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Thermo Electrical Generator Improved Model

Mihail Octavian Cernaianu[1,a], Adrian Cernaianu[2,b], Cosmin Cirstea[1,c] and Aurel Gontean[1,d]

[1] "Politehnica" University of Timisoara, Applied Electronics Department, Timisoara, Romania

[2]University of Craiova, Faculty of Mechanics, Material Technologies Department, Craiova, Romania

[a]mihail.cernaianu@etc.upt.ro, [b]acernaianu@gmail.com, [c]cosmin.cirstea@etc.upt.ro, [d]aurel.gontean@etc.upt.ro

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Abstract: This paper describes the implementation of an automatic measuring system used to acquire the voltage drop from a gradually heated TEG output with and without load. This will help determine the Seebeck coefficient and the internal resistance of the thermo electrical generator. The Seebeck coefficient is one of the TEGs main characteristic and gives valuable information about the output voltage the TEG can generate if its two sides are maintained at different temperatures. Some thermo electrical module (TEM) manufacturers give a constant Seebeck coefficient value for their products while measurements prove that in fact it is temperature dependent. The purpose of this research is to accurately investigate the Seebeck coefficient and internal resistance values depending on temperature and determine the TEMs performance. Using the experimental results we propose to later create an improved thermo electrical model for the TEG.

1. Introduction

The Seebeck effect was first discovered in 1821 by the German physicist Thomas Johann Seebeck. Given a uniform temperature in a closed circuit that is formed by metals, the electromotive contact forces compensate each other and their algebraic sum is zero. Seebeck discovered that this compensation doesn't persist and that an electromotive force appears if one of the contact points between two metals has another temperature than the others [1]. The Peltier effect is the presence of heat at the contact region of two metals when they are electrified [1].

In bulk devices for generation or cooling applications, thermocouples have a typical geometry that consists of two ingot-shaped pellets (thermo-elements) of semiconducting material having dimensions in the order of millimeters connected at one end with an electrically conducting metal strap [2]. A standard TEM is comprised of several thermo-elements thermally connected in parallel and electrically in series.

The figure of merit ZT, defined as $ZT = \frac{\sigma S^2}{k}$, where σ is the electrical conductivity, S the Seebeck coefficient and k the thermal conductivity, indicates the thermodynamic efficiency. A higher value is an indication of greater efficiency.

Measurements of the TEMs parameters have already been made in order to deduce the quantities important for theory and application [4]. In existing thermo electrical models, TEMs parameters are considered constants when in fact they vary with temperature. The purpose of this research is to accurately measure the values for these parameters depending on temperature, and thus to be able to create an improved thermo-electrical model that is useful in simulations and in designing applications based on TEMs.

2. Experimental setup

For the experiments we designed and built a measurement setup that is comprised of two thermo electrical generators sandwiched between an aluminum radiator and a copper plate that is connected to an electrical heater (setup that we will refer to from now on as the TEG tester), as it can be seen in Fig. 1 and 2. The heater is made of serial connected power resistors that are controlled by a P6100 programmable power supply unit that provides a serial interface for communication.

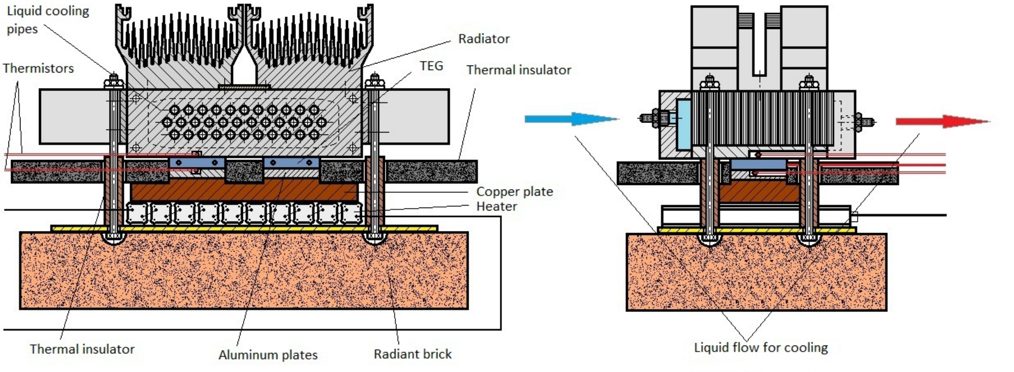

Figure 1: TEG tester cross sections

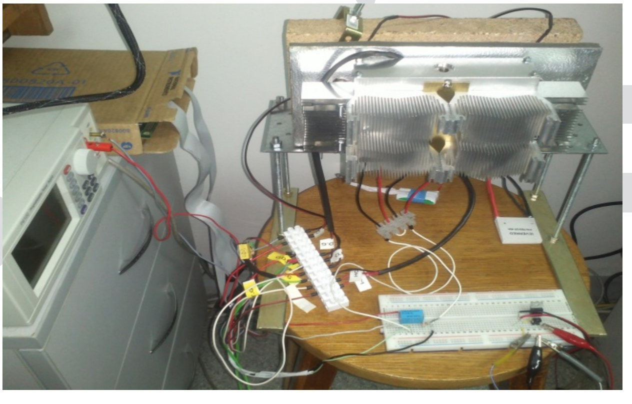

Figure 2: Heatsink side view of the TEG tester

The TEG tester also has incorporated two NTC thermistors located each at the contact point of the TEG with the hot side (copper plate) respectively cold side (aluminum radiator). The setup transversal cross section can be observed in Fig. 1.

The measurement setup configuration is presented in Fig. 3. The PC controls through an application implemented in LabView the DAQ board (NI 6221) and the P6100 power supply unit.

The relay controlled by the DAQ board connects or disconnects the resistive load to the TEG. The DAQ board also measures the hot and cold side temperatures and the TEGs output voltage.

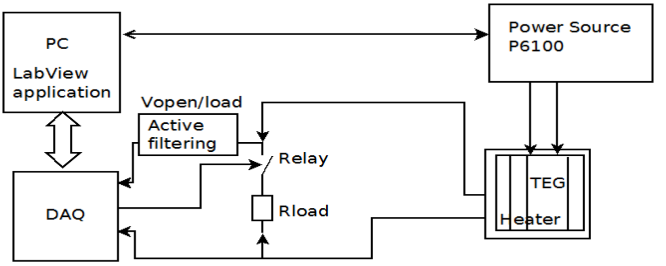

Figure 3: Schematic of the experimental measurement setup

3. Automatic measuring application

A PC application was developed in LabView for automatic measurement of the open loop voltage and load voltage with gradually increasing temperature at the hot side. Values are automatically written in a .csv file format. The measuring application executes the following steps:

1) The power resistors are heated until the desired temperature on the hot side is reached. This is performed with the help of the P6100 programmable power source and a PID regulator that keeps the copper plate at the desired temperature. A settle time of 3600 seconds proves necessary for the equilibrium state to be reached. The default start temperature is 29 ° C.
2) When the temperature has reached the desired value, the settling time has passed and a stable temperature is obtained, the DAQ board measures the open loop voltage.
3) After the open loop voltage has been acquired, the relay is controlled to connect the load to the TEG and the load output voltage is measured.
4) Open loop voltage, load voltage, hot side temperature, cold side temperature and the temperature difference are written in a .csv file.
5) The temperature setpoint is increased with 2 degrees and the process is restarted.
6) The measurement process stops when the temperature setpoint reaches 85 °C.

4. Experimental results

The experiments were conducted using two different TEG manufacturers. One of them (Everredtronics) provides little detailed specifications about the TEMs, only the Seebeck coefficient, thermal conductivity and pellet geometry. The variation of these parameters with temperature is not available. For our model (127 thermocouples – TEG127-40A) the Seebeck coefficient value found on the manufacturers website is S = 0.04236 V/K.

The other manufacturer, Melcor, provides very detailed specifications for its products. For the selected modules: CP1.4-127-06L-RTV the datasheet [3] gives the variation law for the Seebeck coefficient, thermal conductivity and electrical resistivity. However, the Melcor TEM is designed to be used as a heat pump or TEC (thermo electric cooler), so the measurements made with the module configured as a TEG may not be fully compliant with the datasheet specifications.

Fig. 4, 5 and 6 show the experimental results obtained with the Everredtronics product which are plotted with respect to the temperature difference between the two TEGs sides. The curve fitting equation is also computed for each representation.

In Fig. 4, the TEG's output voltage is plotted as the temperature difference increases. The variation proves to be linear and using a linear interpolation we obtain the curve fitting equation:

$$V_{out} = 0.065\Delta T - 0.005 \tag{1}$$

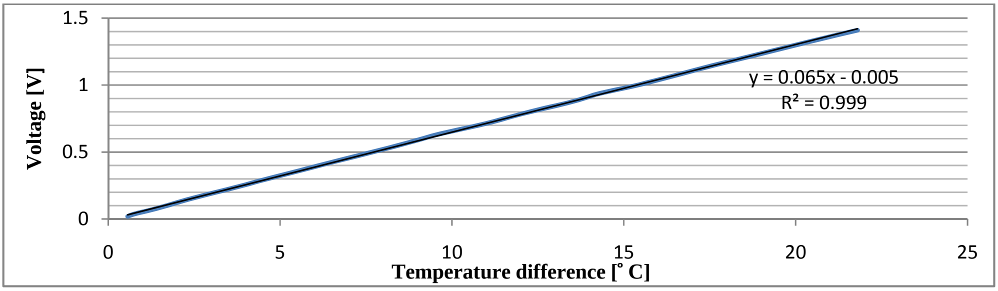

Figure 4: Everredtronics TEG output voltage function of temperature difference

Fig. 5 represents the TEG's internal resistance variation with temperature. The variation curve is best fitted by a 3rd order polynomial function given by the equation:

$$R = 2 \cdot 10^{-5} \Delta T^3 + 0.025 \Delta T + 1.355. \quad (2)$$

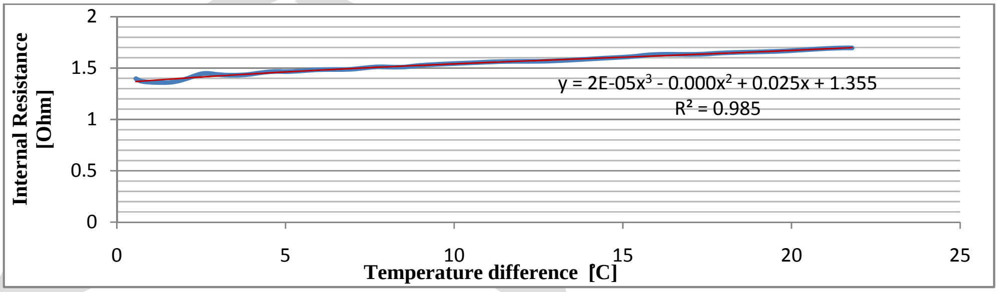

Figure 5: Everredtronics TEG internal resistance function of temperature difference

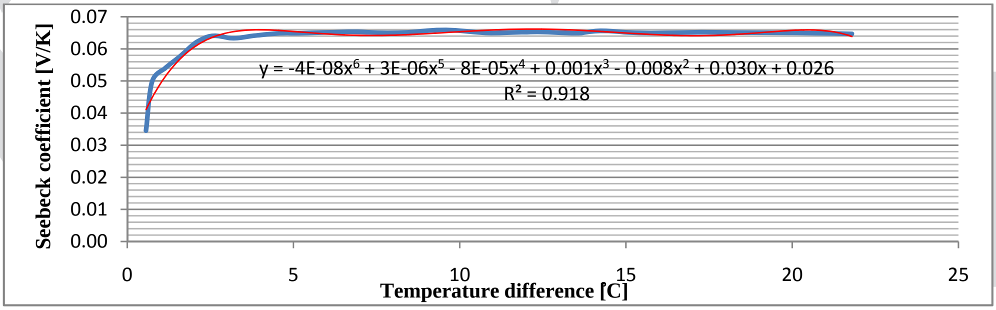

Figure 6: Everredtronics TEG Seebeck coefficient function of temperature difference

In Fig. 6, the Seebeck coefficient is calculated by dividing the output voltage to the temperature difference. The best fitting curve for the Seebeck coefficient is a 6th order polynomial function. The equation is:

$$S = 4 \cdot 10^{-8} \Delta T^6 + 3 \cdot 10^{-6} \Delta T^5 - 8 \cdot 10^{-5} \Delta T^4 + 0.001 \Delta T^3 - 0.008 \Delta T^2 + 0.030 \Delta T + 0.026 \text{ [V/K]}. \quad (3)$$

As we can see from Fig. 7 the Seebeck coefficient varies with temperature and has a mean value of 0.06264 V/K. This measured value is higher than the one provided by the manufacturer (0.04236 V/K).

The measurements made with the Melcor TEMs are represented in Fig. 7, 8 and 9.

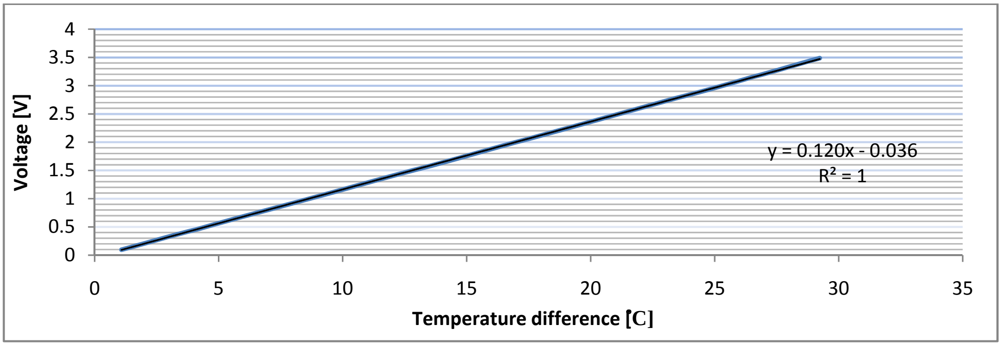

Figure 7: Melcor TEG output voltage function of temperature difference

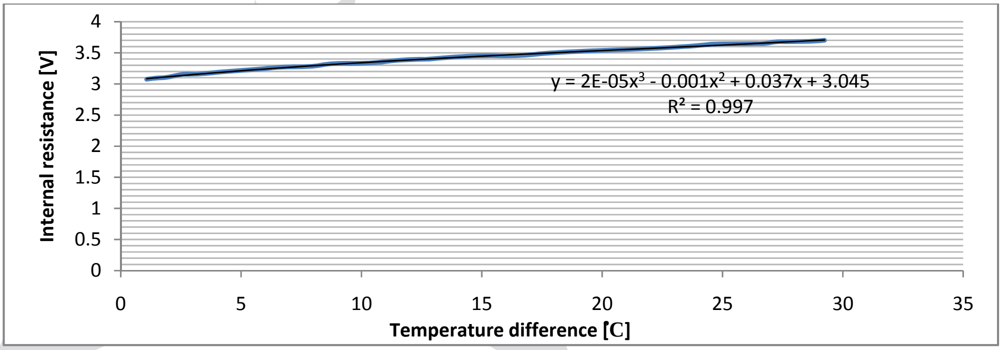

Figure 8: Melcor TEG internal resistance function of temperature difference

In Fig. 7, the output voltage has a linear variation with temperature. The internal resistance variation can be approximated with a 3rd order polynomial function. The Seebeck coefficient has an average value of 0.057 V/K, that is closer to the one provided by the manufacturer (0.0508 V/K). The average internal resistance provided by the manufacturer is 2.2 Ohm. The average value determined by experiment is 3.39 Ohm. From the datasheet this corresponds to another module (CP1.4-127-10).

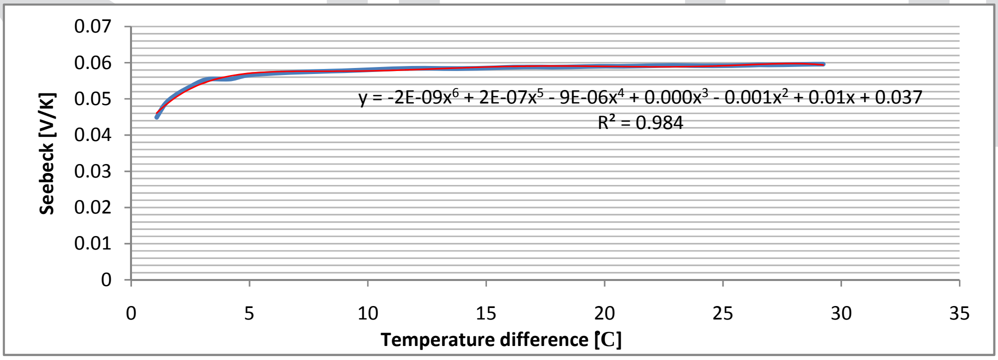

Figure 9: Melcor TEG Seebeck coefficient

The high internal resistance limits the usage of the TEM as a TEG. In this case, the module's performance is much lower than the Everredtronics module.

5. Conclusions

In this paper we have described an experimental method that has helped us determine the variation of a TEG Seebeck coefficient and internal resistance function of temperature. While most manufacturers provide only constant values for these parameters they depend in fact of the temperature difference between the TEGs sides. After implementing an automatic measurement system we were able to represent these variations and generate the fitting curves that describe them. We have observed differences between the datasheet values and the values obtained experimentally. Also, we have determined that the Melcor module has a smooth variation of the parameters with temperature and the experimental values are very close to the ones provided by the manufacturer. For the Everredtronics modules, the experiments show a much higher Seebeck coefficient which gives us the information that the module produces more power than the manufacturer claims. It can be seen that the parameters variation is not as smooth as Melcor's which may be dependent on the manufacturing material or technology. However, the performance is greater than expected.

Our experimental results prove that the TEG's parameters vary with temperature. Using the curve fitting equations we plan to implement a detailed electro-thermal model for the TEG. Spice based thermo-electrical models have already been implemented but they only use the manufacturers datasheet constant parameters when building the model [5, 6, 7]. With a complete and detailed model, simulating TEG based applications will be more accurate. Also, the real performance of these devices can then be used while designing energy harvesting systems or thermo-electric cooling applications.

6. Further work

The next step is to build an electro thermal model for the TEMs. This will be done in a Spice based software. The fitting curves obtained will be implemented to generate an accurate model for the TEM.

7. Acknowledgement

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