Thermal Properties of Commercial Thermoelectric Modules

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Abstract

Thermoelectric semiconductors and the mass production of thermoelectric modules have experienced a big development in the last years, making thermoelectricity attractive for industrial and commercial applications. The design of industrial applications requires deep knowledge about how thermoelectric modules behave. Even in the case of an application designed to work at a certain operating point of the module, it is interesting to evaluate how would it behave at different working conditions. The thermal and electrical characteristics of the commercial thermoelectric modules, provided by the manufacturers, usually represent the optimal working condition or a few points in a narrow area around that point. But the characteristics can not be considered constant, the modules are specially sensitive to the temperature, which is very changeable in real applications and in fact depends on the heat transferred.

This paper shows the results of testing two commercial thermoelectric modules, one is the typical 12V, Tmax=80°C and the other, designed for high temperature, is a 50W, Tmax=200°C. All the results have been obtained experimentally using a test bench designed and built for this purpose. Special procedures were applied in order to be able to control the temperature in both sides of the thermoelectric module during the experiments. A description of the test bench (which is very easy to build for any laboratory) and the procedures for testing modules in a convenient way are also included. The results obtained correspond to a wide range of working conditions: a temperature from −15°C to 190°C, a range of heat power from 10W to 50W, and electric power from 0.1W to 80W.

Introduction

For the design and development of industrial applications, using commercial thermoelectric (TE) modules, it is necessary to know the thermal characteristics of the modules.

The behavior of the modules is mostly estimated using equations or graphs. Equations are based on theoretical aspects of thermoelectricity [4] and graphs are derived from the Universal Performance Graph [2][5]. The universal graph, already relabeled for a specific module, is sometimes provided by the manufacturer of the module. In most cases this is the only information used by engineers. However, these graphs are based on the temperatures at the faces of the module, which are difficult to estimate due to mounting uncertainties and because the temperatures depend on the amount of heat transferred by the module. It is also possible to find the application's working point out of boundary because the graphs provide data only for a few working conditions. Since the modules show quite an important dependency with the temperature, extrapolation is not suitable.

After testing some applications [1][3] we have found worse performance than that estimated using the graphs. The difference is due to a wrong estimation of the module's temperatures or simply because the performance of the modules is not as good as that shown in the graphs. We have also found disagreement in different graphs provided by the manufacturer for the same commercial TE module.

A comparative study of different modules based on the graphs is difficult because the manufacturers may not provide information at the same working points. For example, some graphs are valid for 27°C, 35°C or 50°C in the hot face of the module and other graphs are valid for 25°C, 35°C, 50°C or 65°C. In both cases the temperature range is fairly narrow taking into account that the operating temperature range of the module is -150°C to 80°C.

Information about special working conditions such as heat transfer with negative temperature gradient or electric generation is not available for most Peltier modules. These data are interesting to evaluate some applications out of the critical point used during the design.

A test bench has been designed and built in order to obtain the complete set of curves of commercial TE modules. This paper includes a description of the test bench and the procedures for testing modules in a convenient way. In addition, some experimental results obtained after testing two modules are also included. The first module, coded CP, is designed to be connected directly to a 12V source. It can work only at temperatures less than 80°C and its parameters are the following: Imax=8.5A, Qmax=68.8W, Vmax=15.4V, ΔTmax=65°C. The second module, coded HT, is designed for high temperature applications (up to 200°C) and has the following characteristics: Imax=6A, Qmax=51W, Vmax=14.4V, ΔTmax=63°C.

The notations used in this paper for the variables of the TE modules are the following:

- Qc is the thermal power absorbed in the cold side.
- Pe is the electric power supplied to the module.
- Qh is the thermal power given out of the hot side (Qh=Qc+Pe).
- I is the current applied to the module.
- V is the voltage applied to the module.
- Tc is the temperature at the cold face.
- Th is the temperature at the hot face.
- ΔT (also called DT in the graphs) is the gradient of temperature, that is Th−Tc.

It is important to remark that the subscript 'c' means cold sink. The cold sink is the side in which the module absorbs heat, but not necessarily the side with the lowest temperature. Usually, the cold sink has a lower temperature than the hot sink and therefore ΔT is positive. But in some situations ΔT can be negative, for example to absorb more than 30W of heat in the cold side with just 1A, the temperature in the cold side must be higher than in the hot side. Another example is electric generation.

Description of the Test Bench

The test bench has been designed for commercial TE modules of standard dimensions 40×40mm, but smaller modules can also be tested. Using this bench it is also possible to compare the performance of different heat exchangers in real mounting conditions. The final mounting scheme usually involves several material, conductive gels and a clamping system; the thermal conductivity of the system can be estimated at real working conditions (working temperature and heat transfer).

The test bench has been designed with the following ideas in mind:

- Easy measurement of all thermal variables (heat transfer and temperatures).
- Simple control of the working conditions.
- Possibility to replace the TE module and the heat exchanger easily.
- Effortless testing, with short transients.

Figure 1 depicts the final design. Heat from the left isolated part is transferred to the right part through the TE module and then to the air or water (depending on the kind of heat exchanger).

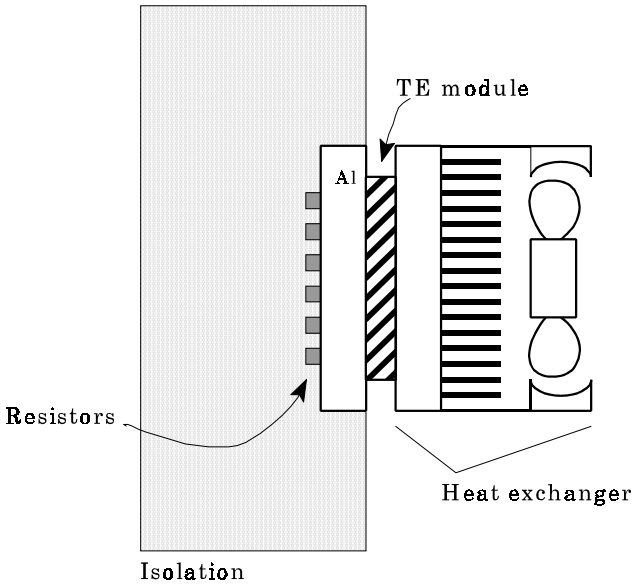

Figure 1: scheme of the test bench

On the left part, thermal power is generated by 6 resistors which are controlled using an external DC power supply. The DC source provides an accurate measure of the heat absorbed by the module, except for small losses through the polyurethane isolation. These losses have been estimated using a 3D finite element model. For the worst case (Tc=200°C and 15°C of ambient temperature) total heat through the isolation is 3.7W, and in most cases less than 1.5W. A correction can be applied rising in this amount the power generated by the resistors.

The resistors are mounted on a block of aluminum in order to have uniform temperatures in the face of the module and to make easier the module replacement. The whole system is put together using two screws (from the head exchanger to the Al block).

Temperatures at the faces of the TE module are measured using thermocouples. The thermocouples are inserted in small holes made in the aluminum block and in the heat exchanger. In the worst case, less than 1°C is the estimated difference between this measurement and the real temperature at the face of the module.

On the right part, the heat exchanger is mounted directly over the TE module, or using intermediate materials to imitate the mounting conditions of the application. It is possible to control the performance of the heat exchanger in order to change the working conditions of the test bench. The conditions are changed by adjusting the fan speed in finned heat exchangers or by adjusting the flow rate in liquid heat exchangers. These operations change the temperatures of the test bench; no additional systems to control the temperature of the cooling fluids are needed. The only limitation is to reach temperatures on the hot face below the temperature of the cooling fluid.

Procedure for Testing

There are three independent variables in the TE module: Th, ΔT, I and two dependent variables: Qc, V. The performance graphs are provided for fixed temperatures Th and then using ΔT and I you find Qc and V. Trying to obtain such graph directly from the test bench is somewhat complicated because it involves a control of the temperatures Th and Tc by changing Qc and the fan speed simultaneously. Temperature control is difficult, sometimes unstable and above all very slow.

In order to have easier testing we decided to fix Qc and I, then read the other variables. Qc and I are controlled using two DC power supplies, in few minutes the system is steady and then voltage and temperatures are read. Information for different temperatures is obtained by changing the performance of the heat exchanger. After a short transient, a different set of temperatures can be read.

Following this procedure, a big amount of reliable data can be obtained quickly. Other conditions, not directly measured, can be calculated by interpolation.

Experimental Results

Two commercial thermoelectric modules have been tested. A broad range of working conditions was studied (greater than that provided by the manufacturer). All tests were made for low electric currents (less than 5A) because the performance of the TE modules is better for lower current. For example, the CP module working at Th=25°C, ΔT=20°C absorbs 27W of heat at

the cold side and 30W of electric power when operated at I=4A (this means an efficiency of 0.9). On the other hand, when operated at I=8A, the heat Qc is only 46W and the electric power 116W (this means an efficiency of 0.4). Therefore for industrial applications it is more interesting to operate TE modules at lower power, using several modules if necessary.

The tests were achieved at I=1, 2, 3, 4, 5A and Qc=10, 20, 30, 40, 50W for both commercial modules (CP and HT). In this paper only a few graphs comparing experimental and theoretical results are shown, but all the measurements of the tests are available via Internet at `http://www.iit.upco.es/~palacios`.

As an example, figure 2 shows the measurements of the CP module when operated at I=3A.

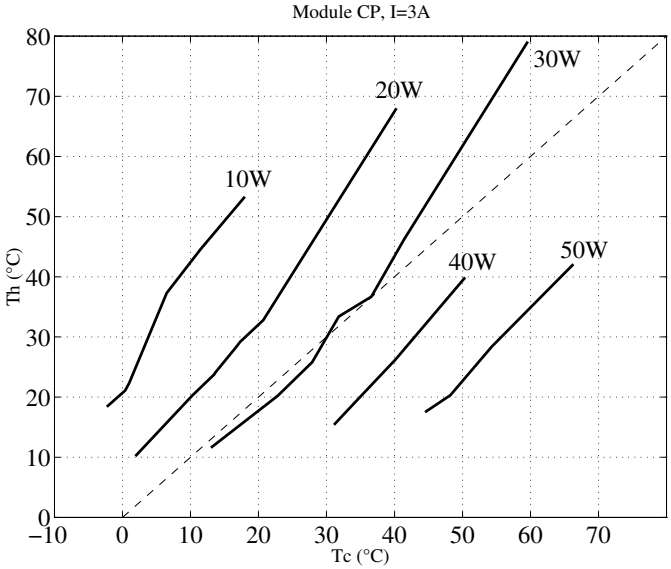

Figure 2: Experimental measurements

In this kind of representation it is easy to see that the CP module working at I=3A is not able to pump more than 40W unless ΔT is negative. More operating points for Qc=40W should have been measured to confirm this statement.

In the following graphs the thick line represents the experimental results, while the thin line represents the values calculated using the performance graphs provided by the manufacturer.

Figure 3 depicts a linear relationship between Qc and ΔT (DT in the graph) for a given Th and I, as illustrated on the universal performance graph. It is interesting to note that the experimental results also show the heat transferred by the module when ΔT is negative, this information is not shown in the manufacturer's graphs. It is also interesting to find that the heat power obtained experimentally is always lower than the power estimated using the performance graph. This difference is bigger for lower values of ΔT.

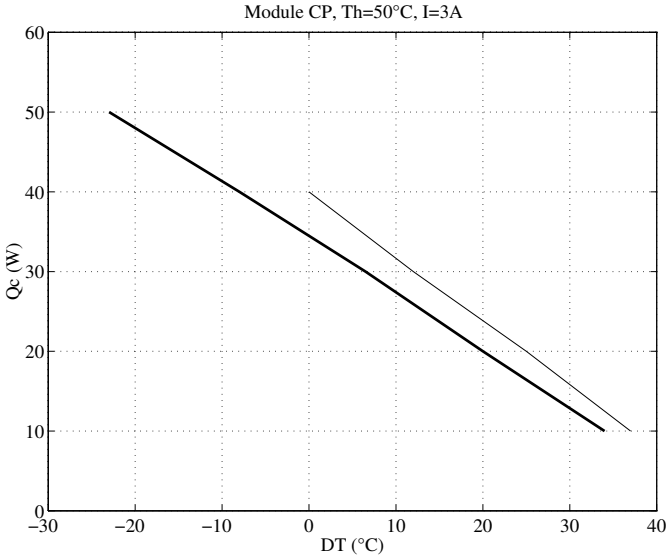

Figure 3: Linear relationship between Qc and ΔT

The proportionality between the voltage and the differential temperature has also been studied. Figure 4 shows the case of the CP module at Th=25°C and I=3A. The experimental values of the voltage are higher than those of the thin line. This means that the electric power needed to obtain a current of 3A is higher, and taking into account that the theoretical heat transfer is also higher (see figure 3), then the theoretical efficiency is unreachable.

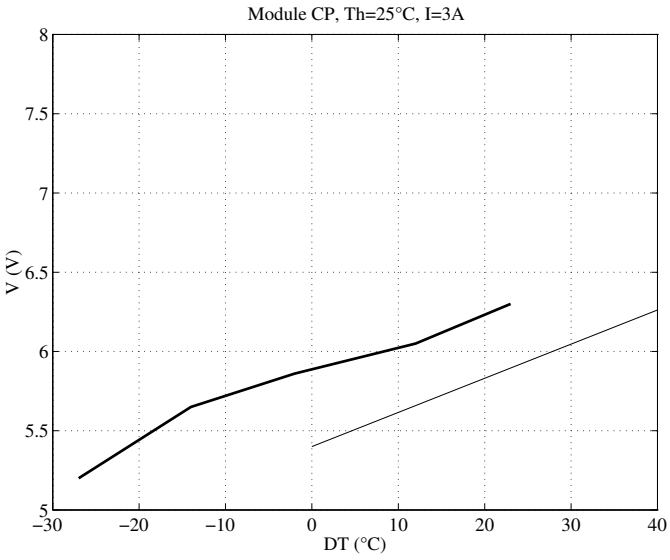

Figure 4: Linear relationship between voltage and ΔT

Finally, two more graphs represent the sensitivity of the TE modules to changes in the operating temperature. Figure 5 stands for the CP module, and figure 6 represents the behavior of the HT module. In the case of the CP module three lines have been drawn: the thick line means experimental, and the thin lines have been obtained using performance graph. The dashed line comes from a graph valid for Th=27°C, 35°C and 50°C, while the continuous line comes from a graph for Th=25°C, 35°C, 50°C and 75°C. Despite the fact that both graph were provided by the manufacturer of the TE module, they slightly disagree.

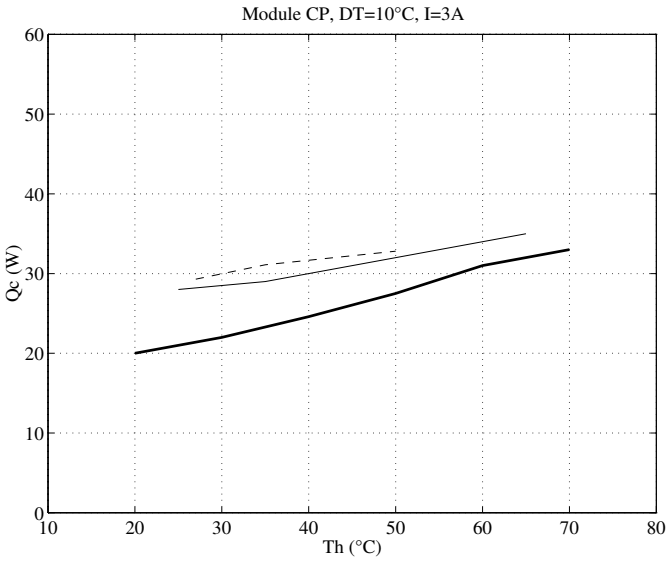

Figure 5: Module CP, sensitivity to the temperature

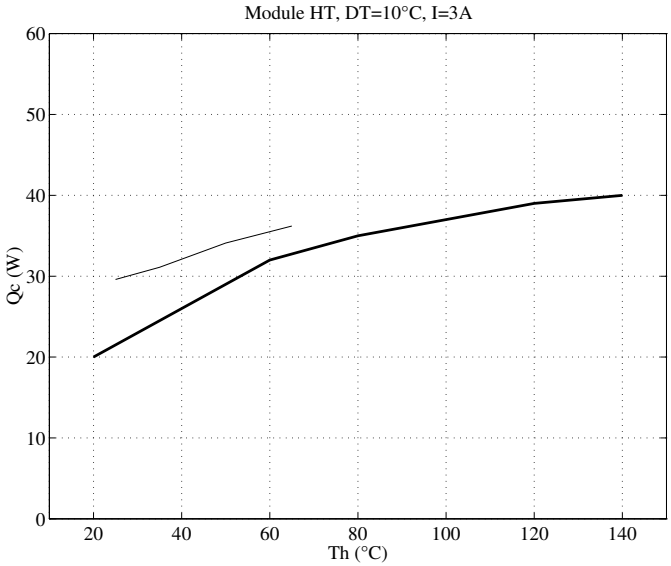

Figure 6: Module HT, sensitivity to the temperature

Figures 5 and 6 show that the heat transfer obtained experimentally is smaller than that estimated with performance graphs. The difference seems to be more significant for lower temperatures. In the case of the HT module a broad range of temperatures have been studied experimentally. In this graph it is clear that the linear extrapolation of the performance graph is not suitable.

Conclusions

This work is focused on obtaining the thermal properties of commercial thermoelectric modules at operating conditions not found in the performance graphs provided by the manufacturers. It is also interesting to be able to compare the characteristics of several modules operating at the same working conditions.

A test bench has been built to measure the thermal properties of commercial TE modules. In this paper the scheme of the test bench and a procedure for testing modules have been presented.

Finally, some experimental results have been included. Two commercial modules were examined in the test bench and the results have been compared with the performance graphs provided by the manufacturer.

- Linear relationships between some variables have been confirmed.
- It has been shown that data provided by the manufacturer for the same TE module can be inconsistent, questioning the validity of this information.
- Experimentally, we have obtained worse results of heat transfer and electric power than those predicted in the performance curves.
- A broad range of working conditions have been obtained.

In following papers we will show the results of the tests for electric generation which are now being performed in the test bench.

Acknowledgments

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