Electrical Properties of Commercial Thermoelectric Modules

Rafael Palacios, Ming Zhu Li

Universidad Pontificia Comillas, Madrid, Spain, Rafael.Palacios@iit.upco.es

Abstract

One of the most promising applications of thermoelectricity is the recovery of waste heat for the production of electrical energy. The best performance in electrical power generation is obtained using specially designed TE elements [7][11], but the mass production of Peltier modules leads to an important reduction in prices. Commercial thermoelectric modules do not have a very high performance but are cheap, robust and easy to install. TE modules are appropriate for waste heat recovery at low temperatures [8].

This paper shows the results of testing a commercial thermoelectric module for electrical power generation. All the results have been obtained experimentally using a test bench designed to study commercial TE modules. Several working conditions have been tested, obtaining voltages up to 2.4 V and currents up to 0.45 A for a single module. Plots of voltage as a function of the current are shown for different heat transfers (up to 28 W). Typical V–I plots for alkaline batteries and Ni–Cd rechargeable batteries have also been obtained to compare the behavior of the TE module as a voltage generator.

Introduction

Commercial TE modules, usually called Peltier modules, can be used to generate electricity from heat power. There are many sources of waste heat in the industry and in everyday electrical household appliances which are not used mainly because they generate heat at low temperatures. Using TE modules it is possible to generate electric power even if the temperature of the heat source is only a few degrees higher than the ambient temperature. The electric power can be used to supply auxiliary equipments [2]. Remarkably in applications where other power generation alternatives may have their own limitations [1][6].

There are thermoelectric generators able to produce big amounts of power with rather good performance from heat power [3][4], but we are more interested in taking advantage of many small heat sources.

Commercial TE modules do not have a very high performance [9], but are cheap, robust and easy to install. A set of tests have been carried out in order to study the electrical properties of a commercial TE module.

Testing procedure

All the experiments have been performed using a test bench specially designed to test commercial TE modules of standard dimensions (40×40 mm). Basically a controlled amount of heat is generated using electrical resistors. The heat goes through the TE module to a heat exchanger and then it is transferred to a cooling fluid (air or water depending on the kind of heat exchanger used). Figure 1 depicts the design of the test bench, a better description can be found in [5].

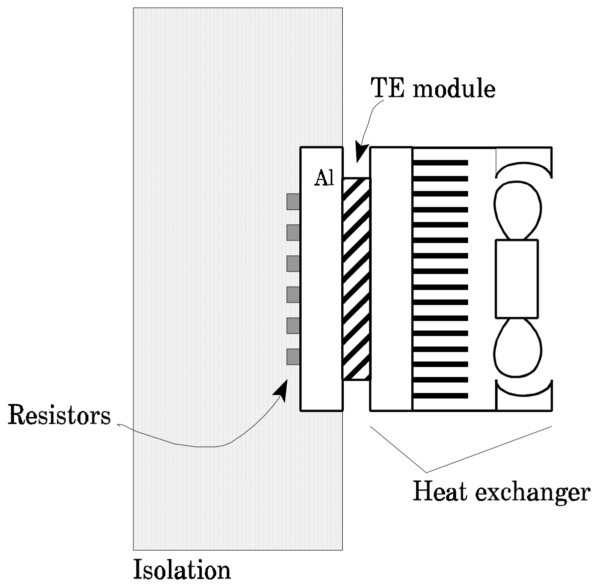

Figura 1: scheme of the test bench

Changing the heat exchanger, or just changing the flow rates of the cooling fluid, it is possible to study the behavior of the TE module at different temperatures. Using a set of external variable resistors it is possible to make the TE module work at different electrical conditions. It was also possible to find at which current the maximum electrical power is obtained and therefore the maximum performance.

Sensitivity to the Temperature

First, we have studied how the temperature at the face of the module may affect to the generated voltage. Figure 2 shows the voltage generated by the TE module as a function of the heat transferred (Qc). The three lines correspond to the three different working conditions: the line marked with '"' is the behavior using a finned heat exchanger with a fan running at low speed (supplied at 8 V); the line with '+' marks corresponds to the same heat exchanger with the fan running at normal speed (supplied at 18 V); and the line with '!' marks was obtained using a heat exchanger with running water.

In all three experiments the temperature of the fluids was 23ºC, but temperatures at the face of the TE module were different. For example, at Qc=22 W the temperature Tc was 70ºC, 65ºC and 54ºC respectively and the corresponding voltages 1.16 V, 1.22 V and 1.26 V. So the variations in the voltage are smaller than the variations in the temperature and therefore it can be said that the TE modules are not very sensitive to the temperature for electric power generation.

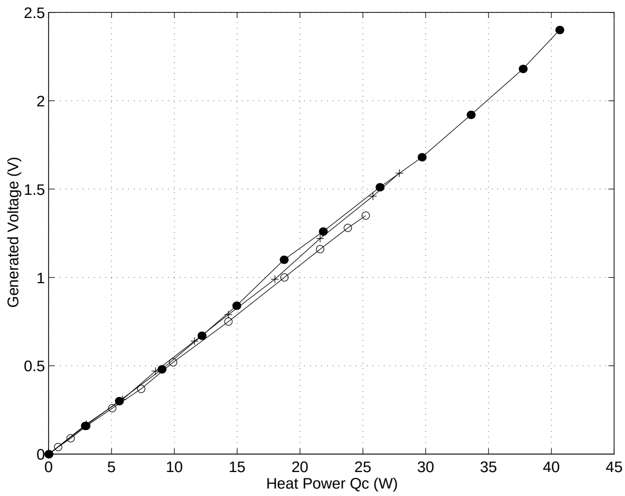

Figura 2: Generated voltage for different working conditions

As shown in figure 2, the voltage generated really depends on the heat power going through the module and not on the temperature. The only important advantage in keeping a low temperature is that it is possible to make the TE module work at higher heat power. Using the finned heat exchanger it was not possible to transfer more than 28 W of heat because the temperature of the module was at the limit (80ºC) and therefore the maximum voltage became 1.6 V. On the other hand, the heat exchanger made of copper with running water was able to transfer more than 40 W for the same temperature and the maximum voltage became 2.4 V.

TE modules to supply electrical appliances

A set of tests have been performed in order to study the electrical behavior of TE modules. To design real applications it is important to know how much electrical power can be obtained from the module and how stable the voltage is. The basic results of these tests are summarized on figure 3, where the graphs of current versus voltage are shown for different heat transfers.

It can be seen that the voltages fall as the currents increase. This is the normal behavior of most electric power supplies, except those that include a feedback controller. In general power supplies are modeled in terms of an internal resistance.

To compare the behavior of TE modules with other possible power supplies, the same kind of graphs have been obtained for an alkaline battery (type AA) and the same size Ni–Cd rechargeable battery [10]. Figure 4 compares the behaviors of both batteries with the TE module working at 28 W.

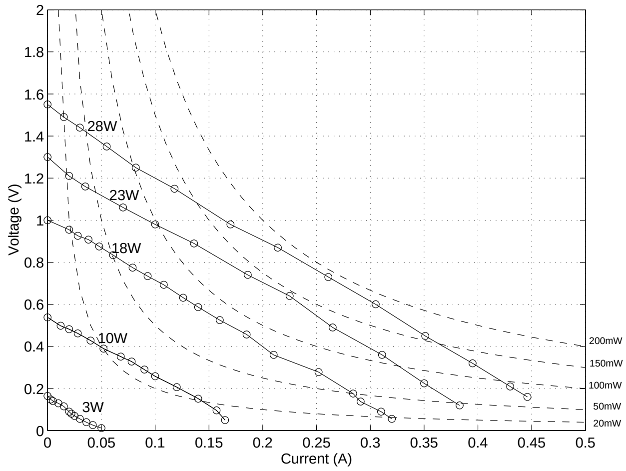

Figura 3: Electrical behavior of the TE module

Ni–Cd battery has the lowest voltage at no current but it also has the smallest internal resistance, therefore its voltage is more stable. This fact makes Ni–Cd rechargeable batteries interchangeable with alkaline batteries for most applications. On the other hand the voltage generated by the TE module degrades very quickly as the current increases, so in most applications it might be necessary to control the heat transfer in order to get the required operating point (defined by the voltage and the current).

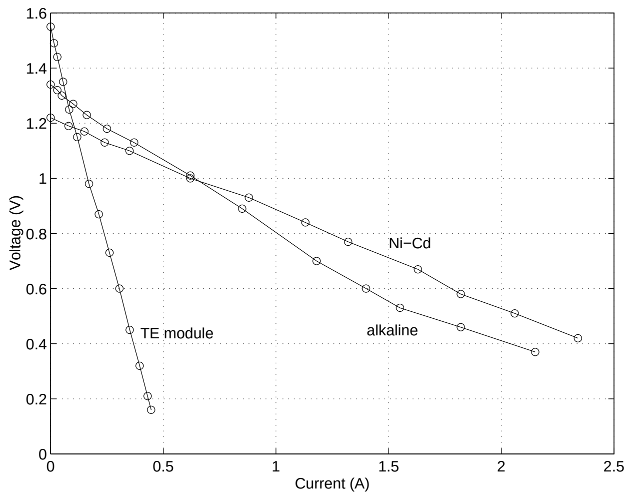

Figura 4: Comparison between batteries and the TE module

The reachable values of current and voltage that can be obtained using the finned heat exchanger are shown, over constant–power lines, on figure 3. In this graph it is also shown that the slope, and therefore the internal resistance, does not depend on the amount of heat going through the module. Nevertheless it has not been checked if it depends on the temperature, so these kind of graphs can not be estimated from the values of voltage of figure 2 for other heat exchanger configurations.

Analysis of performance

Due to the rapid drop in the voltage as the current increase, only during the first few samples in figure 3 the generated power is raising (dashed lines represent constant power contours). For higher currents, the drop in voltage brings a power decrease. This behavior can also be seen in figure 5, where graphs of generated power as a function of the current are shown for different heat powers going through the TE module.

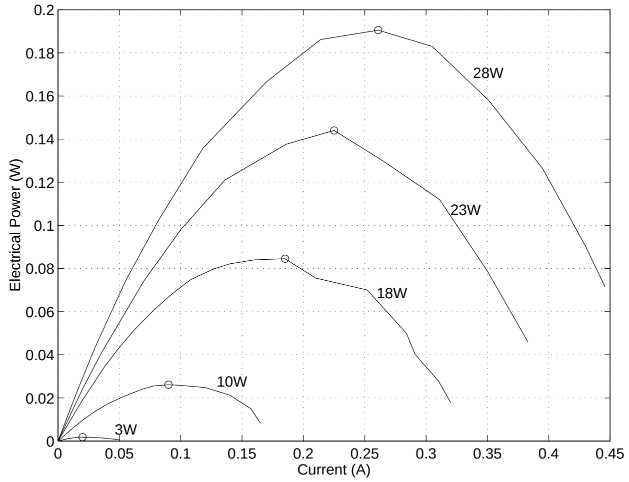

Figura 5: Electrical power generation graphs

In figure 5 the points of maximum electrical power for each heat power transferred have been emphasized. For a given heat power, the emphasized point corresponds to the electrical condition which gives rise to the maximum generation of electrical power and therefore to the maximum performance. Figure 6 shows the maximum performance values (calculated dividing the maximum generated electrical power by the heat power transferred through the module) for different heat powers. It can be observed that we did not reached a performance of 1%, but it always increases with heat power. Higher performance can be obtained using the heat exchanger that uses water and increasing the heat power going through the module.

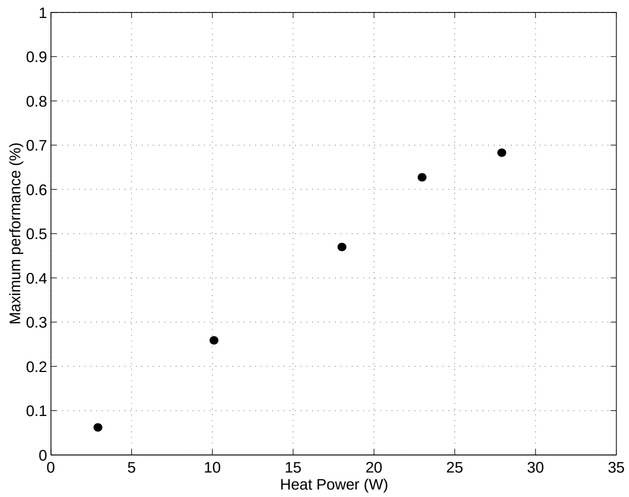

Figura 6: Performance graph

Conclusions

From the first experiments it has been concluded that the voltage generated by the TE module depends mainly on the amount of heat going through the module and slightly on the temperature. Therefore the most important advantage in lowering the temperature is to allow higher heat transfers without threatening the module. It is also important to note that in the performance results obtained, the efficiency always increased with the heat going through the module. So at this moment everything suggest that increasing the heat power is advantageous.

It has been found that the internal resistance of the TE module is higher than that in alkaline of Ni–Cd batteries, so the voltage generated falls very quickly as the current increases. This could be a problem adapting TE generation to some applications that require a stable voltage. At least it has been shown that the value of the internal resistance does not depend on the heat power so the modeling of the TE cell as a power generator is not difficult.

Finally, the efficiency obtained is not very high, but the limit was not found at the conditions tested. Following experiments will try to find higher performances by increasing the heat power.

References

[1] Peter B. Kenington, "Around the world by balloon: an electrical perspective", Computing & Control engineering journal. June 1998

[2] Daniel T. Allen, "Thermoelectric self-powered hydronic heating demonstration", Proceedings of the 6th International Conference on Thermoelectrics. Dresden, Germany 1997

[3] L.I.Anatychuk, Y.Y.Rozver, K.Misawa, N.Suzuki, "Thermal generators for waste heat utilization", Proceedings of the 6th International Conference on Thermoelectrics. Dresden, Germany 1997

[4] John C. Bas, Robert L. Farley, "Examples of power from waste heat for gas fields", Proceedings of the 6th International Conference on Thermoelectrics (ITC). Dresden, Germany 1997

[5] Rafael Palacios, Miguel A. Sanz-Bobi, "Thermal properties of commertial thermoelectric modules", Proceedings of the 6th International Conference on Thermoelectrics. Dresden, Germany 1997

[6] W.Roth, R.Kügele, A.Steinhüser, W.Schulz, G.Hille, "Grid-independent power supply for repeaters in mobile radio networks using photovoltaic–thermoelectric hybrid systems", Proceedings of the 6th International Conference on Thermoelectrics. Dresden, Germany 1997

[7] David Michael Rowe, “Development of improved modules for economic recovery of low temperature waste heat”, Proceedings of the 6th International Conference on Thermoelectrics. Dresden, Germany 1997

[8] Akira Tsuyoshi, Shuzo Kagawa, Masanori Sakamoto, Kenji Matsuura, “A study of commertial thermoelectric generation in a processing plant of combustible solid waste”, Proceedings of the 6th International Conference on Thermoelectrics. Dresden, Germany 1997

[9] M.H.Cobble, “Calculations of generator performance”, CRC handbook of thermoelectrics, CRC Press Inc, 1995.

[10] Robert A. Powers, “Batteries for low power electronics”, Proceedings of the IEEE, Vol. 83, No. 4, April 1995.

[11] Min Gao, D.M.Rowe, “Optimization of thermoelectric module geometry for waste heat electrical power generation”, Journal of Power Sources, Vol 38, 1991