PL Engineering Ltd.

Z-METER DX4085

USER GUIDE

Moscow, 2020

version 1.02

Edition February 2020

WARRANTY

PL ENGINEERING 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 PL ENGINEERING's publicly available specification for a period of one (1) year after date of the Z-Meter was purchased.

PL ENGINEERING 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 PL ENGINEERING 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 PL ENGINEERING 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:

In Russia and CIS

PL Engineering Ltd.
46 Warshawskoe shosse, Moscow 115230, Russia

Tel:	+7-499-678-3231
Fax:	+7-499-678-3258
e-mail:	info@promln.com

In Europe, the USA and other countries

TEC Microsystems GmbH.
Schwarzschildstrasse 8, Berlin 12489, Germany

Phone:	+49-(0)30-6789-3314
Fax:	+49-(0)30-6789-3315
e-mail:	info@tec-microsystems.com

CONTENTS

1. INTRODUCTION

The portable Z-Meter provides measurement of performance and operational operating parameters of thermoelectric (TE) modules. It can measure operation and performance of thermoelectric cooling modules, thermoelectric generators, and thermoelectric sensors.

The performance parameters are the following:

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

Maximal temperature difference ΔT_{max} only for single stage TECs. Because of direct correlation with Figure of Merit is calculated within Harman method approximations.

Additionally new functionality of this device in the family of Z-meters – measurement of operating parameters of TECs:

- Operating voltage (U),
- Working temperature (T_c or T_a).

Measurements of temperature can be used for evaluation of cooling temperature of working TEC (T_c) if thermal sensor is placed on TEC cold side. Or to measure ambient temperature (T_a)of performance measurements – if to place near TEC.

The Z-Meter provides testing of various types of single- and two-stage TE modules. It is 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.

With the device it is also possible to test thermoelectric generators and sensors: voltage at thermoelectric generator (TEG) provided by temperature difference; response of thermoelectric heat flux sensor

ADVANTAGES

- ✓ *Express testing performance of single stage and multi-stage thermoelectric modules.*
- ✓ *Testing performance of TE modules integrated into optoelectronic devices (photodetectors, lasers etc.).*
- ✓ *Operating parameters measurements.*
- ✓ *Compatible with other Z-Meters of PL Engineering Devices Family.*

FEATURES

- ✓ *.Portable device. Metal housing.*
- ✓ *Measurement at direct and reversed current.*
- ✓ *Results normalization to standard temperatures.*
- ✓ *Low power consumption.*
- ✓ *Long autonomous operation.*

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
Voltage (DC)		
Range	V	-20…+20
Accuracy	V	0.02
Temperature Sensor		
Range	°C	-40...+85
Accuracy	°C	±0.25 (typical) ±1 (maximum) +0.05 (typical) lifetime drift
Repeatability	°C	±0.06
Power Supply		
Build-in battery Li-ion	V	3.7 (2050mAh)
Power Supply		

Parameters	Units	Values
AC Voltage	V	110...240
Frequency	Hz	50/60
Voltage DC	V	5
Power (max)	W	5
Operational Conditions		
Temperature range	°C	+15...+35
Humidity	%	0...95
Storage		
Temperatures range	°C	-20…+60
Humidity	%	5…95
Mechanical Parameters		
General Unit		
Dimensions	mm	70x160x21
Mass	g	280

2.2. Delivery Kit

1	Z-meter unit	1 pc.
2	Temperature sensor	1 pc.
3	Measuring terminal*	1 ps.
4	USB cable	1 pc.
5	AC/DC power adapter	1 pc.

** Measuring terminals can be supplied optional on the basis of Kelvin clips of various designs.*

2.3. Design overview

Portable design. Aluminum metal housing.

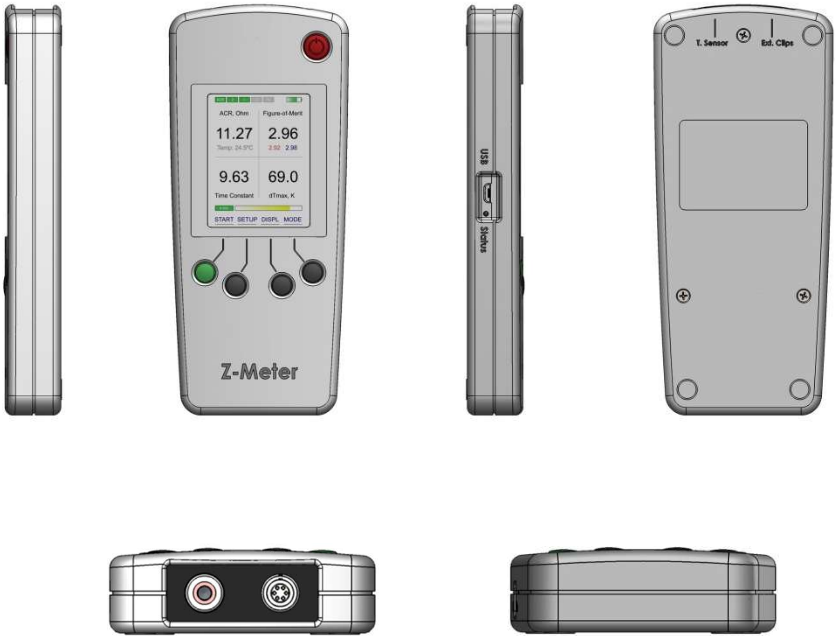
Large screen 2.4 TFT.

Built-in Li-ion battery provides 8 hours of continuous operation during a day.

Option of working with remote computer and common software for Z-meter family.

Developed for testing of thermoelectric modules: performance and operational operating parameters of thermoelectric (TE) modules.

It can measure operation and performance of thermoelectric cooling modules, thermoelectric generators, and thermoelectric sensors.



3. PREPARATIONS FOR WORKING

Before very first use of the device we recommend to charge battery of the device to 100%. Details are in chapter “Battery charge procedure”

Before routine switch ON the device connect the measuring probes and external temperature sensor – chapter “Connections”.

Connect examining TEC by use of measuring probes – Chapter “TEC connection”.

3.1. Charging battery

For charging built-in battery use standard cable microUSB-USB A and AC-DC power adaptor from delivery kit.

Connect cable to USB port of device and other connector to AC-DC adaptor.

Charging status is placed in to top-right of status line and the main screen. Additionally LED near USB port indicate status of charging.

Is device is switch OFF the LED light red. If device is ON – it lights orange

Additional information on charge status given by LED or indicator at device screen is the following

Status	Device is OFF	Device is ON
Cable is not connected	LED pulses green one time per 5 seconds. Number of pulses indicates: 1 pulse - <25 %; 2 pulses - 25...50%; 3 pulses – 50…75%; 4 pulses >75%	Pictogram of battery charge indicates battery status
Charging cable is connected	LED lights red during charging and OFF when 100%	Pictogram indicates charging

3.2. Connections

Measuring probes and external temperature sensor are connected to corresponding connectors on top side of device housing/


Connection of measuring probes


Connection of temperature sensor

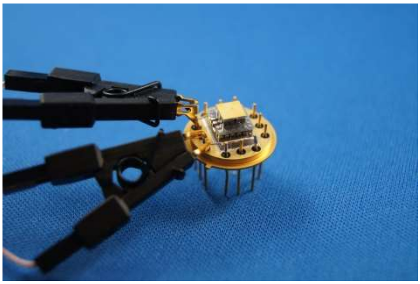
Attention! *Do not connect or disconnect external temperature sensor during device is ON.*

Note! *If temperature sensor is not connected then all following measurements to be related to standard temperature – default value 300K.*

3.3. TE module connections

Examining TEC must be contacted to working devices by measuring probes and (in particular case) – with external temperature sensor.

Connect your TEC firmly as shown below.



Please temperature sensor near measuring module.

3.4. Device power ON and power OFF

To power ON the device push the power button (red) shortly.

Device initialization takes few seconds. During the time the TFT screen indicates initialization by pictogram and LED (near cable connector lights green.

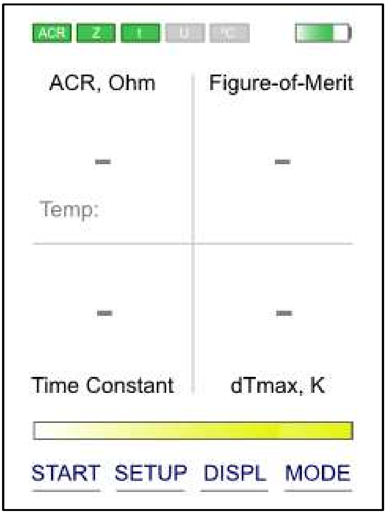
To switch the device – do the same. push the power button (red) shortly.

If the device is in a status of measurement switch of the device is possible only after finish of the measurement cycle.

Attention! *Dump is possible in any status of device if to push the power button for 5 seconds. .*

4. DEVICE INTERFACE

Device main windows onto 2.4' TFT screen consists of three areas: top status string; large working area and bottom command string connected with command buttons.



Top status string indicates operation mode, including sigh of measurement of voltage, and indication of battery status.

4.1. Navigations

Interface navigations provided by command buttons. Their functions are indicated by bottom command string.

START SETUP DISPL MODE

4.2. Operation modes

The device provides the following modes of operation:

- Main Mode - measurement of TEC performance parameters (Figure-of-Merit, AC resistance, time constant), calculated capacity is calculated, ambient temperate is measured (if temperature sensor is connected)
- Resistance Mode – measurement only of AC resistance (express measurement).
- Operating Mode – measurement of operation parameters of working TEC – working voltage and cooling temperature is external sensor if placed onto cold side.
- Working with remote computer software. Expanded options of measurements due to use of databases, corrections calculations and storage of results – see chapter “Operation with remote computer”..

Top status string indicates selected operation mode.

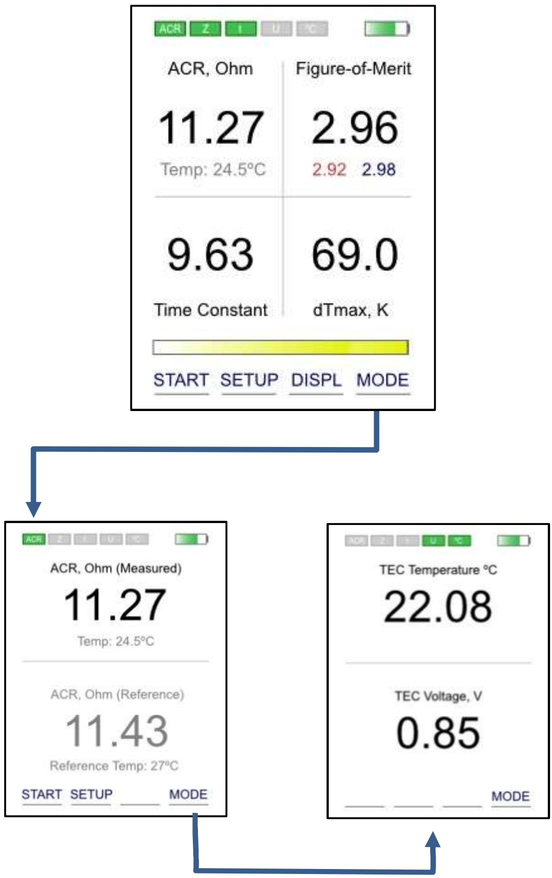
4.3. Selection of operation mode

Select of operation mode is made by command button and indicated at bottom string <MODE>.

Press the button <MODE> to change the modes one by one:

MAIN MODE -> RESISTANCE MODE-> OPERATING MODE.

Note! *Main mode is default on device switch ON.*



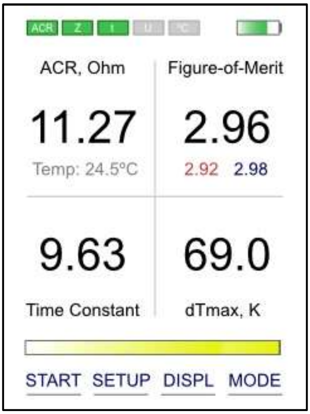
4.4. Main Mode

Main mode provides measurement of thermoelectric module performance parameters.

- AC Resistance (R)

- Figure-of-Merit (Z)
- Time Constant (τ)
- Maximum Temperature Difference (ΔT_{max})

This is relatively long procedure takes up to minute or more.



Note! *Make sure that before the testing thermoelectric module is correspondingly connected to measuring probe and external temperature sensor is placed correctly – see chapter "TE module connections".*

4.4.1. Set of measuring parameters

Measurement parameters are the following:

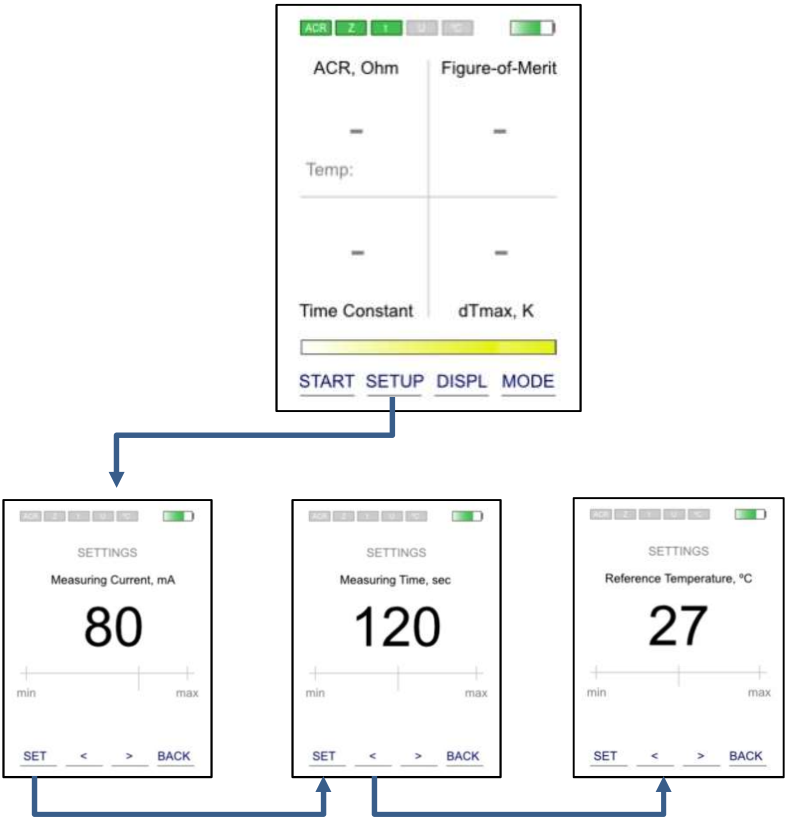
- Measurement current
- Total time of measurements
- Time step between measuring points.

Set of the parameters are provided by use one command button <SETUP>.

Press the button and retrieve setting windows of the above mentioned parameters one by one.

Select required value by buttons “<” and “>”.

After set of required value press <SET> and come to the another parameter by <SETUP> or return back by <BACK>



4.4.2. Measurements

Start measurement cycle by button <START>.

The measurement cycle is relatively long. It takes tens of seconds (selected total measuring time).

Colored bar at the bottom of screen indicates progress of the measurements – yellow color.

During measurements and after finish, it is possible to change screen from general view of measurement of all the parameters in the cycle to particular parameters. Selected parameter indication becomes bigger although other ones – smaller.

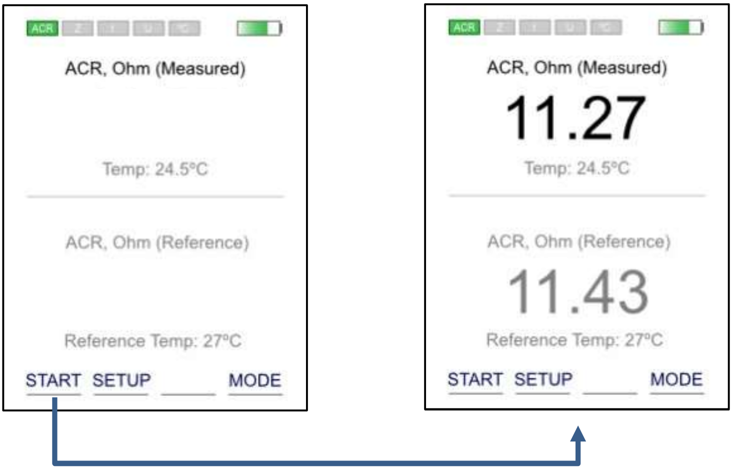
The changes are provided by command button <DISP>. Press the button and the screen with be changes one by one.

4.5. Measurement of AC Resistance

Note! *Make sure that before the testing thermoelectric module is correspondingly connected to measuring probe and external temperature sensor is placed correctly – see chapter “TE module connections”.*

Select measurement mode by command button <MODE>

Start the measurement by button <START>.



Result will be indicated with two values:

- Top value – AC resistance measured as is at ambient temperature measured by temperature sensor.
- The bottom value – recalculated AC resistance to standard reference temperature 27°C (300K). The default reference is 27°C (300K). Optional reference temperature can be set – see chapter “Main mode”.

Note! *If temperature sensor is not connected to device then all following measurements to be related to standard temperature – default value* 27°C (300K).

4.6. Measurement of operating voltage and temperature

This is useful mode which provides measurement of operating voltage at thermoelectric modules.

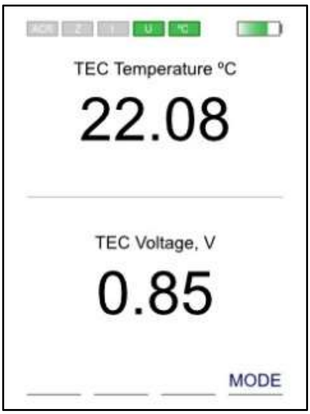
It is important information for testing of:

- Operating voltage of thermoelectric cooling module in an application.
- Voltage at thermoelectric generator (TEG) provided by temperature difference.
- Voltage response of thermoelectric heat flux sensor

Additionally external temperature sensor gives useful information on temperature at thermoelectric module: cooling performance of TEC or temperature difference at TEG or sensor. .

Select measurement mode by command button <MODE>

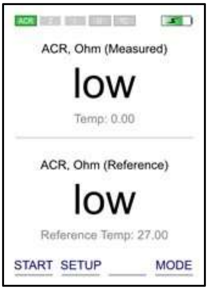
By the selection, it is not needed start measurements. They come automatically with periodicity 10 times in a second.



5. ADDITIOONAL MESSAGES

In the resistance measurement mode.

Measured resistance is high and comes out of specification



Measured resistance is low and comes out of specification

At switch ON the device

The temperature sensor is not found (not connected)

In the Main mode

Probably the measuring component (module) is not thermoelectric module

6. WORWING WITH REMOTE COMPUTER

The device has option of connecting with computer and measuring on operating software. The operating software provides some additional useful options of measuring:

- storage of measurement results,
- use of database of known thermoelectric modules.
- use of correction factors.
- visualizing of measurement cycle (main mode).

6.1. System Requirements

The Z-Meter could work 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 software can be download from website http://www.tec-microsystems.com/downloads.html.

The Z-Meter is operated by computer under the operating system Windows 98/2000/XP/Vista/7/10.

The requirements are the following:

- 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.

6.2. 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.

6.3. 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.

6.4. Getting Ready

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

Connect Z-meter to USB port of your PC.

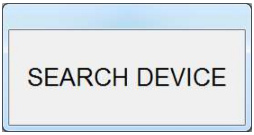
To select this operation mode press command button <MODE> for about 5 seconds.

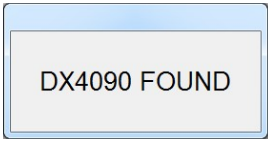
Connect by microUSB cable the device with USB port of computer.

6.5. Measurements

6.5.1. Run the "Z-Meter II" software

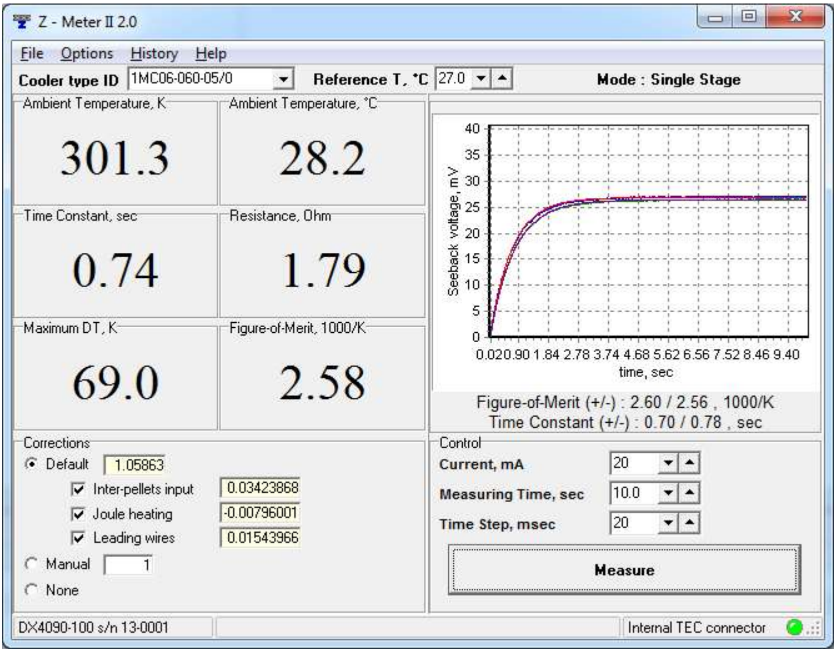
The following windows will be displayed one after another in case you run Z-meter program:





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).

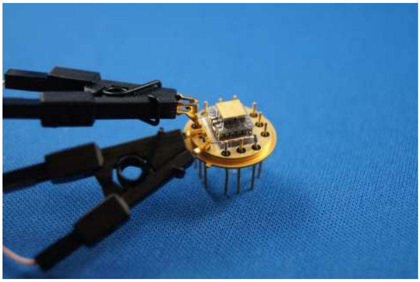
The main window will appear:



Important! T*EC polarity check option must be switched off (See "Software"). The Z-Meter type DX4085 does not support the option.*

6.5.2. TE Modules Connection

Connect your TEC firmly as shown below.



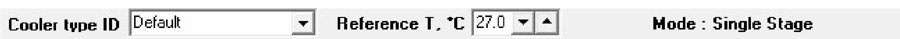
Ensure minimum possible air convection in the area of measurement. It is recommended to place the TEC as close to the Z-meter as possible keeping internal chamber opened. Remember temperature sensor is located in the chamber and considerable difference of TEC and thermosensor's temperature will result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

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

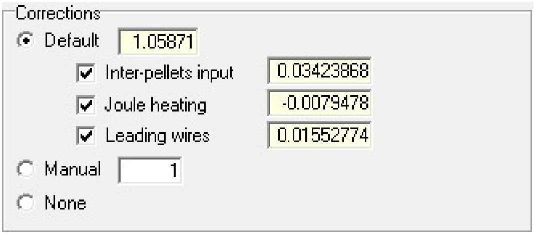
6.5.3. Make the pre-sets for measurements

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.



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

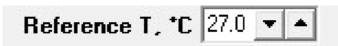


If type is unknown then the state is “Default”.

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.



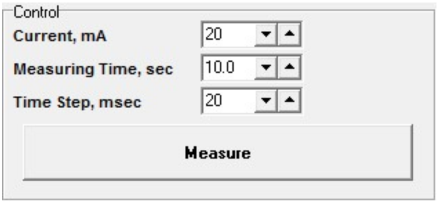
Note! Default - 27 °C (300K).

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.



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.

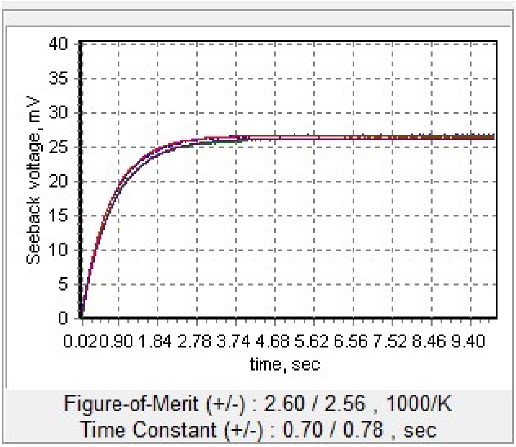
Time step

Recommended value – 20 millisecond.

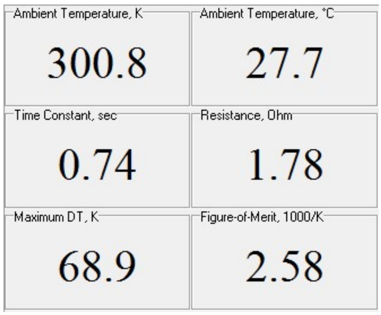
6.5.4. Measurements

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



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

6.5.5. 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:

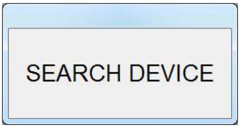
More detailed descriptions of working with results and with software are described in Article – “Software”

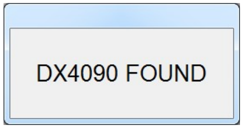
7. SOFTWARE

7.1. 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:

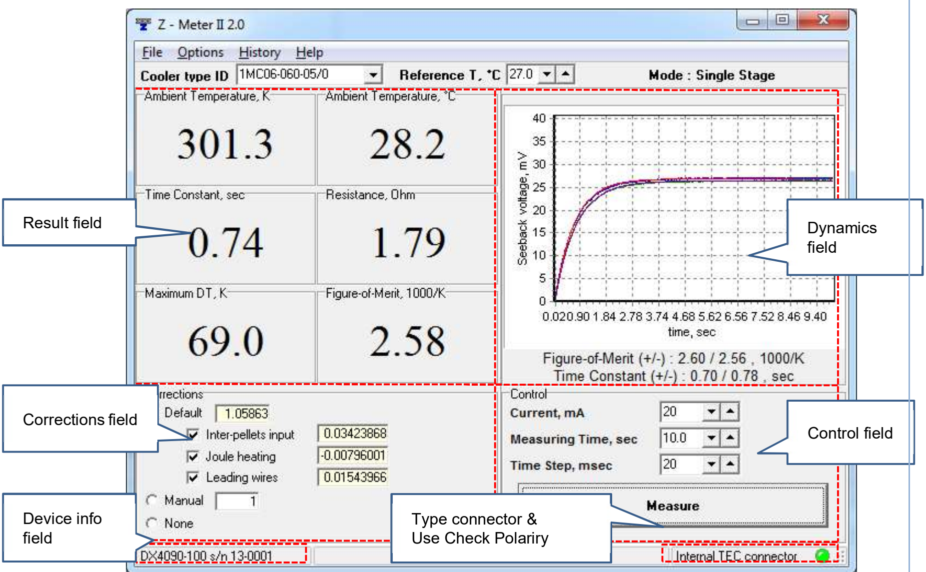




If the "DEVICE NOT FOUND" message pops up, please make sure the device is properly connected. Also check whether the USB drivers have been properly installed and repeat USB driver installation procedure if required (see 3.1. above).

7.2. Main Window

The main program window is shown in the screenshot below.



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

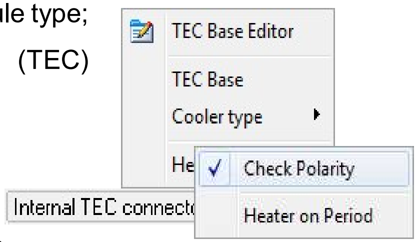
- Single-stage TE module;
- Single-stage TE sub-mount;
- Two-stage TE module.

7.2.1. Menu Bar

There are four items in the Menu bar.

- ***"File"*** is used when it is necessary to reconnect the Device or exit.

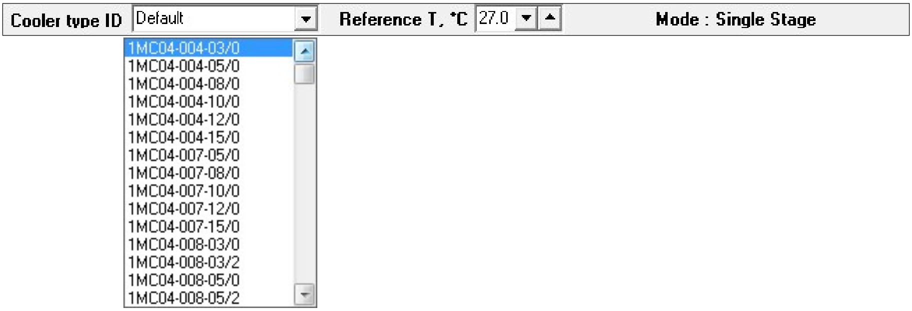
- "Options" allows:
  1) adding/editing a TE module type;
  2) selecting a TE module (TEC) database;
  3) choosing a TE module (Cooler) type;
  4) enabling/disabling check polarity TE module (internal TEC connection only)



- ***"History"*** allows switching from current measuring results to database with previous measurements.
- ***"Help"*** provides information concerning the Z-Meter software

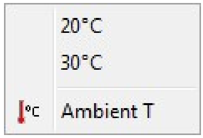
7.2.2. Reference Bar

There are two fields in the Reference bar.



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.

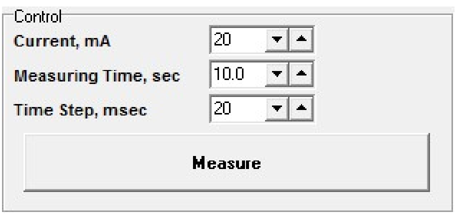


You may also choose a value from standard reference temperatures which are 20°C or 30°C, or ambient.

7.2.3. Functional Fields

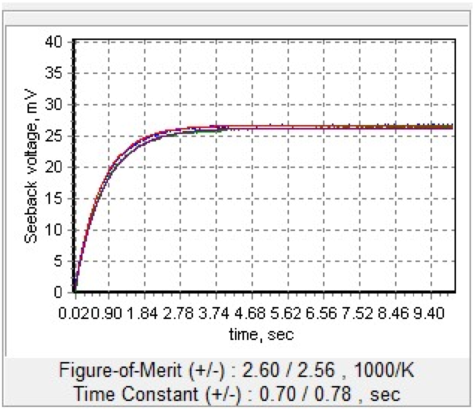
There are four functional fields in the main window:

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



The button "Measure" starts the measuring procedure.

- ***Dynamics*** field depicts the chart window of the Seebeck voltage Uα(t) temporal behavior telemetry.

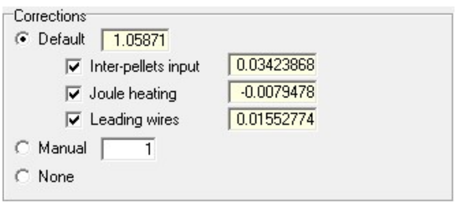


It also indicates obtained values of:

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 9.3 for details). .



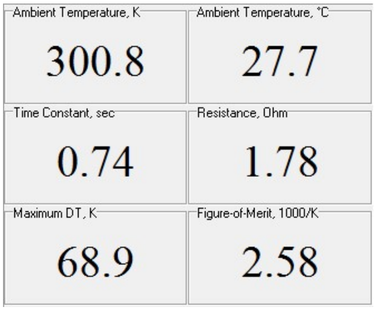
Following possibilities of a correction exist:

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:



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).

7.3. Measurement Presets

7.3.1. Temperature Setting

Z-meter allows re-calculation of the main TEC parameters to various temperatures (see Chapter 9.3).

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

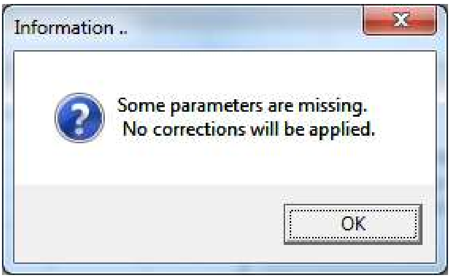
The most convenient ambient temperature to which the parameters are recalculated may be selected from a “Reference T” list of entered manually.

7.3.2. 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. PL ENGINEERING 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.*

7.3.3. Correction Coefficients

With all TEC parameters available, the corrections as well as their equivalent coefficient A are taken into account by default (see Equation 9.3.3.1). 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.

7.3.4. 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:

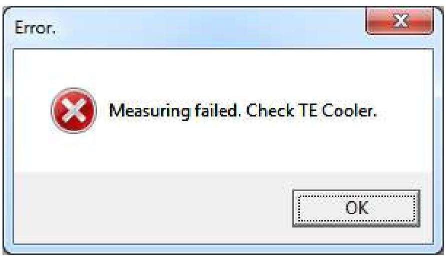
1) header material thermal conductivity;
2) header base thickness;
3) mounted TE module fully described in the Z-meter database.

7.4. 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:

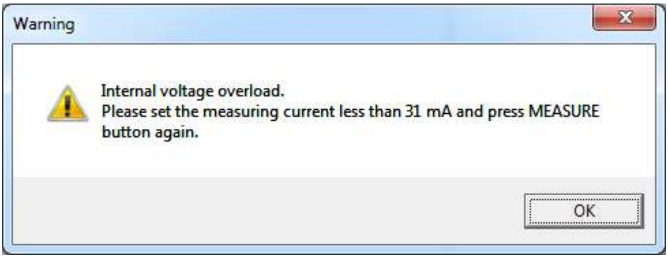


appeared shortly after clicking “Measure” means that either:

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

Note the last case is hardly possible in practice according to PL ENGINEERING'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.*



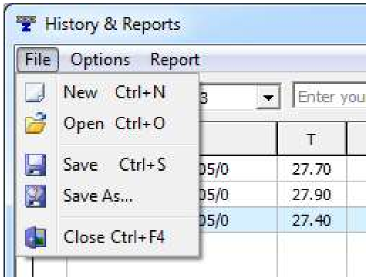
As mentioned above, the DX4090 Meter may be also used for measurement of AC resistance in coolers with more than two stages. To do this, leave the "TE Cooler Type" unselected (Default Type in the "TE Cooler Type" field). Insert a TE module into the DX4090 Meter and click the "Measure" button.

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

7.5. History

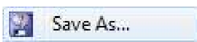
7.5.1. File

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



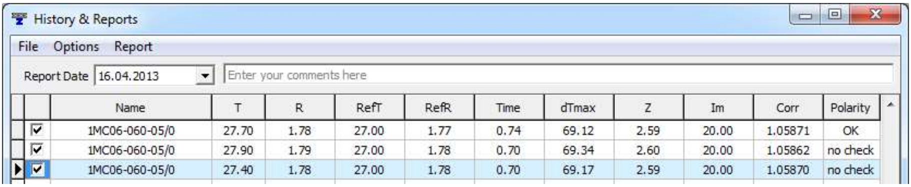
The history file is created in the "/History" folder of the "/Z-meter" directory during every measuring session after the first successful measurement. ("Measuring session" means the period between the first successful measurement and the program exit). The history file name has the form of the date and time of the history file creation. "Comment" field on the top of the "History" window allows adding of additional comments to history files.

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



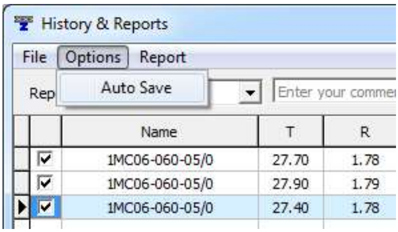
The "New" command closes the current history file and opens a new one with no data.

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



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".

7.5.2. Options

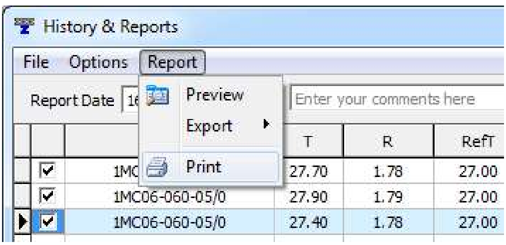


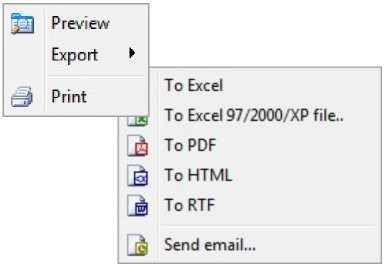
If menu item "Auto Save" is checked, the "History" file will be saved automatically.

7.5.3. Report

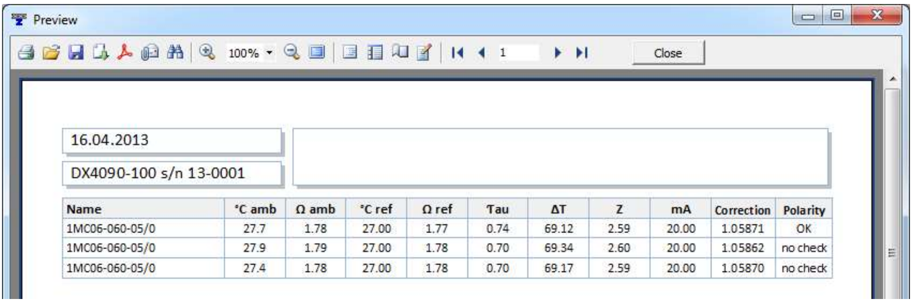
With the "Print" command you can make the hard copy of the "History" file on a default printer.

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





The example of Preview Report is shown below.



Name	°C amb	Ω amb	°C ref	Ω ref	Tau	ΔT	Z	mA	Correction	Polarity
1MC06-060-05/0	27.7	1.78	27.00	1.77	0.74	69.12	2.59	20.00	1.05871	OK
1MC06-060-05/0	27.9	1.79	27.00	1.78	0.70	69.34	2.60	20.00	1.05862	no check
1MC06-060-05/0	27.4	1.78	27.00	1.78	0.70	69.17	2.59	20.00	1.05870	no check

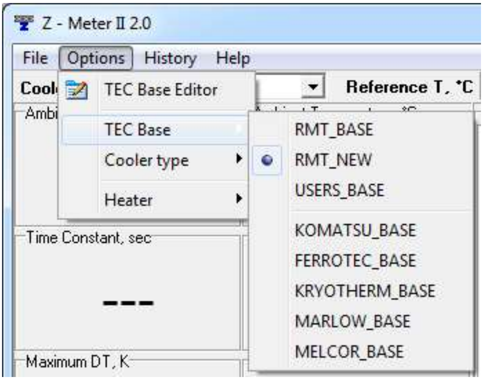
7.6. TE Modules Database Update

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:

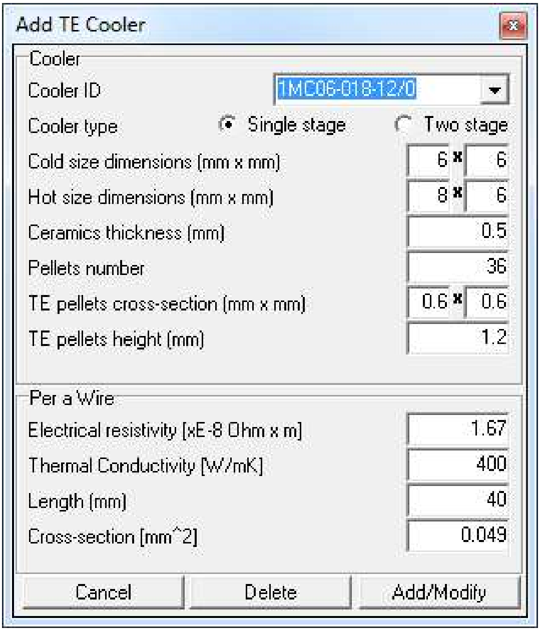
1) TE module cold and hot sides dimensions;
2) Pellets number (for a two-stage TE module the pellets numbers ratio);
3) Pellet cross-section;
4) Pellet height;
5) Leading wires material,
6) Leading wires length,

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.



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.

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.

9. APPENDIX 1. THEORETICAL GROUNDINGS

9.1. Time Constant

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:

$$\Delta T(t,x) = \sum_{i=1}^{\infty} A_n U_n(x) e^{-m_n t} + \Delta T_{st}(x) \qquad (9.1.1)$$

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 (9.1.1) 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:

$$m_{min} \ll m_n \qquad (9.1.2)$$

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

$$\tau = \frac{LC_1C_2}{(C_1 + C_2)\left(1 + \frac{L\alpha j}{k_0}\right) s_0 k_0 N} \qquad (9.1.3)$$

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. (9.1.3) 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.

9.2. 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:

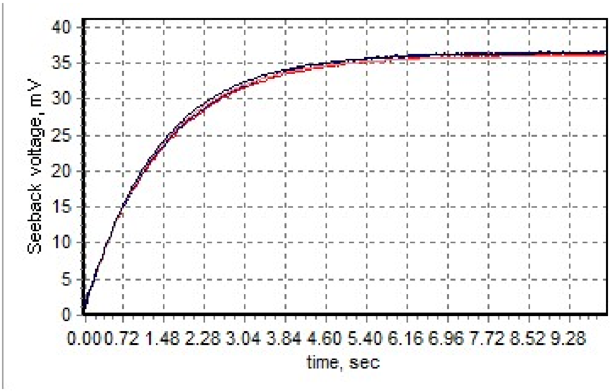
$$U_\alpha \sim \Delta T \qquad (9.2.1)$$

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:

$$U_\alpha(t) = U_{st_\alpha}(1 - e^{-t/\tau}) \quad (9.2.2)$$

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}.

9.3. Figure-of-Merit Z

9.3.1. Single-stage TE Module Z

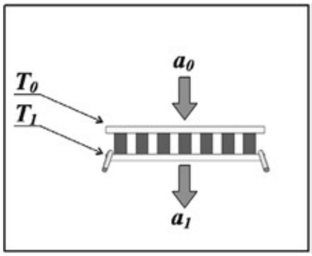
Among the parameters (R, Z, ΔT_{max}, τ), measured by the Z-Meter the AC resistance R is the only measured directly. The R measurement method is described in the Section "AC Resistance Measurement".

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:

$$Z = \frac{\alpha^2}{kR} \tag{9.3.1.1}$$

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

$$\begin{cases} \alpha I T_0 - \frac{1}{2} I^2 R - k'(T_1 - T_0) = \frac{a_0}{N}(T_a - T_0) \\ \alpha I T_1 + \frac{1}{2} I^2 R - k'(T_1 - T_0) = \frac{a_1}{N}(T_2 - T_a) \end{cases} \tag{9.3.1.2}$$

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:

$$\frac{a_0}{N} \ll k', \quad \frac{a_1}{N} \ll k' \qquad (9.3.1.3)$$

We also suppose that electric current is small:

$$I \ll \frac{k'}{\alpha} \qquad (9.3.1.4)$$

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 (9.3.1.3) and (9.3.1.4), we obtain for Z:

$$Z = \frac{1}{T_a}\left[\frac{U_\alpha}{U_R}\right]_{AV} \frac{(1+b_{th})(1+b_r)}{(1+b_T)} \qquad (9.3.1.5)$$

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. (9.3.1.5) 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. (9.3.1.5) remains fair if inequalities (9.3.1.3) are modified as:

$$\frac{a_0}{N} =\ll k', \quad a_0 \ll a_1 \qquad (9.3.1.6)$$

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:

$$\Delta T_{max}(T_1) = T_1 - \frac{\sqrt{1 - 2ZT_1} - 1}{Z} \qquad (9.3.1.7)$$

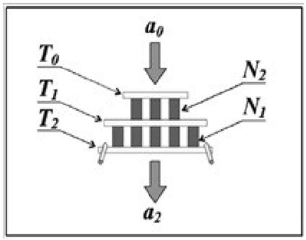
9.3.2. Two-stage TE Module Z

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:

$$\begin{cases} \alpha I T_0 - \frac{1}{2} I^2 R - k^{'}(T_1 - T_0) = \frac{a_0}{N_1}(T_a - T_0) \\ \alpha I T_1 + \frac{1}{2} I^2 R - k^{'}(T_1 - T_0) + \frac{a_1}{N_1}(T_a - T_1) \\ \quad = \frac{N_2}{N_1}\left[\alpha I T_1 - \frac{1}{2} I^2 R - k^{'}(T_2 - T_1)\right] \\ \alpha I T_2 + \frac{1}{2} I^2 R - k^{'}(T_2 - T_1) = \frac{a_2}{N_2}(T_2 - T_a) \end{cases} \qquad (9.3.2.1)$$

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_2$2 are the same:

$$\frac{a_1}{N_1} = \frac{a_2}{N_2} = a = const \qquad (9.3.22)$$

The first and third equations of (9.3.2.1) can be written as:

$$\begin{cases} \alpha I T_0 - \frac{1}{2} I^2 R - k'(T_1 - T_0) = a(T_a - T_0) \\ \alpha I T_2 + \frac{1}{2} I^2 R - k'(T_2 - T_1) = a(T_2 - T_a) \end{cases} \qquad (9.3.2.3)$$

If temperature differences on the cascades can be considered equal:

$$\Delta T_1 = \Delta T_2 \qquad (9.3.2.4)$$

we obtain:

$$Z = \frac{1}{T_a}\left[\frac{U_\alpha}{U_R}\right]_{AV}(1 + b_{th} + b_a + b_r) \qquad (9.3.2.5)$$

Attention! I*n real testing Eq. (9.3.2.4) is not rigorous, and* Z *(9.3.2.5) 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 (9.3.2.4), though mathematically not obligatory, is carried out similarly to a single-stage module case for accuracy purposes.

9.3.3. Alternative Correction

It is convenient sometimes to reduce all the corrections discussed above to a certain coefficient A. Then Eqs. (9.3.1.5) and (9.3.2.5) can be written as:

$$Z = A\frac{1}{T_a}\left[\frac{U_\alpha}{U_R}\right]_{AV} \qquad (9.3.3.1)$$

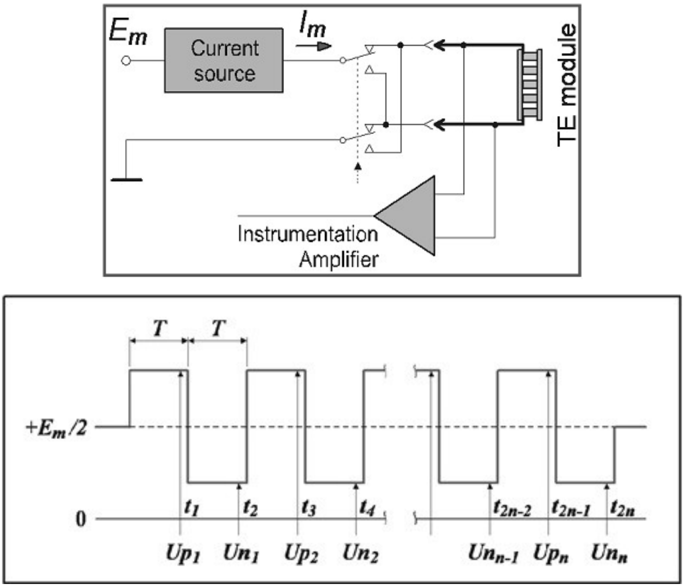
The coefficient A can be also obtained empirically by correlating directly measured ΔT_{max} and the value obtained by Z-Meter.

10. APPENDINX 2. MEASURING PROCESSES

10.1. 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 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:

$$R = \frac{\sum_{i=1}^{n}(U_{pi} - U_{ni})}{2 I_m A_V n} \qquad (10.1.1)$$

where

A_V - voltage gain of the instrumentation amplifier;

n - total number of readouts per measurement.

Typical values of parameters in formula (10.1.1) are:

I_m = 2 mA,

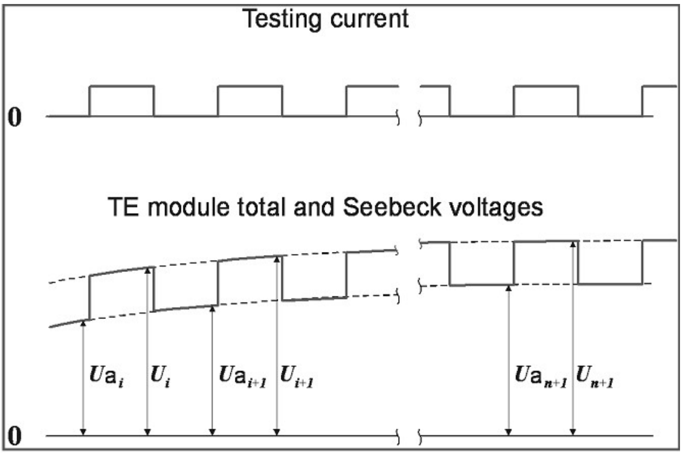
A_V = 5 or 50,

n = 50.

10.2. 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

10.3. Voltages for Testing Z

Equations (9.3.1.5) and (9.3.2.5) 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 (9.3.1.5) and (9.3.2.5) is equal to the stationary value U_{st_α} obtained by the interpolation procedure (see Eq. (9.2.2)).

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:

$$U_R = \frac{1}{10} \sum_{i \geq (N-10)} [U(t_i) - U_\alpha(t_i)] \qquad (10.3.1)$$

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

PL Engineering Ltd.

46 Warshawskoe shosse
Moscow 115230 Russia
e-mail: info@promln.com
phone: +7-499-678-3231
fax: +7-499-678-3258
website: www.promln.ru

Overseas Sales representative

TEC Microsystems GmbH
Schwarzschildstrasse 8
Berlin 12489, Germany
phone: +49-(0)30-6789-3314
fax: +49-(0)30-6789-3315
e-mail: info@tec-microsystems.com
website:www.tec-microsystems.de