Z-meter: Easy-to-use Application and Theory

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Abstracts

The paper is divided into two parts. The first part is an applying one. We present a handy, easy-to-operate user-addressing Z-meter. The device provides measurement of thermoelectric (TE) modules parameters: AC resistance (R), thermoelectric figure-of-merit (Z) and maximum temperature difference (ΔT_{max}).

The second part is of a theoretical value. As a rule, the device exposure does not happen to be ideally insulated and vacuum-like. Consequently need to take into consideration heat losses of various sorts. In this part we are to discuss specific formulae for estimating heat-exchanging uncertainties involved by Z-metering. All the expressions are explicit

On the basis of theoretical estimations it is advised and realized in Z-meter new availabilities to measure performance parameters of single stage TE modules with corrections factors, as well as modules mounted into packages and two-stage modules.

Introduction

Applications of thermoelectrical (TE) modules are becoming wider from year to year. Having started from commercial use mainly in consumer fields (TE refrigerators, cool boxes and so on) now applications of TE modules increase dramatically in optoelectronics, electronics laser technique and come from specialized fields, such as military and airspace, to commercial mass production.

In many emerging applications TE modules are critical components because they affect the temperature of the whole device, can have an effect on its correct operation, and impact on the heat dissipation.

That is why reliability requirements to TE modules are very high and are still growing even if comparing with consumer applications. That is why severe test procedures (precise and express) are required when a specific TEC type needs to be used in experimental and serial production.

Any TEC must provide high performance and a long operation lifetime without failure. The suggested failure criteria for reliability tests are the following:

- A drop in TEC maximum cooling capacity (ΔT_{max}) below its specified rating. Measurements of Figure-of-Merit Z is used here as $\Delta T_{max} = f(Z)$
- An increase (5% is usual value) or higher in TEC resistance.

The reason of setting forward the two parameters is due to the AC Resistance (R) and Figure-of-Merit Z (and, therefore, ΔT_{max} calculated based on the Z value) being very sensitive to latent defects or damage of TE modules. The slightest change of these parameters during operation or storage could be the result of destruction of the TE module. That is why AC R and Z are very useful for control of TE modules quality and reliability.

Although there are a lot of methods for measurement of TE modules parameters[1,2,3] only express methods are useful for certifications and mass production quality control.

On the basis of Harman method[4] our company RMT developed its own series of testing facilities (Z-meters) and has developed corresponding methods to examine a range of TE modules, as well as modules mounted into complete devices.

1. Classical Review of Harman Approach

Papers[4,5,6,7] describe and develop an approach for measuring thermoelectric (TE) properties and Figure-of-Merit of Peltier modules. This method was first suggested by T.C. Harman[4] in 1958 and bears his name.

A small current I passes through the system generating a slight temperature differential along the module pellets. By measuring the Joule and Seebeck voltage drops one can find some thermoelectric parameters. Let us show it.

If the Peltier effect results in the temperature gradient $T_0<T_1$, in the simplest case the thermal rate equations for a 1-stage TEC can be written this way:

$$\begin{cases} \alpha I T_0 - \frac{1}{2} I^2 R - k\Delta T = \frac{a_0}{N}(T_a - T_0) \\ \alpha I T_1 + \frac{1}{2} I^2 R - k\Delta T = \frac{a_1}{N}(T_1 - T_a) \end{cases} , \qquad (1.1)$$

here T_0 - cold side temperature; T_1 - hot side temperature; $\Delta T=T_0-T_1$; k - pellet thermal conductance; R - pellet electrical resistance; N - pellets number; T_0 - ambient temperature; a_i - heat flux at the cold (i=0) and hot (i=1) sides. The energy dissipation should be small but enough for Joule losses runaway.

If the environment by the hot and cold sides are the same and in similar conditions, and in case cold and hot areas are equal, it is possible to admit

$$a_0 = a_1 = a \qquad (1.2)$$

Summing up two equations (1.1) and taking into account (1.2) we derive:

$$Z\overline{T} = (1 + \frac{a}{2Nk})\frac{U_\alpha}{U_R} , \qquad (1.3)$$

where the Figure-of-Merit $Z=\alpha^2/kR=\alpha^2/\kappa\rho$ (α - Seebeck coefficient; κ and ρ - thermal conductivity and electrical resistivity respectfully), $\overline{T} = \frac{T_1 + T_0}{2}$ - the average sample temperature, $U_\alpha = \alpha\Delta T$, $U_R = IR$, I - the device current.

If (1.2) is justified and the current I is small enough, we

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can assume $T_0 = T_a - \xi$ and $T_1 = T_a + \xi$, and the average device temperature approximately equals the ambient temperature T_a.

With this assumption and in case ***a/2Nk<<1*** the main Harman relation takes the following form:

$$ZT_a = \frac{U_\alpha}{U_R} \qquad (1.4)$$

This relation is commonly used in thermoelectricity. However the $\overline{T} = T_a$ requirement remains not clear. We will discuss it further. Meantime, with the help of (1.1) and (1.4) ΔT_{max} is estimated as

$$\Delta T_{\max} = \frac{1}{2} Z T_0^2 \qquad (1.5)$$

Or, as related to the ambient temperature

$$\Delta T_{\max}(T_a) = T_a - \frac{\sqrt{1 + 2ZT_a} - 1}{Z} \qquad (1.6)$$

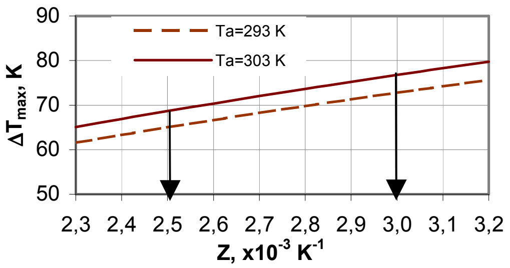

Fig. 1.2 The plot ΔT_{max} vs Z

In Fig. 1.2 the range of ***Z***-values (approx 2.5-3.0) commonly achieved by most of commercial TE modules suppliers is marked. That is why anyone can find that in standard specifications of the single stage TE modules ΔT_{max} falls within the range of 65-75 K.

2. Z-Meter Arrangement and Principles of Operation

The above described solution for the Z parameter requires accurate measurements of U_α, U_R and T_a. Additionally AC resistance is required for TE module qualification as mentioned above in

Z-meter Outside and Inside

For solution of the task we developed series of portable Z-Meters. The outlook of our Z-Meter is placed in Fig. 2.1.

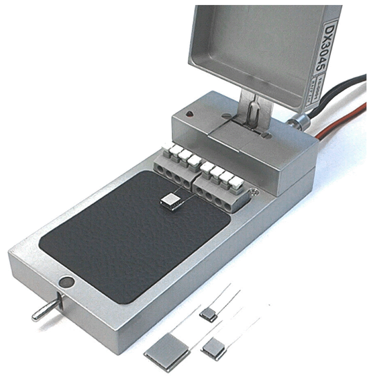

Fig. 2.1. The outlook of Z-Meter

The Z-Meter package is made of aluminium alloy. The metal package plays the role of passive thermostat for testing modules. Temperature o is measured with built-in digital thermometer with accuracy 0.1°C.

Measurement of AC resistance and Z parameters are performed separately. The ACR measurement is made first.

AC Resistance Measurement

Module is tested by AC current of small amplitude. The AC is simulated with the Commutator (Fig.2.3), which periodically (with 50% duty circle) reverses a circuit of a reference current I_m.

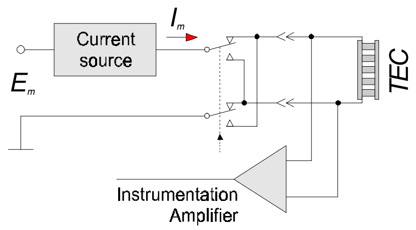

Fig. 2.3 Simplified Diagram of AC R Measurement

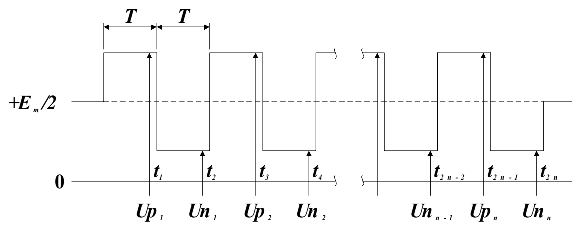

Fig. 2.4 Time diagram of AC *R* measurement

In the no input signal state the output voltage of the Instrumentation Amplifier is equal to $E_m/2$ (Fig. 2.4).

During AC resistance measuring the output voltage is sampled and measured by 12 bit ADC every time before I_m current reversing. The sampling points are marked as t_i in the figure. The voltage drops U_{pi} and U_{ni} corresponding to the positive and negative polarities are used for a TE module resistance (R) calculation with the help of the following formula:

$$R = \frac{\sum_{i=1}^{n} (Up_i - Un_i)}{2 \cdot I_m \cdot A_V \cdot n} \qquad (2.1)$$

where I_m - operating current; U_{pi} - voltage drop on TE module at positive operating current; U_{ni} - voltage drop negative

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operating current; A_V - voltage gain of instrumentation amplifier; n - total number of samples per measurement.

Z and ΔT_{max} measurements

The measurement of Z and ΔT_{max} is based on the Harman method (1.4-1.6).

At measurement of U and U_α parameters the small voltage E_T is applied to a module (Fig. 2.4). The E_T voltage is disconnected periodically with time T_{off} sufficient to measure voltage on a module with ADC. The U_α is measured during T_{off}. During T_{on} period the U_i is measured. Finally U_R is calculated.

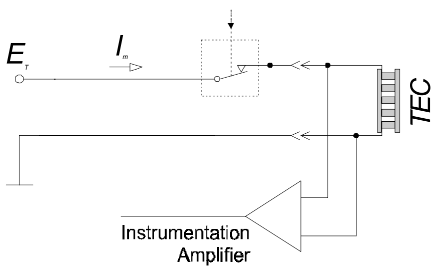

Fig. 2.4 Simplified Diagram of U and U_α measurements

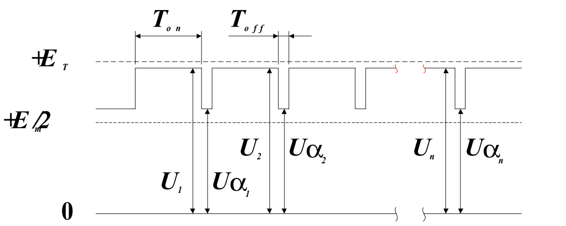

Fig. 2.5 Time diagram of U and U_α measurements

The following formulas are used:

$$U\alpha = \frac{\sum_{i=1}^{n} U\alpha_i}{A_V \cdot n} - \frac{E_m}{2} \quad , \tag{2.2}$$

$$U = \frac{\sum_{i=1}^{n} U_i}{A_V \cdot n} - \frac{E_m}{2} \quad , \tag{2.3}$$

$$U_R = U - U_\alpha \quad , \tag{2.4}$$

where A_V - voltage gain of instrumentation amplifier, n - total number of samples per measurement.

Correct value of U_α (and U) can be measured correctly only if a module is in the state of thermodynamic balance, i.e. if feeding energy is equal to that dissipated. So the special "run-up" phase should precede a measuring.

Fig. 2.6 illustrates this. During the "run-up" phase the values U and U_α are being stabilized. Duration of the phase is usually a few seconds.

Operation mode of Z-Meter contains algorithm, which allows to start measurements only after stabilizing of U and U_α results.

An example of experimental time diagram ($U=U(t)$ and $U_\alpha=U(t)$) is presented in Fig. 2.7 .

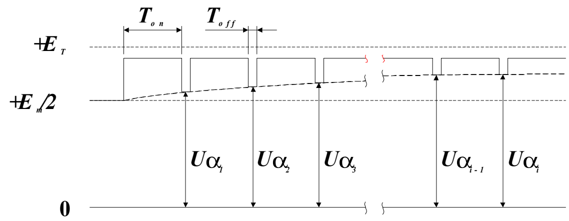

Fig. 2.6 "Run-up" phase diagram

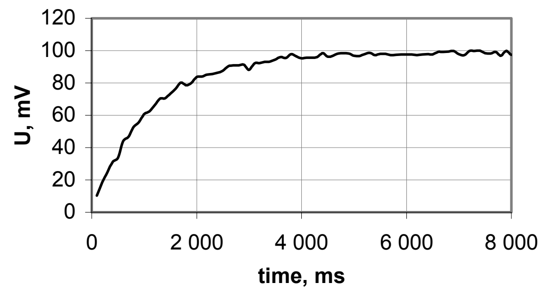

Fig. 2.7 Experimental U_α time diagram (TEC 1MC06-032-12)

Correction factors

Z-measurements yield some effective Figure-of-Merit Z_{eff}, and not the true Z-value=$\alpha^2/\kappa\rho$, because a non-zero thermal heat load takes place due to real air environment, actual current impact and design of the measured module.

3. Theoretical Approach: 1-stage TEC

In the experimental technique as described above, a TE module is examined in the actual arrangement. Some heat exchange with ambient vicinity takes place, Joule heating is not of a zero value and so on (Fig. 3.1). So a lot of correction factors need to be taken into account to apply Harman's equation to obtain the true Z and the corresponding ΔT_{max}.

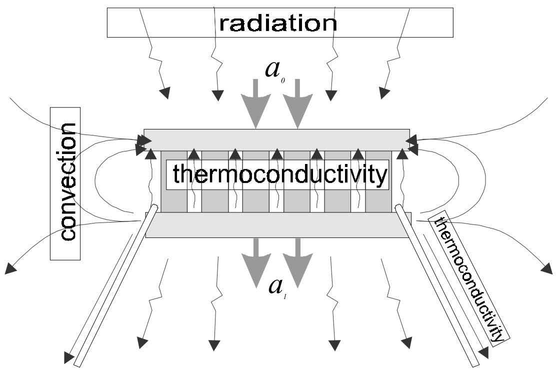

Fig. 3.1. A scheme of thermal exchanges to take into account

Described above classical basis of Harman method leaves certain important questions beyond its scope:

1. What is the requirement for using the ambient temperature T_a and the average temperature value?

2. What is the current and, therefore, Joule heating limitation?
3. If the TEC is not in vacuum, what way is ratio (1.4) modified and what corrections are to be calculated?
4. What way is ratio (1.4) transformed and what are the means of allowing for asymmetry, that is for a real case when (1.2) is not true?

Commonly the thermal rate equations for a 1-stage TEC must be written the following way:

$$\begin{cases} \alpha I T_0 - \frac{1}{2} I^2 R - k' \Delta T = a_1 (T_a - T_0)/N \\ \alpha I T_1 + \frac{1}{2} I^2 R - k' \Delta T = a_2 (T_1 - T_a)/N \end{cases}, \quad (3.1)$$

where N is pellets number, a_1 - thermal conductance from the outer cold side, a_2 is thermal conductance from the outer hot side ($a_1 \neq a_2$), k' is effective pellets thermal conductance allowing for the air and electromagnetic field between them.

The term k' describes thermal conductance normalized to one pellet between the cold and hot surfaces:

$$k' = k(1 + b_{th}), \quad (3.2)$$

where

$$b_{th} = B_{cond} + B_{rad}, \quad (3.3)$$

The B_{cond} and B_{rad} are corrections for inter-pellet thermal conductance values through air thermal conductivity and radiation, respectively:

$$B_{cond} = \frac{\kappa_{air}}{\kappa}\left(\frac{1}{\beta} - 1\right), \quad (3.4)$$

Here pellets filling term is:

$$\beta = \frac{Ns}{S}, \quad (3.5)$$

where S is cold side dimensions;

$$B_{rad} = \gamma \frac{S}{Nk} \sigma T_a^3 (1 - \beta), \quad (3.6)$$

where σ - Boltzman constant, γ - thermal emissivity.

As for (3.6) it can only be regarded as a rough estimate. We do not take into account air convection between the pellets as Grasgof and Prandtl criteria show for this case[8]

Solving equations (3.1) we find the following:

$$T_1 = \frac{1}{\left(\frac{\alpha^+ \alpha^-}{(k')^2} - 1\right)} \left(\frac{\alpha^+ \left(\frac{1}{2} I^2 R + \frac{a_2}{N} T_a\right)}{(k')^2} + \frac{\left(\frac{1}{2} I^2 R + \frac{a_1}{N} T_a\right)}{k'} \right), \quad (3.7)$$

$$T_0 = \frac{1}{\left(\frac{\alpha^+ \alpha^-}{(k')^2} - 1\right)} \left(\frac{\alpha^- \left(\frac{1}{2} I^2 R + \frac{a_1}{N} T_a\right)}{(k')^2} + \frac{\left(\frac{1}{2} I^2 R + \frac{a_2}{N} T_a\right)}{k'} \right) \quad (3.8)$$

,

where

$$\alpha^+ = k' + \frac{a_1}{N} + \alpha I \text{ and } \alpha^- = k' + \frac{a_2}{N} - \alpha I \quad (3.9)$$

Transforming equations (3.8) with

$$\frac{a_1}{N} << k', \ \frac{a_2}{N} << k' \text{ and } I << \frac{k'}{\alpha}, \quad (3.10)$$

we have

$$\overline{T} = T_a \left(1 + \frac{a_1 a_2}{N(a_1 + a_2)k'}\right) + \frac{I^2 RN}{a_1 + a_2}\left(1 + \frac{a_1 + a_2}{4nk'}\right) + T_a \frac{\alpha I (a_2 - a_1)}{2k'(a_1 + a_2)} \quad (3.11)$$

and

$$\Delta T = \frac{\alpha I}{k'}\left(T_a + \frac{I^2 RN}{a_1 + a_2}\right) + \frac{a_1 - a_2}{k'(a_1 + a_2)} \frac{I^2 R}{2} \quad (3.12)$$

Let us discuss in what way Harman Z-measuring involves the above mentioned.

Allowing for (3.12) we obtain the following expressions for the thermoelectric power and voltage ratio:

$$U_\alpha = \frac{\alpha^2 IN}{k'}\left(T_a + \frac{I^2 RN}{a_1 + a_2}\right) + \frac{(a_1 - a_2) I^2 RN\alpha}{2k'(a_1 + a_2)} \quad (3.13)$$

$$\frac{U_\alpha}{U_R} = \frac{\alpha^2}{k'R}\left(T_a + \frac{I^2 RN}{a_1 + a_2}\right) + \frac{(a_1 - a_2) I\alpha}{2k'(a_1 + a_2)}, \quad (3.14)$$

or

$$\frac{U_\alpha}{U_R} = Z'\left(T_a + \frac{I^2 RN}{a_1 + a_2}\right) + \frac{(a_1 - a_2) I\alpha}{2k'(a_1 + a_2)}, \quad (3.15)$$

where $Z' = \frac{\alpha^2}{k'R}$. Unlike equations (1.2) – (1.4) relation (3.14) contains directly the ambient temperature. If using the average temperature (see (1.3) and (3.11)) we should have allowed for the additional term ~ $a/2Nk$ characterizing heat dissipation from the external surfaces. Formula (3.14) takes this term into account automatically via T_a, leaving just the corrections discussed below.

So, the true Z $(=\alpha^2/kR)$ could be defined as

$$Z = \frac{1}{T_a(1 + b_T)}\left\{\frac{U_\alpha}{U_R}(1 + b_{th})(1 + b_r) + b_A\right\}, \quad (3.16)$$

where

1) $b_T = \frac{1}{T_a} \frac{I^2 RN}{a_1 + a_2}$ - Correction factor to ambient temperature

2) $b_A = \frac{(a_2 - a_1) I\alpha}{(a_2 + a_1) 2k}$ - Correction factor because of asymmetry of heat exchange with environment;

3) $b_{th} = B_{cond} + B_{rad}$ - Correction factor to pellet thermoconductivity due to additional heat flux from warm to cold side through the ambient (according to (3.3));

4) $b_r = \dfrac{r}{R_{TEC}}$ - Correction factor because of non-zero resistance of TE module wires where $R_{TEC} = NR$ (The total voltage drop U_R is a sum of the drop U_{TEC} at the module and some additional drop at contacting wires (r is their resistance), so $U'_R = I(R_{TEC} + r) = IR_{TEC}(1 + b_r)$, $U_R = \dfrac{U'_R}{1 + b_r}$

Due to the above formulated correction factors equation (3.16) shows effect of actual arrangement of Z-metering technique.

We can analyze the relative share of the correction factors in the resulted true Z taking the example of standard series of modules that our company supplies.

In case of modules differing by number of pellets the sum of corrections factors raises from big modules to small ones (Fig.3.2). The biggest factor is the resistivity of wires. For small modules the role of testing environment is quite important.

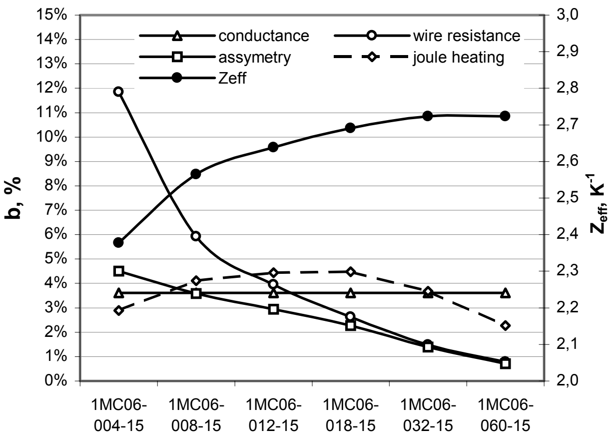

Fig. 3.2 Correction factors and Z_{eff} for TE modules ordered by number of pellet pairs

In case of modules with different height (pellet height) there is also tendency of reduction of ambient factor corrections from thick to thinner types (Fig. 3.3). Again the biggest factor is the resistivity of wires and the smallest is radiation.

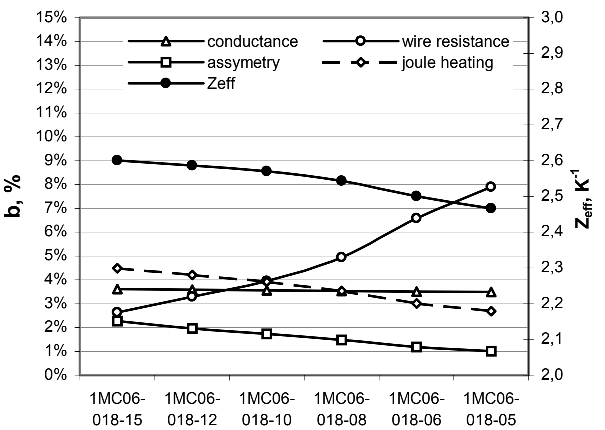

Fig. 3.3 Correction factors and Z_{eff} for TE modules ordered by pellet height

If comparing modules by pellet cross-section the dependence is very slight (Fig. 3.8-3.10). And summary effect is within approx 5% of Z only.

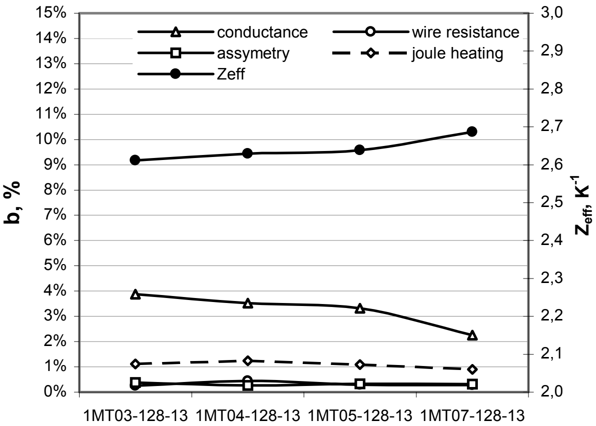

Fig. 3.2 Correction factors and Z_{eff} for TE modules ordered by pellet cross-section

4. Z-measuring of a TEC mounted on the heat sink

In most applications TE modules are mounted into devices such as laser diodes, detectors and so on. It is not possible and not reasonable to disassembly the device to examine TE module, but often the examinations are required, for instance, for quality control of assembling procedures and so on. Thus a more suitable way is to examine a TE module assembled.

Let us consider availability of the Harman method and Z-metering technique for this practically important application.

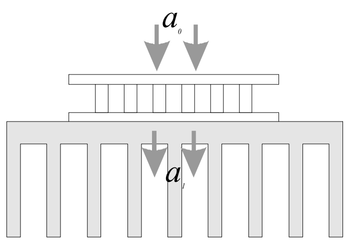

Fig. 4.1. A TEC on the heat sink

One can find that if placing an assembly into the Z-meter, some value $\dfrac{U_\alpha}{U_R}$ will be resulted.

How is it correlate with TE module performance and is it possible to estimate true Z parameter this way?

Heat sink means a noticeable increase of heat dissipation through the basement. It must be taken into account when estimating the role of this factor in measurement results.

Equation (3.16) allows for heat dissipation through the warm side of TE with corresponding terms (b_A and b_T). So the estimation of Z value of the assembled TE module is possible if taking into account thermal properties of the heat sink.

$$a_2 = k_s \frac{S}{L}, \qquad (4.1)$$

where κ_S - thermal specific conductivity of the heat sink; S,

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L - surface and length of the heat sink , correspondingly.

In Fig.4.2-4.3 we demonstrate the effect of heat sink on the effective Figure-of-Merit measured by the technique on the basis of equation 3.16 and 4.1.

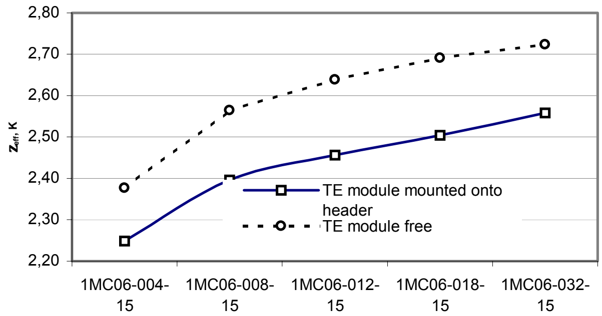

Fig. 4.2 Effective Z_{eff} of TE modules free and mounted one onto heat sink module (Z=2.8x10^{-3} K)

One can see that mounting of a TE module onto the heat sink leads to decrease of the measured Z_{eff} in comparison with the effective Z_{eff} of the TE module in the free space. In Fig. 4.4 we demonstrate experimental results of measurement of TE modules before and after mounting. The results are in good correlation with the above theoretical estimations.

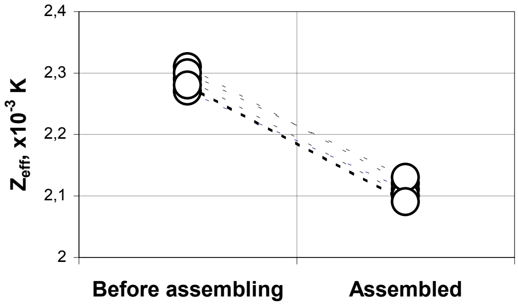

Fig. 3.4 Effective Z_{eff} measured before and after assembling of TE modules (1MT03-012-15) onto TO5 headers

The positive result of the above estimations is that the measured Z_{eff} for assembly correlates with the true Z performance of a TE module.

Of course, assumptions made in theoretical approach put many limitations in application of Z-metering technique for specific packages and arrangements of mounted TE modules.

Nevertheless there are two ways to use the technique for examination of assembled TE modules:

1. One can analyze equations 3.15 and 3.16 and find that averaging of measuring results of two cases with change of the current polarity allows to exclude effect of the heat sink on Z resulted.

The second term in 3.14 and 3.16 generates a certain correction. It is remarkable however that this term is a linear function of the current. Then marking one of polarities by (+), and the other by (-) we have:

$$\left(\frac{U_\alpha}{U_R}\right)_+ = \frac{\alpha^2}{k'R}\left(T_a + \frac{I^2RN}{a_1+a_2}\right) + \frac{(a_1-a_2)I\alpha}{2k'(a_1+a_2)} \qquad (4.2)$$

$$\left(\frac{U_\alpha}{U_R}\right)_- = \frac{\alpha^2}{k'R}\left(T_a + \frac{I^2RN}{a_1+a_2}\right) + \frac{(a_2-a_1)I\alpha}{2k'(a_1+a_2)} \qquad (4.3)$$

Summing (4.2) and (4.3) we come to:

$$\left(\frac{U_\alpha}{U_R}\right)_+ + \left(\frac{U_\alpha}{U_R}\right)_- = 2Z'\left(T_a + \frac{I^2RN}{a_1+a_2}\right)_a \qquad (4.4)$$

that is we manage to solve the problem avoiding any corrections challenge.

2. It is possible to introduce some empirical correction factor that is certainly unique for a concrete package and arrangement of assembly, like as TO standard types, for instance, or others.

3. The effective parameter Z_{eff} directly measured without any corrections can be used as a failure criterion for reliability tests of assemblies.

5. Z-measuring of a 2-stage TEC

If placing a two-stage TE module into the Z-Meter it is possible to measure some value $\frac{U_\alpha}{U_R}$ as could be done for a single stage module.

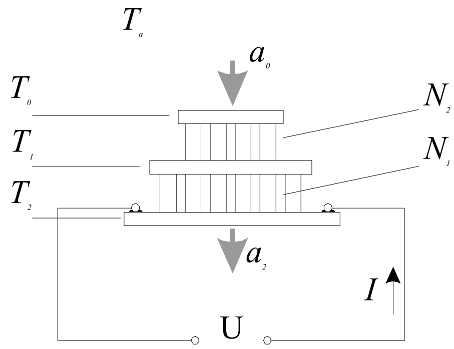

Fig. 5.1. A view of a 2-stage TEC

Let us consider if this ratio correlates with the true Z value of a two-stage module and whether it is possible to transform the correlation into a similar Harman equation. In other words: is it possible to apply the Harman method to two-stage TE modules?

A simplified drawing of two-stage TE module is placed at Fig. 5.1.

The general formulae for a two-stage module cold and hot sides are:

$$\begin{cases} \alpha I T_0 - \frac{1}{2}I^2R - k'_1(T_1 - T_0) = \frac{a_0}{N_1}(T_a - T_0) \\ \alpha I T_2 + \frac{1}{2}I^2R - k'_2(T_2 - T_1) = \frac{a_1}{N_2}(T_2 - T_a) \end{cases}, \qquad (5.1)$$

where T_0, T_1 and T_2 - TE module's cold side, medium and hot side temperatures, respectively.

Since $a_i = A_i S_i$ and assuming the stage pellets number $N_i \sim S_i$ where S_i is the cold side area of the corresponding stage, we can make approximations

$$\frac{a_1}{N_1} = \frac{a_2}{N_2} = A = const \tag{5.2}$$

$$\beta_i = \frac{N_i s}{S_i} = const \tag{5.3}$$

Taking (5.2) and (5.3) and setting $k'_1 = k'_2 = k'$ we modify (5.1) the following way:

$$\begin{cases} \alpha I T_0 - \frac{1}{2} I^2 R - k'(T_1 - T_0) = A(T_a - T_0) \\ \alpha I T_2 + \frac{1}{2} I^2 R - k'(T_2 - T_1) = A(T_2 - T_a) \end{cases} \tag{5.4}$$

Summing up equations in (5) we derive:

$$2\alpha I \overline{T} = (k' + A)\Delta T \ , \tag{5.5}$$

where $\overline{T} = \frac{T_2 + T_0}{2}$ is the average module temperature.

Solving the following set of equations

$$\begin{cases} 2\alpha I \overline{T} = (k' + A)\Delta T \\ I = \frac{1}{2R}\left(\frac{U_{R_1}}{N_1} + \frac{U_{R_2}}{N_2}\right), \\ \Delta T = \frac{1}{\alpha}\left(\frac{U_{\alpha_1}}{N_1} + \frac{U_{\alpha_2}}{N_2}\right) \end{cases} \tag{5.6}$$

we obtain the following

$$Z\overline{T} = (1 + b_{th})(1 + b_r)\frac{U_\alpha}{U_R} \ . \tag{5.7}$$

Here

$$b_{th} = B_{cond} + (B_{conv} + A_{conv}) + (B_{rad} + A_{rad}) \tag{5.8}$$

The parameters $B_{cond}, B_{conv}, B_{rad}$ are described above (3.4-3.7).

$$A_{conv} = \frac{al}{\kappa\beta} \tag{5.9}$$

$$A_{rad} = \frac{\gamma}{\kappa\beta}\sigma T_a^3 l \tag{5.10}$$

Equation (5.7) is rather similar to (1.4) and (3.18). It proves that we can apply the Harman method to a 2-stage TEC meeting requirements (5.2) and (5.3).

Of course, the equation for estimation of ΔT_{max} for single stage modules (1.5) is not valid here. But knowing the *Z*-value we can evaluate ΔT_{max} finding the maximum of the following function:

$$\Delta T(x) = T_a - \frac{x^2}{2Z(x+1)} - \frac{1}{((\xi - 1)x + \xi + 1))(x+1) - 1} \times \left[(\xi + 1)\frac{x^2}{2Z} + T_a + \frac{x^2}{2Z(x+1)}\right]$$

Thus the Harman method could be used for estimation of two-stage TE modules.

In Fig. 5.2-5.4 we demonstrated calculated results and taking into account above advised corrections to estimate *Z* value of two stage modules basing on the data measured by the Z-meter.

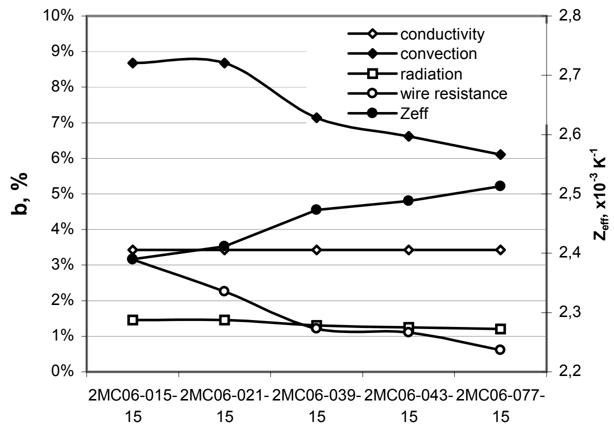

Fig. 5.2 Correction factors for 2MC06-*XXX*-15 TEC types

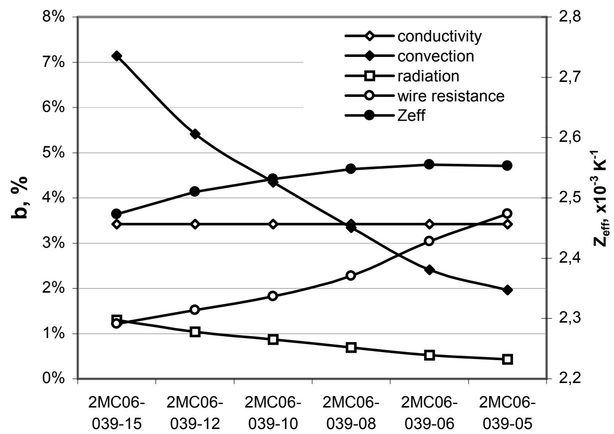

Fig. 5.3 Correction factors for 2MC10-039-*XX* TEC types

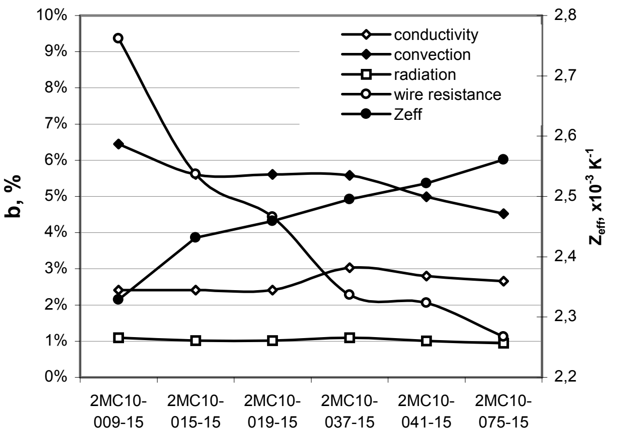

Fig. 5.4 Correction factors for two stage TEC types of 2MC10 series

6. AC Resistance Measurement

The AC resistance of TE module is as mentioned above one of the important quality control parameters of a TE module. The method of measuring of the AC *R* is quite simple – it is necessary to measure precisely resistance of TE at AC current. Within Z-meter technique based on the Harman method it is possible to make the measurements during *Z* metering.

As Z-metering voltage drop U_R is obtained, AC *R* only requires to find the TE module current additionally.

In our Z-meter technique we prefer another known method of separate measurement of TE module resistance at precisely fixed AC current.

There is the reason to use an independent method of AC resistance measurement.

If to use Z technique then both resulted parameters *Z* and AC *R* become directly coupled. Accuracy of the resulted AC resistance depends on the accuracy of *Z* examination (accuracy of *U* and U_α). I.e.:

$$\frac{\delta R}{R} = 3\frac{\delta U}{U} , \qquad (6.1)$$

where $\frac{\delta R}{R}$ - accuracy of AC *R* measurement; $\frac{\delta U}{U}$ – accuracy of voltage drop measurement. Factor 3 (three) takes place as for ACR examination it is required to measure *U*, U_α and I_m.

Independent techniques provide more accurate result, as:

$$\frac{\delta R}{R} = 2\frac{\delta U}{U} , \qquad (6.2)$$

Where factor 2 is due to requirements to measure both negative and positive voltage drops at fixed current.

Finally it is necessary to note that in any case the resulted AC resistance is a sum of the actual resistance on a TE module and some resistance of contacting wires.

$$R = R_{TEC} + r \qquad (6.3)$$

For some types of TE modules, particularly with low resistance, the wires' part is quite large and must be taken into account.

7. Conclusion

There were advised a new series of portable Z-meters suitable for precise examination of *Z* and AC *R* parameters of TE modules, which is very important for certification, quality control and failure monitoring.

Detailed theoretical estimations confirm that application of Z-technique could be broadened from classical measuring of single stage TE modules to two stage ones and also for TE modules mounted into a device housing.

New Z-meter technique applications are very important for end-used practice as well as could be useful for TE modules manufacturing process.

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