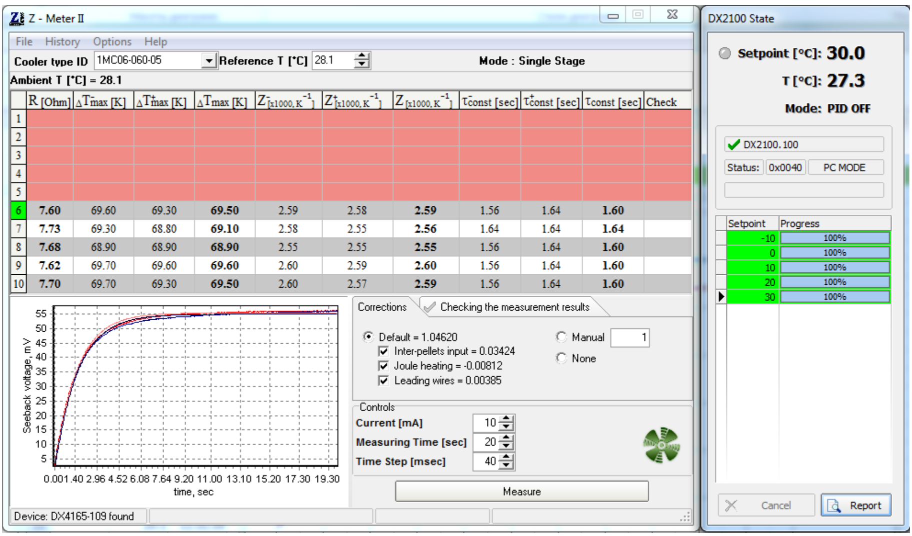


The measurement cycle will begin. The whole measuring process is displayed on the screen as follows.

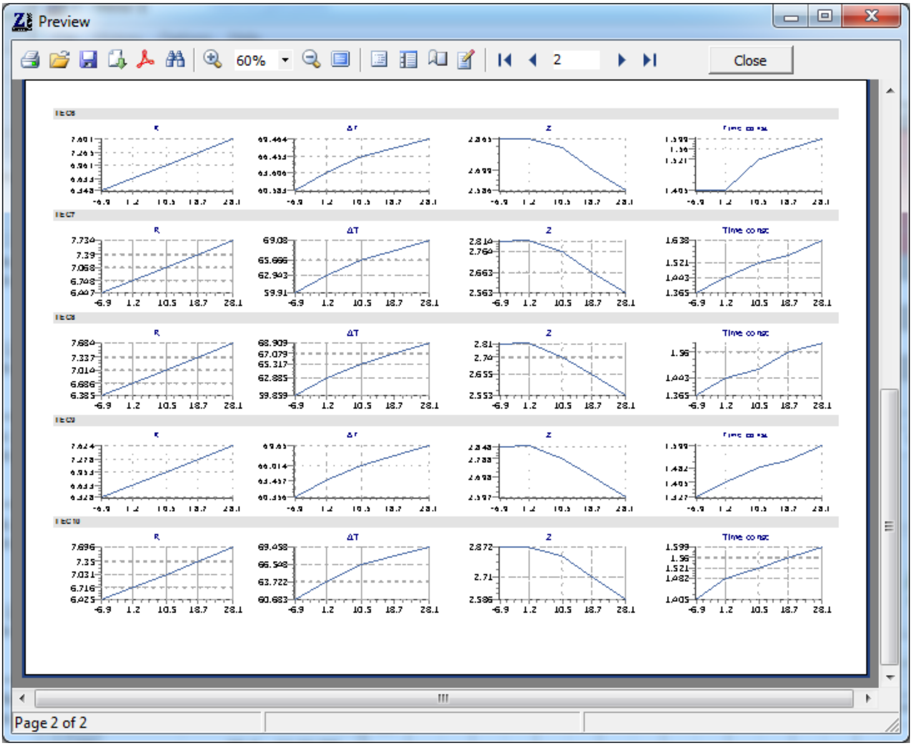
- "Progress" displays the status of set point settling;
- Dark-green highlights the line at the time of Z-metering;
- Light-green highlights the lines at which the measuring is over;


DX2100 State
Setpoint [°C]: 0.0
T [°C]: -0.0
Mode: PID RUN
DX2100. 100
Status: 0x0140 PC MODE
Setpoint Progress
-10 100%
0 100%
10
20
30
Cancel
Report


DX2100 State
Setpoint [°C]: -10.0
T [°C]: 23.8
Mode: PID RUN
DX2100. 100
Status: 0x0040 PC MODE
Setpoint Progress
-10 3%
0
10
20
30
Cancel
Report


Z - Meter II
File History Options Help
Cooler type ID 1MC06-060-05 Reference T [°C] 28.1 Mode : Single Stage
Ambient T [°C] = 28.1
R [Ohm] ΔTmax [K] ΔTmax [K] ΔTmax [K] Z [x1000, K-1] Z [x1000, K-1] Z [x1000, K-1] τconst [sec] τconst [sec] τconst [sec] Check
6 7.60 69.60 69.30 69.50 2.59 2.58 2.59 1.56 1.64 1.60
7 7.73 69.30 68.80 69.10 2.58 2.55 2.56 1.64 1.64 1.64
8 7.68 68.90 68.90 68.90 2.55 2.55 2.55 1.56 1.64 1.60
9 7.62 69.70 69.60 69.60 2.60 2.59 2.60 1.56 1.64 1.60
10 7.70 69.70 69.30 69.50 2.60 2.57 2.59 1.56 1.64 1.60
Seebeck voltage, mV
time, sec
Corrections Checking the measurement results
Default = 1.04620
Inter-pellets input = 0.03424
Joule heating = -0.00812
Leading wires = 0.00385
Manual 1
None
Controls
Current [mA] 10
Measuring Time [sec] 20
Time Step [msec] 40
Measure
Device: DX4165-109 found
DX2100 State
Setpoint [°C]: 30.0
T [°C]: 27.3
Mode: PID OFF
DX2100. 100
Status: 0x0040 PC MODE
Setpoint Progress
-10 100%
0 100%
10 100%
20 100%
30 100%
Cancel
Report

After the end of the measuring procedure, the results can be viewed by clicking on the button **"Report"**:



The generated report can be saved, exported to various formats or printed.

6. THEORETICAL GROUNDINGS

6.1. Time Constant Measuring

Let us consider a single-stage TE module. The ambient temperature is T_a. At a certain moment $\tau = 0$ electric current is applied to the module. The differential equation describing transient dynamics for a pellet of the TE module can be presented as the following exponential superposition:

$$\Delta T(t,x) = \sum_{i=1}^{\infty} A_n U_n(x) e^{-m_n t} + \Delta T_{st}(x) \qquad (6.1.1)$$

where

$\Delta T(t,x) = T - T_a$,

T - temperature of the pellet point located at a time t and a generalized coordinate x,

U_n , m_n - the eigen functions and eigen-values,

A_n - thermal amplitudes,

$\Delta T_{st}(x)$ - stationary ΔT value.

The solution (6.1.1) analysis yields that the cooling process can be divided into two stages: irregular and regular. The first one is dictated by the initial moment's conditions and is described by a multi-exponential interference. This phase fades out rather quickly and in case TEC pellets thermal conductance is high enough, the temporal behavior can be characterized by the only exponent, i.e for all possible n:

$$m_{min} \ll m_n \qquad (6.1.2)$$

The theory yields the following expression for the time constant $\tau = 1/m_{min}$ of a single-stage TE modules:

$$\tau = \frac{LC_1C_2}{(C_1 + C_2)\left(1 + \frac{L\alpha j}{k_0}\right) s_0 k_0 N} \qquad (6.1.3)$$

Where

C_1 , C_2 - TE module cold side and hot side heat capacities,

α - TE material Seebeck coefficient,

k_0 - TE material thermal conductivity,

N - TE module pellets number,

L - pellets height,

s_0 - pellets cross-section,

j - electric current density.

As Eq. (6.1.3) shows, τ calculation is stumbling because in practice the values involved are never known with accuracy required. The Z-meter allows measuring time constants of single-stage TE modules and estimating those of more-stage ones.

6.2. Interpolation Results

The procedure of handling the time constant measurement data is as follows.

The temporal behavior of a single-stage TE modules temperature difference $\Delta T(t)$ is measured via the Seebeck voltage that is a corresponding proportional value:

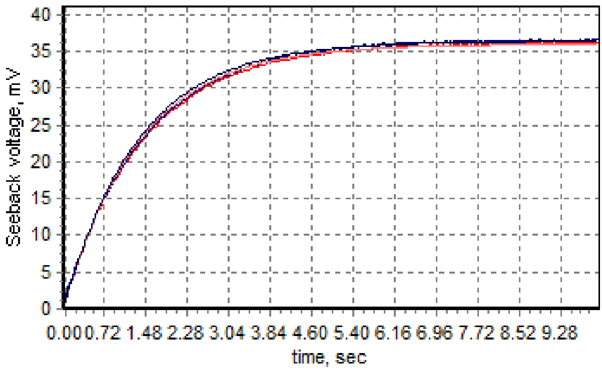
$$U_\alpha \sim \Delta T \tag{6.2.1}$$

For a two- or more-stage TE module this simple ratio is not applicable. However the time constant can be estimated by the temporal dependence of the Seebeck voltage and the approach for obtaining the stationary voltage values is the same.

Note! *TE module time constant τ is the time during which TE module temperature difference ΔT grows from 0 to 0.63ΔT_{st} (T_{st} is steady state ΔT value) at electric current turned on.*

The measuring procedure is carried out both for two electric supply polarities. The data collection duration and time step can be varied. The measuring time duration and step can be varied, too.

The measuring chart window is presented on the Figure below.



Measuring window of TEC dynamics

The obtained experimental data is then fitted by the following function:

$$U_\alpha(t) = U_{st_\alpha}(1 - e^{-t/\tau}) \qquad (6.2.2)$$

The exponential regression is based on the method of least squares. As its outcome, the procedure provides the time constant τ and the stationary Seebeck voltage U_{st_α}.

6.3. Figure-of-Merit Z Measuring

6.3.1. Single-stage TE Module Z

Among the parameters (R, Z, ΔT_{max}, τ), measured by the Z-Meter the AC resistance R is the only measured directly. The R measurement method is described in the Section "AC Resistance Measurement".

The determination of the Figure-of-Merit Z and the maximum temperature difference ΔT_{max} of a TE module implements an indirect method, which allows avoiding labour-consuming thermophysical measurements. This approach is based on the Harman method.

The Figure-of-Merit Z is one of most important parameters of a TE module. In a simplified form it may be defined as:

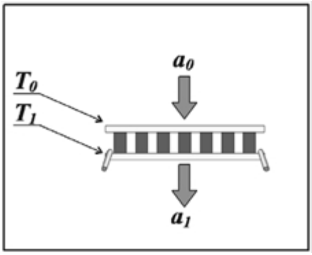
$$Z = \frac{\alpha^2}{kR} \tag{6.3.1}$$

Where:

α − TE material Seebeck coefficient,

R − TE module pellet electric resistance,

k − TE module pellet thermal conductance.



Hereinafter we deal with the stationary mode values only (if not mentioned otherwise, see Section 6.1). The base equations that describe a single-stage TE module thermal balance are as follows:

$$\begin{cases} \alpha I T_0 - \frac{1}{2} I^2 R - k'(T_1 - T_0) = \frac{a_0}{N}(T_a - T_0) \\ \alpha I T_1 + \frac{1}{2} I^2 R - k'(T_1 - T_0) = \frac{a_1}{N}(T_2 - T_a) \end{cases} \tag{6.3.1.2}$$

where

I - electric current,

R - electric resistance of a TE module pellet,

T_0 - TE module cold side temperature,

T_1 - TE module hot side temperature,

T_a - ambient temperature,

N - TE module pellets number,

a_0 - heat exchange coefficient for the cold side,

a_1 - heat exchange coefficient for the hot side,

k' - efficient thermal conductance of a pellet allowing for additional heat fluxes between the pellets.

We assume that the heat exchange coefficients meet the following requirements:

$$\frac{a_0}{N} \ll k', \quad \frac{a_1}{N} \ll k' \qquad (6.3.1.3)$$

We also suppose that electric current is small:

$$I \ll \frac{k'}{\alpha} \qquad (6.3.1.4)$$

Attention! *We recommend the measuring current* $I = 0.01\, I_{max}$. *See* I_{max} *values in the TEC specifications*

To the accuracy of the first-order infinitesimals of the values (6.3.1.3) and (6.3.1.4), we obtain for Z:

$$Z = \frac{1}{T_a}\left[\frac{U_\alpha}{U_R}\right]_{AV} \frac{(1+b_{th})(1+b_r)}{(1+b_T)} \qquad (6.3.1.5)$$

Where

$U_\alpha = N\alpha(T_1 - T_0)$ - TEC Seebeck voltage,

$U_R = NIR$ - TEC Ohmic component of the voltage.

The ratio of the voltages U_α and U_R in Eq. (6.3.1.5) must be averaged for two directions of the current (the index AV=average), as it eliminates expressions depending linearly on the current and allows extracting the corrections b_{th}, b_r, b_T.

The value b_{th} is the correction for additional heat flux between the pellets; b_r is the correction for leading wires electric resistance; b_T is the correction allowing for inequality of the TE module average temperature and the ambient temperature.

The values a_0, a_1 are estimated with account of free convection in the air and of thermal radiation: $a_{0,1} = (\alpha_{conv} + \alpha_{rad})S_{0,1}$, where α_{conv}, α_{rad} are thermal exchange coefficients of convection and of heat emission calculated for each TE module individually, $S_0$and S_1 are the surfaces of the cold and hot sides of the TE module tested.

Eq. (7.1.5) remains fair if inequalities (7.1.3) are modified as:

$$\frac{a_0}{N} =\ll k', \quad a_0 \ll a_1 \tag{6.3.1.6}$$

That means that the method allows finding the value Z of a TE module when the heat exchange on one side of the module is intensive enough. Therefore, the Z-Meter enables testing of a TE sub-assembly: TEC mounted on a header. In this case the value a_1 is the header thermal resistance (calculated by the Program).

The measured Z of a single-stage TE module allows estimating ΔT_{max} of the module at the hot side temperature T_1:

$$\Delta T_{max}(T_1) = T_1 - \frac{\sqrt{1 - 2ZT_1} - 1}{Z} \tag{6.3.1.7}$$

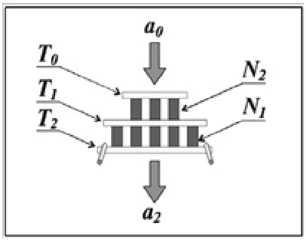
6.3.2. Two-stage TE Module Z

For a two-stage TE module Z can be estimated with the help of the Harman method and can only be regarded as a criterion of an average quality of pellets if certain requirements are met.

Here are heat rate equations for a two-cascade TE module:

$$\begin{cases} \alpha I T_0 - \frac{1}{2} I^2 R - k'(T_1 - T_0) = \frac{a_0}{N_1}(T_a - T_0) \\ \alpha I T_1 + \frac{1}{2} I^2 R - k'(T_1 - T_0) + \frac{a_1}{N_1}(T_a - T_1) \\ \quad = \frac{N_2}{N_1}\left[\alpha I T_1 - \frac{1}{2} I^2 R - k'(T_2 - T_1)\right] \\ \alpha I T_2 + \frac{1}{2} I^2 R - k'(T_2 - T_1) = \frac{a_2}{N_2}(T_2 - T_a) \end{cases} \quad (6.3.2.1)$$

Here



$T_{0,1,2}$ - substrates temperatures,

T_a - ambient temperature,

$N_{1,2}$ - numbers of pellets on the stages,

$a_{0,1,2}$ - heat exchange coefficients for the cold, hot and medium substrates, respectively.

Let us assume that the ratios of the heat transfer coefficients a_0 and a_2 from the surfaces S_0 and S_2 to the pellets number N_1, N_{22} are the same:

$$\frac{a_1}{N_1} = \frac{a_2}{N_2} = a = const \quad (6.3.2.2)$$

The first and third equations of (6.3.2.1) can be written as:

$$\begin{cases} \alpha I T_0 - \frac{1}{2} I^2 R - k'(T_1 - T_0) = a(T_a - T_0) \\ \alpha I T_2 + \frac{1}{2} I^2 R - k'(T_2 - T_1) = a(T_2 - T_a) \end{cases} \quad (6.3.2.3)$$

If temperature differences on the cascades can be considered equal:

$$\Delta T_1 = \Delta T_2 \quad (6.3.2.4)$$

we obtain:

$$Z = \frac{1}{T_a}\left[\frac{U_\alpha}{U_R}\right]_{AV}(1 + b_{th} + b_a + b_r) \tag{6.3.2.5}$$

Attention! I*n real testing Eq. (6.3.2.4) is not rigorous, and Z (6.3.2.5) is only a relative criterion of a TE module quality.*

Here b_{th} is the correction for additional heat flux between the pellets; b_a is the correction for external heat fluxes; b_r is the correction for leading wires electric resistance. The value a is estimated by the software taking into account free convection in the air and heat emission.

Averaging the voltages ratio (6.3.2.4), though mathematically not obligatory, is carried out similarly to a single-stage module case for accuracy purposes.

6.3.3. Alternative Correction

It is convenient sometimes to reduce all the corrections discussed above to a certain coefficient A. Then Eqs. (6.3.1.5) and (6.3.2.5) can be written as:

$$Z = A\frac{1}{T_a}\left[\frac{U_\alpha}{U_R}\right]_{AV} \tag{6.3.3.1}$$

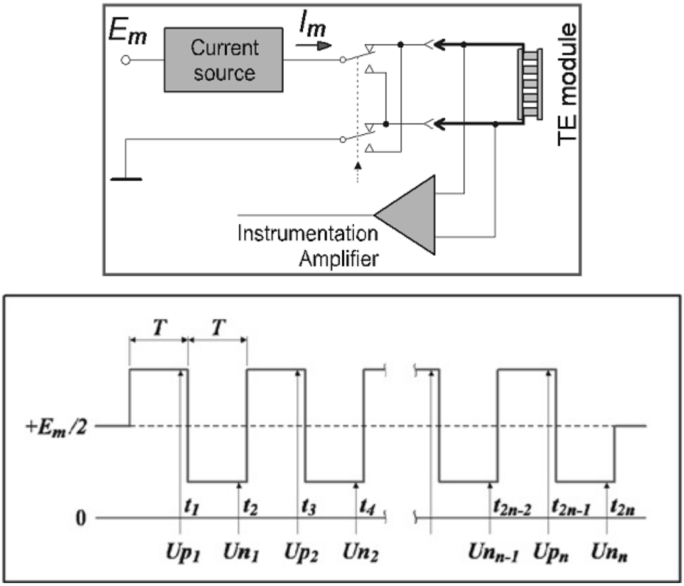
The coefficient A can be also obtained empirically by correlating directly measured ΔT_{max} and the value obtained by Z-Meter.

7. MEASURING PROCESSES

7.1. AC Resistance

AC resistance is measured by applying a small AC signal to TE module. The AC is generated by a “Commutator” (switch), which periodically (with 50% duty circle) reverses a circuit of the reference current I_m. The "Commutator's" simplified diagram is shown below.

If there is no input signal, the output voltage of the instrumentation amplifier equals to $E_m/2$, where $E_m = 4.096\ \mathrm{V}$.



AC R testing simplified diagram

Output signal of instrumentation amplifier when AC R is tested

During AC resistance measurement the output voltage of the instrumentation amplifier is sampled and measured by a 12-bit ADC each time before reversing the current I_m. The sampling points are marked as t_i in above figure. The voltage drops on TE module for the positive signal (U_{pi}) and negative signal (U_{ni}) are used for a TE module resistance (R) calculation by the following formula:

$$R = \frac{\sum_{i=1}^{n}(U_{pi} - U_{ni})}{2 I_m A_V n} \qquad (7.1.1)$$

where

A_V - voltage gain of the instrumentation amplifier;

n - total number of readouts per measurement.

Typical values of parameters in formula (7.1.1) are:

I_m = 2 mA,

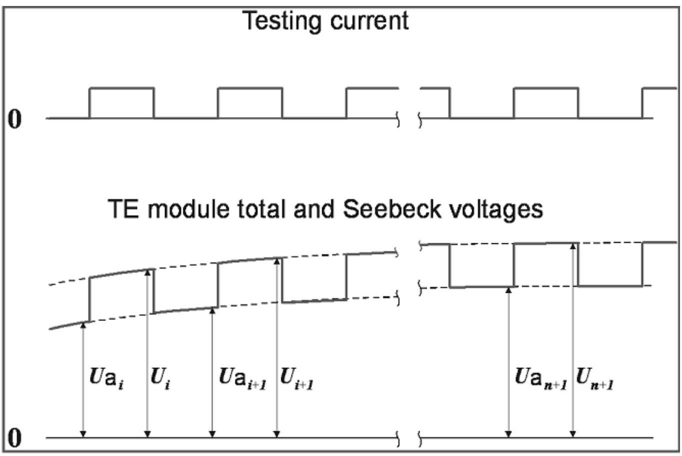
A_V = 5 or 50,

n = 50.

7.2. The U and U_α Telemetry

During measurement of the parameters U and U_α, a small current I_m is applied to TE module periodically (with 50% duty cycle).

Two successive measuring sessions are necessary to obtain the U and U_α values at different testing current polarities.



Testing current and voltage schematic temporal behavior

7.3. Voltages for Testing Z

Equations (7.1.5) and (7.2.5) contain both U_R and U_α. These are the voltage values referred to the time t at which the process becomes steady.

The Seebeck voltage U_α in (6.3.1.5) and (6.3.2.5) is equal to the stationary value U_{st_α} obtained by the interpolation procedure (see Eq. (6.2.2)).

The Ohmic voltage drop U_R is also calculated with reference to the steady-state time t. It should be done for the reason the TE module resistance R undergoes a change due to a slight evolution of its average temperature. At the current $I_T = 0.01 I_{max}$ it may have about 1÷1.5 % growth. So, the value U_R is resulted from the following averaging over the last 10 time points of the testing procedure at one current:

$$U_R = \frac{1}{10} \sum_{i \geq (N-10)} [U\,(t_i) - U_\alpha(t_i)] \qquad (7.3.1)$$

> **Attention!** *Make sure the measured TE module has reached the steady state. To assess it, the telemetry capability is available (see dynamics window).*

7.4. Checking of TE Module Polarity

To verify a TE module polarity the Z-Meter involves a procedure of a short-time heating of the bottom substrate of the module when finishing the procedure of voltage measuring on "direct" polarity.

The averaged voltage U'_α measured while heating is compared with the value U_α averaged over last 10 points of U_α:

$$U_\alpha = \frac{1}{10} \sum_{i \geq (N-10)} U_\alpha\,(t_i) \qquad (7.4.1)$$

If the TEC polarity is right:

$$U'_\alpha > U_\alpha \qquad (7.4.2)$$

In case of the polarity confused:

$$U'_\alpha < U_\alpha \qquad (7.4.3)$$

8. MAINTENANCE

The Z-Meter does not require any particular maintenance or service.

Nevertheless if for any reason you feel doubtful about the device accuracy, you can check it by measuring a precision resistor instead of a TE module.

The “R-meter” program should be used. We suggest measuring a resistor of 5 to 20 Ohms. Measure the resistor by “R-meter” program and digital multimeter with accuracy the same or better than 3 decimal digits.

Compare the data obtained. If the difference in the resistance values is within 0.5%, the Z-Meter can be further used for measurements.

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