



PromLegion Ltd.

Z-METER DX4090

User Guide



Moscow, 2016

version 1.03

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.

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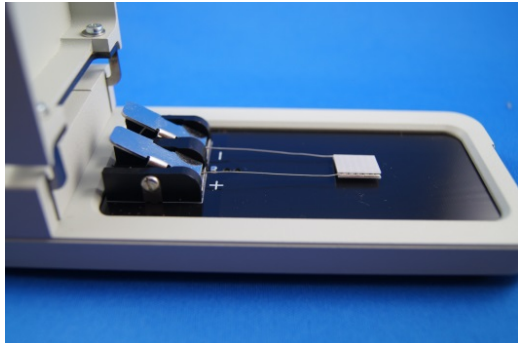
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1. INTRODUCTION

The Z-Meter provides measurement of following parameters of thermoelectric (TE) modules (also TE coolers, TECs):

- AC Resistance (R)
- Figure-of-Merit (Z)
- Time Constant (τ)
- Maximum Temperature Difference¹ (ΔT_{max})



Basing on the results of these measurements, the TE module maximum temperature difference ΔT_{max} (for a single-stage module) is calculated.

The parameters are measured at the ambient temperature. The software provides recalculation of TEC resistance and maximum temperature difference to other ambient temperatures if required.

The Z-Meter allows testing of various types of single- and two-stage TE modules and sub-mounts with a single-stage TECs.

It also allows evaluation of quality of more-stage TE modules by measurement of their AC resistance.

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

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.

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

- ✓ *Portable design*
- ✓ *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...4
Accuracy	%	1.5
Repeatability	%	0.4
Time Constant τ		
Range	s	1...100
Accuracy	%	1.5
Repeatability	%	1
Power Supply		
Voltage	V	+5 (USB connector)
Current	mA	250
Operational Conditions		
Ambient temperature range	°C	+15...+35
Humidity	%	0...95
Storage		
Temperatures range	°C	-20...+60
Humidity	%	5...95
Mechanical Parameters		
Dimensions	mm	160x66x30
Weight	kg	0.24

2.2. Delivery Kit



Z-meter DX4090

1 pcs.



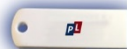
Cable with 4-wire terminals
for external testing *

1 pcs.



Cable USB AM / miniUSB-B

1 pcs.



CD or USB Flash (Software,
Manual)



* Measuring terminals can be
made on the basis of Kelvin
klips of various designs.

2.3. Features

- The Z-meter has an internal chamber for placing a TEC under measurements. It is always recommended to place TECs into this chamber. If TEC size does not fit the chamber, such a TEC may be placed outside and connected to Z-meter by external cable enclosed. In both cases, four-wire connections are used to ensure the most precise measurements. Note free air convection around the TEC is required in case of measurements of TECs outside the internal chamber.
- The Z-meter allows checking of TEC polarity simultaneously with TEC parameters measurement.

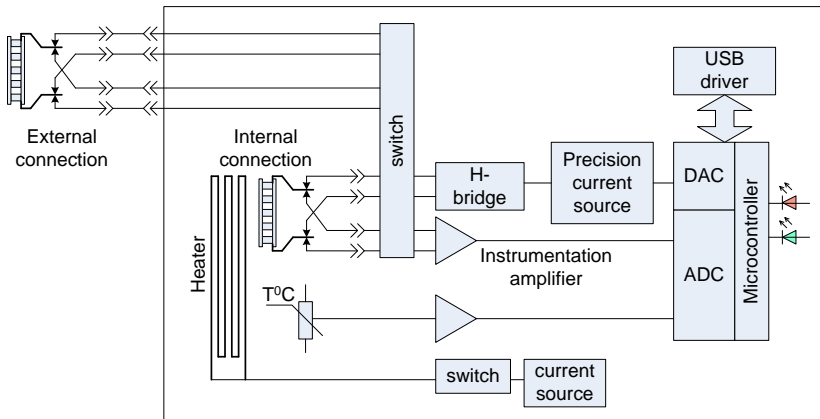
2.4. Design overview

The Z-meter is a single-unit device with internal chamber for TECs. Chamber's cover is magnetically locked when closed or opened.

The internal chamber is a passive thermostat which provides constant TEC temperature during measurements. Terminals inside allow easy connection of measured TEC. Temperature inside the chamber is measured by an appropriate temperature sensor. There is also a heater inside the chamber for measurement of TEC polarity. There is also a LED for visual control of measurements status.

USB connector for connection to a PC, and connector for a cable for external TEC measurements are located on the back of the device.





Z-meter: back view and functional scheme

2.5. System Requirements

Any Z-Meter requires connection to a PC and installation of “Z-meter” software. The software is delivered along with Z-Meters or may be downloaded from www.promln.com. The interface is simple and does not require User's special knowledge or experience.

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

General system requirements are as follows:

- 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. Drivers Installation

Install USB drivers using enclosed CD/flash. The latest versions of drivers are also available at <http://www.ftdichip.com/Drivers/VCP.htm>

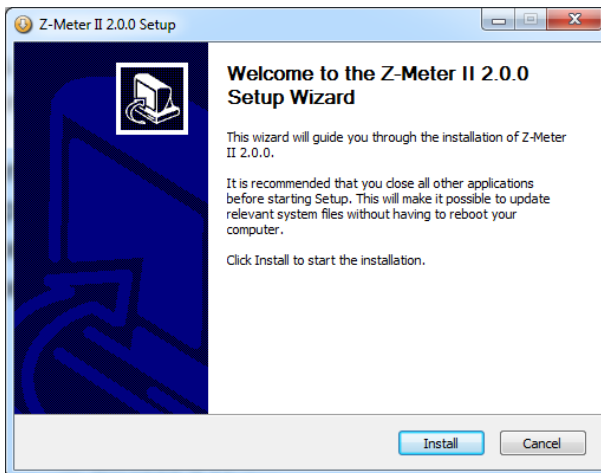
Installation procedures for a specific version of Windows may be also found at <http://www.ftdichip.com/Support/Documents/InstallGuides.htm>

USB Serial Converter should appear in the Windows Device Manager after successful installation.

3.2. Software Installation

Insert the CD/flash to a PC and start the Setup program.

The window of the standard Windows installer will appear – see below.



Click “Install” and proceed according to the installer directions. Remember at least 20 MB of a space should be initially available at selected logic disk, and that the size will increase when you’ll add new TECs to a database with measurement results.

3.3. Getting Ready



Attention! If any Z-Meter was stored at / subjected to temperatures below +10°C before measurements, it must be kept at expected ambient test conditions for at least 2 hours.

3.3.1. External connections

Connect Z-meter to USB port of your PC.

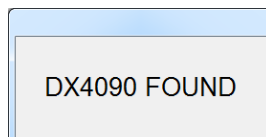
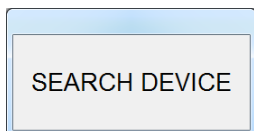


Connect the cable for external measurements to the connector **Ext** if you plan external characterization of TEC(s). Otherwise this cable should not be disconnected to the Z-meter.

3.4. Measurements

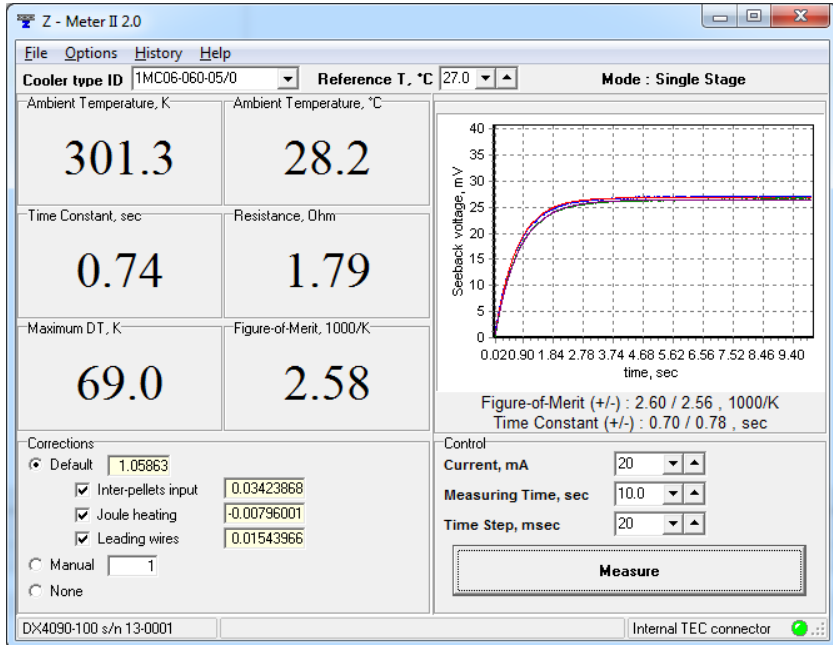
3.4.1. Run the “Z-Meter II” software

The following windows will be displayed one after another in case you run Z-meter program:



If the “**DEVICE NOT FOUND**” message pops up, please make sure the device is properly connected. Also check whether the USB drivers have been properly installed and repeat USB driver installation procedure if required (see 6).

The main window will appear:



Important! TEC polarity check option must be switched off (See “Software”). The Z-Meter type DX4095 does not support the option.

3.4.2. TE Modules Connection

Measurements of TECs in



internal chamber

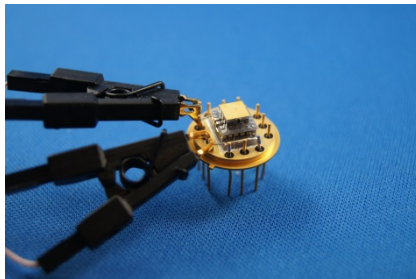
Open the cover of the Z-Meter.

Connect TEC to terminals firmly (see right).

Close the cover and run the Z-Meter program.

External TEC measurements

Connect your TEC firmly as shown below.



Ensure minimum possible air convection in the area of measurement. It is recommended to place the TEC as close to the Z-meter as possible keeping internal chamber opened. Remember temperature sensor is located in the chamber and considerable difference of TEC and thermosensor's temperature will result in mistakes in measurements.



Note! TEC polarity check option must be switched of in case of external measurements.

3.4.3. Make the pre-sets for measurements

TEC ID

If serial number of the testing is known or identified (in a case of testing of RMT TECs) set the s/n using Cooler type ID from listed database at reference Bar.

Cooler type ID Reference T, °C Mode : Single Stage

In the case software will extract default corrections factors for the particular TEC type in the field of corrections

Corrections

Default

Inter-pellets input

Joule heating

Leading wires

Manual

None

If type is unknown then the state is “Default”.

If the TEC type is not listed into software database one can stay correction coefficient as 1 (One), or to set own corrections coefficients if they are known of can be calculated.

Reference Temperature

Set required reference temperature at reference bar.

Reference T, °C



Note! Default - 27 °C (300K).

Parameters of measurement

In “Control” field one can set parameters of measurement

Working Current

Recommended value is 1% of I_{max} according to specification of examined TEC unit. If it is not known – use default – 5mA for the beginning.

Control	
Current, mA	20
Measuring Time, sec	10.0
Time Step, msec	20
Measure	

Time of measurement

Set the total measurement time.

Recommended value – more than 5-6 of time constant of the TEC. If the value is unknown set stay default – 10 second for the beginning.

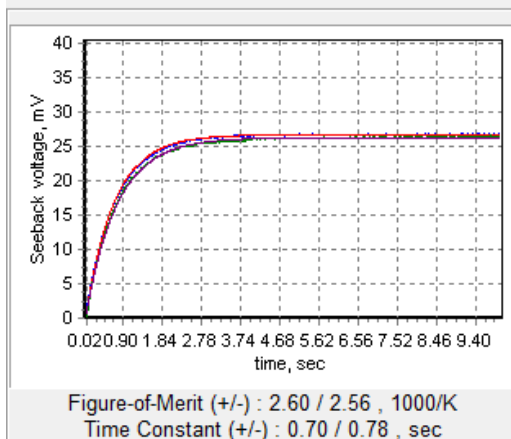
Time step

Recommended value – 20 millisecond.

3.4.4. Measurements

If everything is OK and pre-sets are made then push button “Measurement”.

At Graph field you will observe curves of Seebeck voltage measurement in time under applied working current.



After two curves appear (direct and reversed current measurement) the software will calculate all measured parameters

Ambient Temperature, K	Ambient Temperature, °C
300.8	27.7
Time Constant, sec	Resistance, Ohm
0.74	1.78
Maximum DT, K	Figure-of-Merit, 1000/K
68.9	2.58

TECs and Z-meters must be kept at ambient conditions expected during tests for at least of one hour before any measurement.

3.4.5. Measurement results

The results of each measurement are stored in the file. You can view

or clear it using the "File" command/

With the "Print" command you can make the hard copy of the "History" file on a default printer.

Submenu "Export" will help you to keep a «History» file in various formats:

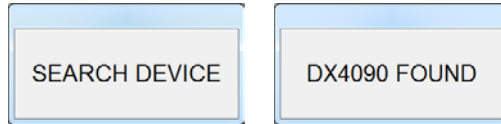
More detailed descriptions of working with results and with software are described in Article – “Software”

4. SOFTWARE

4.1. Introduction

The Z-meter must be plugged-in to PC before running the Program.

The following windows will be displayed one after another in case you run Z-meter program for the first time, see below:



If the “DEVICE NOT FOUND” message pops up, please make sure the device is properly connected. Also check whether the USB drivers have been properly installed and repeat USB driver installation procedure if required (see 3.1. above).

4.2. Main Window

The main program window is shown in the screenshot below.

The screenshot shows the Z-Meter II 2.0 software interface. The window title is "Z - Meter II 2.0". The menu bar includes "File", "Options", "History", and "Help". The interface is divided into several sections:

- Top Bar:** "Cooler type ID" (1MC06-060-05/0), "Reference T, °C" (27.0), and "Mode: Single Stage".
- Measurement Fields:**
 - Ambient Temperature, K: 301.3
 - Ambient Temperature, °C: 28.2
 - Time Constant, sec: 0.74
 - Resistance, Ohm: 1.79
 - Maximum DT, K: 69.0
 - Figure-of-Merit, 1000/K: 2.58
- Graph (Dynamics field):** A plot of "Seebeck voltage, mV" vs "time, sec". The y-axis ranges from 0 to 40, and the x-axis ranges from 0 to 9.40. The curve shows a rapid rise from 0 to approximately 25 mV within the first 1.84 seconds, then levels off. Below the graph, it displays "Figure-of-Merit (+/-) : 2.60 / 2.56 , 1000/K" and "Time Constant (+/-) : 0.70 / 0.78 , sec".
- Corrections field:**
 - Default: 1.05863
 - Inter-pellets input: 0.03423868
 - Joule heating: -0.00796001
 - Leading wires: 0.01543966
- Control field:**
 - Control Current, mA: 20
 - Measuring Time, sec: 10.0
 - Time Step, msec: 20
- Device info field:** DX4090-100 s/n 13-0001
- Measure field:** A "Measure" button with a tooltip that says "Type connector & Use Check Polarity".
- Connection:** A "J Internal IEC connector" status indicator.

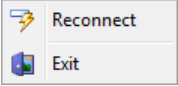
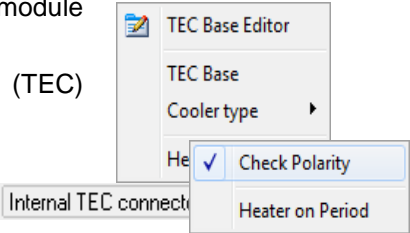
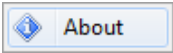
Its functional structure is the same for three Z-Meter measurement options:

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

4.2.1. Menu Bar

There are four items in the Menu bar.

File Options History Help

- **"File"** is used when it is necessary to reconnect the Device or exit.
 
- **"Options"** allows:
 - 1) adding/editing a TE module type;
 - 2) selecting a TE module (TEC) database;
 - 3) choosing a TE module (Cooler) type;
 - 4) enabling/disabling check polarity TE module (internal TEC connection only)
- **"History"** allows switching from current measuring results to database with previous measurements.
- **"Help"** provides information concerning the Z-Meter software
 

4.2.2. Reference Bar

There are two fields in the Reference bar.

Cooler type ID	Default	Reference T, °C	27.0	Mode : Single Stage
	<ul style="list-style-type: none"> 1MCD4-004-03/0 1MCD4-004-05/0 1MCD4-004-08/0 1MCD4-004-10/0 1MCD4-004-12/0 1MCD4-004-15/0 1MCD4-007-05/0 1MCD4-007-08/0 1MCD4-007-10/0 1MCD4-007-12/0 1MCD4-007-15/0 1MCD4-008-03/0 1MCD4-008-03/2 1MCD4-008-05/0 1MCD4-008-05/2 			

The field "Cooler type ID" allows selecting a TE module type to be tested.

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

You may also choose a value from standard reference temperatures which are 20°C or 30°C, or ambient.

20°C
30°C
°C Ambient T

4.2.3. Functional Fields

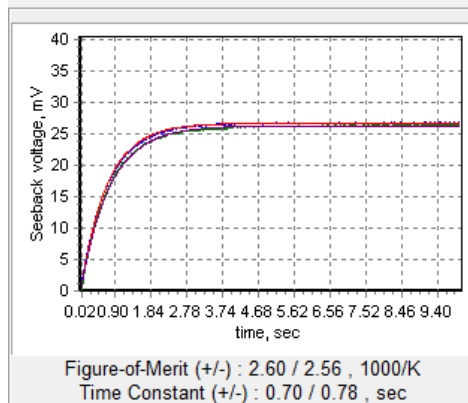
There are four functional fields in the main window:

- **Control** field presents the following test parameters: electric current, total time of measurement, time step.

Control	
Current, mA	20
Measuring Time, sec	10.0
Time Step, msec	20
<input type="button" value="Measure"/>	

The button "Measure" starts the measuring procedure.

- **Dynamics** field depicts the chart window of the Seebeck voltage $U_{\alpha}(t)$ temporal behavior telemetry.



It also indicates obtained values of:

- 1) Time constants at different current polarities,
 - 2) Z at different current polarities
- **Corrections** field shows the important calculated corrections values which will be used for calculation of them main performance parameters like, for example, Z (see Chapter 5.3 for details). .

Corrections

Default

Inter-pellets input

Joule heating

Leading wires

Manual

None

Following possibilities of a correction exist:

- 1) **Default** - using of the calculated corrections (only for the TE modules fully described in the database);
 - 2) **Manual** - using a User's own coefficient value A, manually inputted;
 - 3) **None** – no use of any correction.
- **Results** field contains the following measured/calculated results:

Ambient Temperature, K	Ambient Temperature, °C
300.8	27.7
Time Constant, sec	Resistance, Ohm
0.74	1.78
Maximum DT, K	Figure-of-Merit, 1000/K
68.9	2.58

- 1) Electrical AC 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).

4.3. Measurement Presets

4.3.1. Temperature Setting

Z-meter allows re-calculation of the main TEC parameters to various temperatures (see Chapter 7).



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

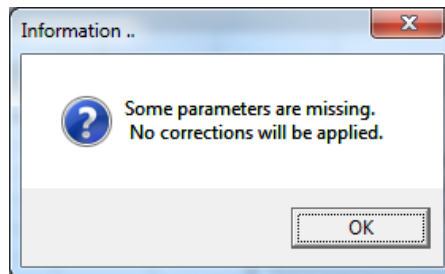
The most convenient ambient temperature to which the parameters are recalculated may be selected from a "Reference T" list of entered manually.

4.3.2. TE Module Type

Select a "Single-stage" or a "Two-stage" option following "Option>> Cooler Type". Note if no option is chosen, corrections are set zero.

Choose the type of a TE module from the "Cooler type ID" list. PROMLEGION is the default TE modules base. Other databases may be found/selected following "File"->"TEC Base Editor".

Automatic notice will appear if any TEC parameter required for further calculations is missed. Add correspondent parameter to the database.



If necessary TEC type is absent in the list, add module parameters to the database manually (see Chapter "Database Update").



Attention! *If no information on parameters of tested TEC is available in the database, no corrections/coefficients will be used in calculations of TE module parameters by default. "TE Cooler Type" field will change to DEFAULT in this case.*

4.3.3. Correction Coefficients

With all TEC parameters available, the corrections as well as their equivalent coefficient A are taken into account by default (see Equation 5.3.3.1). The corrections are specified in the Table below. It is possible to switch particular correction on/off by correspondent radio button pairs. The Results window fits the changes automatically.

Symbol	Description	Comments
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 only
b_R	Allows for additional electrical resistance of leading wires	For single-and two-stage modules

In other words, any user is given an opportunity either to take into account the corrections via the calculated values selected by a User and their equivalent coefficient A (by default), or to suggest one's own value of A, or to refuse all the corrections.

4.3.4. Package Thermal Resistance

Z-Meters also allow characterization of TE cooler sub-assemblies by choosing correspondent option in the Manu. In this case, however, following parameters should be available/ added:

- 1) header material thermal conductivity;
- 2) header base thickness;
- 3) mounted TE module fully described in the Z-meter database.

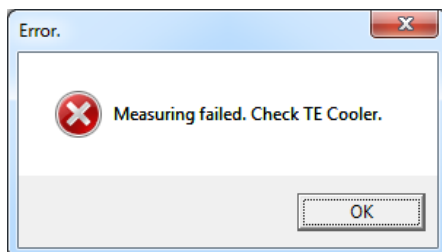
4.4. Measurement Procedure and Notes

Measurement cycle is started simply clicking “Measure” in the Program Main Window.



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 keep a pause of at least 3x measured time constant before any new measurement. It is usually 30 sec on average. This time is usually enough to stabilize the TE module temperature*

The message:



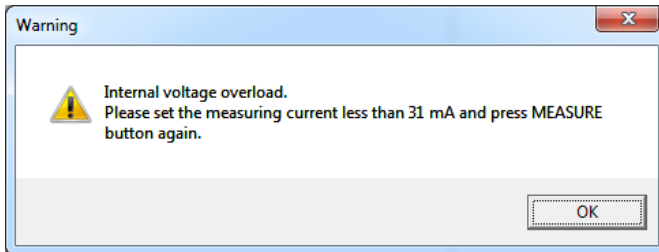
appeared shortly after clicking “Measure” means that either:

- open circuit inside the TE module,
- short circuit inside the TE module.

Note the last case is hardly possible in practice according to PROMLEGION's experience. Therefore, open circuit is more likely the reason. Double-check the terminals for proper contacting TEC. Retry measuring. Occurring of the message indicates on TE module failure/malfunction.



Attention! Selection of a too higher TEC control current (see the Main Window) may result in exceeding of a full scale of ADC used. The message as shown below will be generated automatically. In such a case, select the value recommended for measurements and try again.



As mentioned above, the DX4090 Meter may be also used for measurement of AC resistance in coolers with more than two stages. To do this, leave the "TE Cooler Type" unselected (Default Type in the "TE Cooler Type" field). Insert a TE module into the DX4090 Meter and click the "Measure" button.



Attention! You must ignore all the results except the resistance value in such a case.

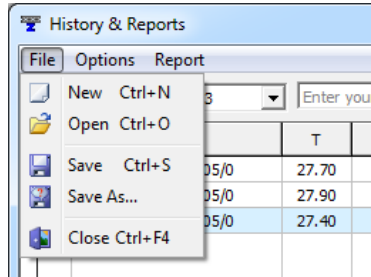
4.5. History

4.5.1. File

The results of each measurement are stored in the file. You can view or clear it using the "File" command.

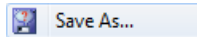
The history file is created in the "/History" folder of the "/Z-meter" directory during every measuring session after the first successful measurement. ("Measuring session" means the period between the

first successful measurement and the program exit). The history file name has the form of the date and time of the history file creation. "Comment" field on the top of the "History" window allows adding of additional comments to history files.



Report Date	16.04.2013	Enter your comments here
-------------	------------	--------------------------

If you need to save the "History" file under other name, use the "Save As" command.



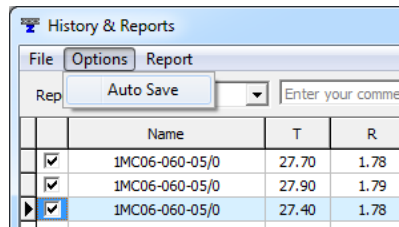
The "New" command closes the current history file and opens a new one with no data.

Data arrangement in the "History" window is represented below.

	Name	T	R	RefT	RefR	Time	dTmax	Z	Im	Corr	Polarity
<input checked="" type="checkbox"/>	IMC06-060-05/0	27.70	1.78	27.00	1.77	0.74	69.12	2.59	20.00	1.05871	OK
<input checked="" type="checkbox"/>	IMC06-060-05/0	27.90	1.79	27.00	1.78	0.70	69.34	2.60	20.00	1.05862	no check
<input checked="" type="checkbox"/>	IMC06-060-05/0	27.40	1.78	27.00	1.78	0.70	69.17	2.59	20.00	1.05870	no check

The "Chk" field is assigned for records marking. Note only marked records will be copied on a printer under the "Print" command. The marking/unmarking is performed with the mouse left button click on the appropriate field. The default record state is "Marked".

4.5.2. Options

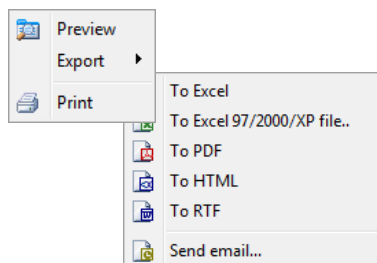
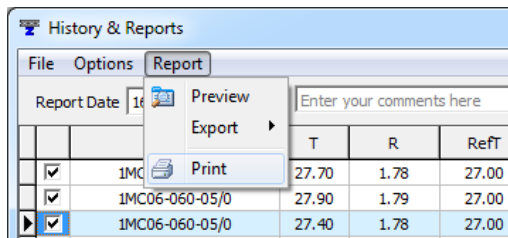


If menu item "Auto Save" is checked, the "History" file will be saved automatically.

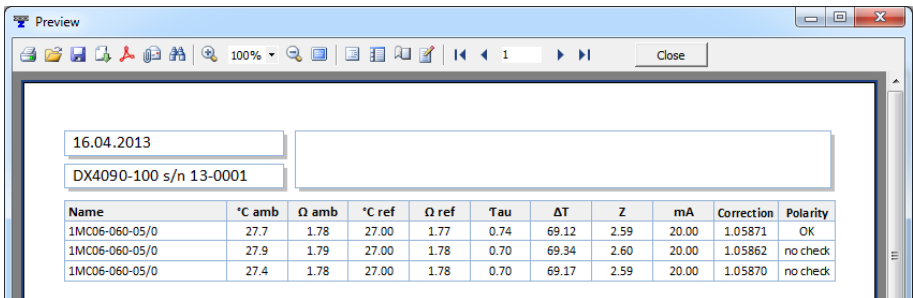
4.5.3. Report

With the "Print" command you can make the hard copy of the "History" file on a default printer.

Submenu "Export" will help you to keep a «History» file in various formats:



The example of Preview Report is shown below.

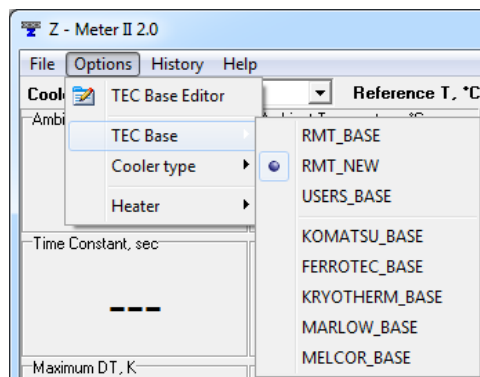


4.6. TE Modules Database Update

If the parameters of any TE module are not available in the database, you can add them by yourself. The full set of parameters consists of:

- 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 the database you want to change (see the figure above, example only). Select the "File" -> "TEC Base Editor" command from the "Main" menu. The window titled "Add TE cooler" will appear.



There are two input boxes in the window: "Cooler" and "Leads". All or a few fields may be already filled in. Enter correct/required parameters by yourself when required.

Add TE Cooler ✖

Cooler

Cooler ID

Cooler type Single stage Two stage

Cold size dimensions (mm x mm) *

Hot size dimensions (mm x mm) *

Ceramics thickness (mm)

Pellets number

TE pellets cross-section (mm x mm) *

TE pellets height (mm)

Per a Wire

Electrical resistivity [$\times E-8$ Ohm x m]

Thermal Conductivity [W/mK]

Length (mm)

Cross-section [mm²]

The contents of "Cooler ID" field are not used for calculations. You can fill any information in this field.

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" button.

5. THEORETICAL FOUNDINGS

5.1. Time Constant Measuring

Let us consider a single-stage TE module. The ambient temperature is T_a . At a certain moment 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:

$$\Delta T(t, x) = \sum_{i=1}^{\infty} A_n U_n(x) e^{-m_n t} + \Delta T_{st}(x) \quad (5.1.1)$$

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 (5.1.1) 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 :

$$m_{min} \ll m_n \quad (5.1.2)$$

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

$$\tau = \frac{LC_1C_2}{(C_1 + C_2) \left(1 + \frac{L\alpha j}{k_0}\right) s_0 k_0 N} \quad (5.1.3)$$

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. (5.1.3) 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.

5.2. 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 is measured via the Seebeck voltage that is a corresponding proportional value:

$$U_\alpha \sim \Delta T \quad (5.2.1)$$

For a two- or more-stage TE module this simple ratio is not

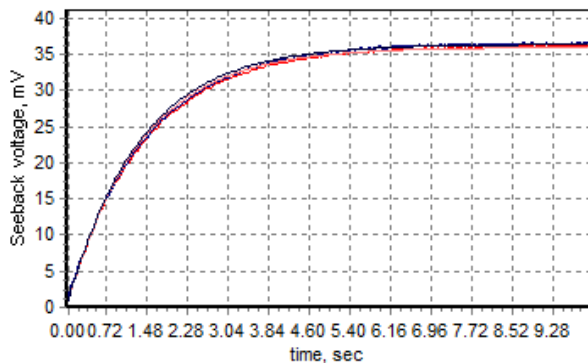
applicable. However the time constant can be estimated by the temporal dependence of the Seebeck voltage and the approach for obtaining the stationary voltage values is the same.



Note! *TE module time constant τ is the time during which TE module temperature difference ΔT grows from 0 to $0.63\Delta T_{st}$ (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:

$$U_{\alpha}(t) = U_{st\alpha}(1 - e^{-t/\tau}) \quad (5.2.2)$$

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 $U_{st\alpha}$.

5.3. Figure-of-Merit Z Measuring

5.3.1. 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".

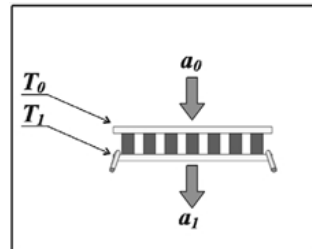
The determination of the Figure-of-Merit Z and the maximum temperature difference ΔT_{max} of a TE module implements an indirect method, which allows avoiding labour-consuming thermophysical measurements. This approach is based on the Harman method.

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

$$Z = \frac{\alpha^2}{kR} \quad (5.3.1.1)$$

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 5.1). The base equations that describe a single-stage TE module thermal balance are as follows:

$$\begin{cases} \alpha I T_0 - \frac{1}{2} I^2 R - k'(T_1 - T_0) = \frac{a_0}{N} (T_a - T_0) \\ \alpha I T_1 + \frac{1}{2} I^2 R - k'(T_1 - T_0) = \frac{a_1}{N} (T_2 - T_a) \end{cases} \quad (5.3.1.2)$$

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:

$$\frac{a_0}{N} \ll k', \quad \frac{a_1}{N} \ll k' \quad (5.3.1.3)$$

We also suppose that electric current is small:

$$I \ll \frac{k'}{\alpha} \quad (5.3.1.4)$$



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 (5.3.1.3) and (7.1.4), we obtain for Z :

$$Z = \frac{1}{T_a} \left[\frac{U_\alpha}{U_R} \right]_{AV} \frac{(1 + b_{th})(1 + b_r)}{(1 + b_T)} \quad (5.3.1.5)$$

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. (5.3.1.5) 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. (5.3.1.5) remains fair if inequalities (5.3.1.3) are modified as:

$$\frac{a_0}{N} \ll k', \quad a_0 \ll a_1 \quad (5.3.1.6)$$

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 :

$$\Delta T_{max}(T_1) = T_1 - \frac{\sqrt{1 - 2ZT_1} - 1}{Z} \quad (5.3.1.7)$$

5.3.2. 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:

$$\begin{cases} \alpha IT_0 - \frac{1}{2} I^2 R - k'(T_1 - T_0) = \frac{a_0}{N_1} (T_a - T_0) \\ \alpha IT_1 + \frac{1}{2} I^2 R - k'(T_1 - T_0) + \frac{a_1}{N_1} (T_a - T_1) \\ \quad = \frac{N_2}{N_1} \left[\alpha IT_1 - \frac{1}{2} I^2 R - k'(T_2 - T_1) \right] \\ \alpha IT_2 + \frac{1}{2} I^2 R - k'(T_2 - T_1) = \frac{a_2}{N_2} (T_2 - T_a) \end{cases} \quad (5.3.2.1)$$

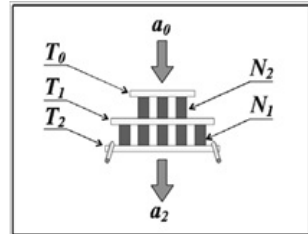
Here

$T_{0,1,2}$ - 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:

$$\frac{a_1}{N_1} = \frac{a_2}{N_2} = a = const \quad (5.3.2)$$

The first and third equations of (7.2.1) can be written as:

$$\begin{cases} \alpha IT_0 - \frac{1}{2} I^2 R - k'(T_1 - T_0) = a(T_a - T_0) \\ \alpha IT_2 + \frac{1}{2} I^2 R - k'(T_2 - T_1) = a(T_2 - T_a) \end{cases} \quad (5.3.2.3)$$

If temperature differences on the cascades can be considered equal:

$$\Delta T_1 = \Delta T_2 \quad (5.3.2.4)$$

we obtain:

$$Z = \frac{1}{T_a} \left[\frac{U_\alpha}{U_R} \right]_{AV} (1 + b_{th} + b_a + b_r) \quad (5.3.2.5)$$



Attention! In real testing Eq. (7.2.4) is not rigorous, and Z (7.2.5) 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 (5.3.2.4), though mathematically not obligatory, is carried out similarly to a single-stage module case for accuracy purposes.

5.3.3. Alternative Correction

It is convenient sometimes to reduce all the corrections discussed above to a certain coefficient A . Then Eqs. (5.3.1.5) and (5.3.2.5) can be written as:

$$Z = A \frac{1}{T_a} \left[\frac{U_\alpha}{U_R} \right]_{AV} \quad (5.3.3.1)$$

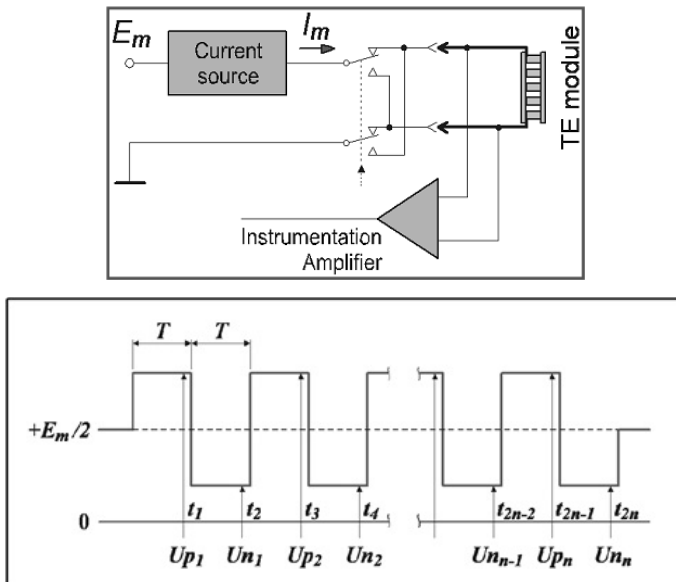
The coefficient A can be also obtained empirically by correlating directly measured ΔT_{max} and the value obtained by Z-Meter.

6. MEASURING PROCESSES

6.1. 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 $E_m = 4.096$ 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 the figure above. 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:

$$R = \frac{\sum_{i=1}^n (U_{pi} - U_{ni})}{2I_m A_V n} \quad (6.1.1)$$

where

A_V - voltage gain of the instrumentation amplifier;

n - total number of readouts per measurement.

Typical values of parameters in formula (6.1.1) are:

$I_m = 2$ mA,

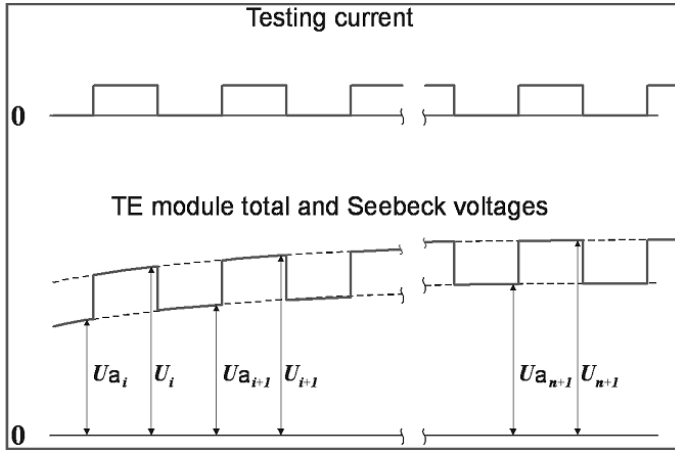
$A_V = 5$ or 50 ,

$n = 50$.

6.2. 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

6.3. Voltages for Testing Z

Equations (5.3.1.5) and (5.3.2.5) contain both U_R and U_α . These are the voltage values referred to the time at which the process becomes steady.

The Seebeck voltage U_α in (5.3.1.5) and (5.3.2.5) is equal to the stationary value U_{st_α} obtained by the interpolation procedure (see Eq. (5.2.2)).

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 $I_T = 0.01I_{max}$ 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:

$$U_R = \frac{1}{10} \sum_{i \geq (N-10)} [U(t_i) - U_\alpha(t_i)] \quad (6.3.1)$$



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

6.4. 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 :

$$U'_\alpha = \frac{1}{10} \sum_{i \geq (N-10)} U_\alpha(t_i) \quad (6.4.1)$$

If the TEC polarity is right:

$$U'_\alpha > U_\alpha \quad (6.4.2)$$

In case of the polarity confused:

$$U'_\alpha < U_\alpha \quad (6.4.3)$$

7. 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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