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Master of Science in Mechanical Engineering

THERMOELECTRIC CELL CHARACTERIZATION FOR A SPACEBORNE MICROBALANCE

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Master Thesis of: Mechanical Engineering

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Abstract

For over 30 years, Quartz Crystal Microbalances (QCM) have been used as a way of measuring and controlling particle deposition on sensitive surfaces such as optical mirrors, thermal radiators, solar arrays, and other equipment used in space exploration. In recent years their applications have multiplied as well as their required performances in cryogenic environment. In that case, an effective cooling has to be provided, and passive cooling base con radiation is not generally a viable solution, since, in order to allow condensation, a lower temperature with respect to the heat sink is required. The cooling problem of the QCM has found promising heat removal results from the use of Thermoelectric Cells (TEC), with compact size and light weight.

Cooling performance or the TEC at low temperature environment is not easy to evaluate and a characterization in expected environment is generally required. Thus, in this work, characterization of the TEC designated to cool down a Double QCM will be described . That is, performance of the cell will be retrieved in order to verify its cooling power, when subjected to different conditions, in order to verify its applicability, endurance and reliability for the development of a space borne microbalance.

Keywords: Quartz Crystal Microbalance (QCM), cryogenic temperatures, Thermoelectric Cell (TEC),

1 Chapter

INTRODUCTION

This chapter will introduce general concepts of Contamination Assessment for space applications and the use of Quartz Microbalance systems in order to perform the corresponding measurements. Moreover, the Double Cristal Microbalance Model, proposed on a previous work, will be explained, concentrating our attention on the cooling strategy.

1.1 CAM Project

When space-crafts approach orbit latitudes, the atmospheric density drops down to low levels and the mean free path for gases becomes larger than the dimensions of the craft. At this point, a cloud of Volatile Condensable Material (VCM) starts to envelope all over the craft's body. This cloud consists mainly of the outgassing of the materials used on its construction, desorption of surface contamination, rocket exhaust and waste dumps. Most of the particles, in this induced contamination, will stream off into space, with no adverse effect on the surfaces; but a fraction of these particles will stay inside and contaminate the sensitive surfaces. This becomes a problem for the high precision instruments space missions carried within, because these must work under strictly low levels of contamination.

Contamination Assessment Microbalance (CAM) is developed by different research institutes, focused on measuring contamination levels around the equipment. Quartz Crystal Microbalances (QCMs) are commonly used to measure the deposition rate of molecular species on a surface. The process consists on measuring the deposition rate of a specific material and calculate mathematically a source term, or outgassing rate for the material. The source term, which is representative of the material's outgassing rate, can be used as input data for computer programs that predict the deposition rate of the emitted or outgassed material on another surface.

The outgassing process is diffusion controlled, and the release rate, or outgassing, is temperature dependent. Outgassing measurements are not typically used to measure the release of material due to degradation of the base material or the material generated by chemical interactions of released compounds that result in the production and deposition of a different chemical species.

The deposition process is temperature dependent with the efficiency of the condensation process increasing as the deposition surface temperature becomes increasingly colder than the temperature of the outgassing material. The species, molecular or atomic, released from a material during the outgassing process are typically quantified and described in two ways: (1) The total amount of material lost through the outgassing process is often referred to as the total mass loss for the material, and (2) material released during the outgassing process that will recondense on another surface is often identified as volatile condensable material (VCM). Both quantities can be expressed as a percentage of the original sample mass, but only VCM can also be expressed as an outgassing rate when measured with an instrument such as a QCM.[1]

Besides measuring the mass of condensed matter, the Quartz Crystal Microbalance (QCM) for CAM program needs to achieve the certain condensing temperatures (30°C less than the heat sink down to -50°C), therefore, a cooling system of the microbalance is needed. CAM, in fact, will have to deal with the rough working conditions of spacecraft in space environment. Thus, though under vacuum, its operating modes includes thermal cycles down to -200°C and up to 130°C associated to the temperature of the spacecraft interface and peaks up to 150°C for the sensing crystal every time it needs to be regenerated. QCMs typically fall into two major categories: QCMs either have a single quartz crystal or

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[1] John J. Scialdone, Swales Aerospace, Beltsville, MD; Alex F. Montoya – *Material Outgassing, Identification and Deposition, Molidep System*

a matched pair of quartz crystals, forming a clear distinction between the two major classes of QCMs. This work will address the QCMs that have a matched pair of quartz crystals, only in which one of the crystals serves as a reference oscillator while the deposition of VCMs occurs on the surface of the other quartz crystal.

So far, it has been proven that using a Peltier Cell (commonly called TEC - Thermo-Electric Cooler - or TEM - Thermo-Electric Module) to cool the microbalance's system to the desired temperature, is possible. TEC exhibits advantages that in the space field cannot be neglected but also limitations in performances and low efficiencies. The primary task of this work is to assess the possibility of adapting available commercial TEC to the CAM application. To this purpose experimental characterization and modeling of the TEC have been carried-out because of the wide range of conditions for which TEC performances were available[2].

1.1.1 Quartz Crystal Microbalance - Double Crystal Model

As explained before, Quartz Crystal Microbalance (QCM) are commonly used to measure the rate of deposition of molecular species on a surface, using material's deposition rate, or outgassing rate, which is used as input data for computer programs that predict the deposition rate of the emitted or outgassed material on another surface[3].

In order to do that, different configurations have been studied. These are summarized in the table below.

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[2] Julien Cornali, *Thermal Design of a Microbalance for Space Application,*

[3] D. McKeown and C. R. Claysmith – *Quartz Crystal Microbalance Systems for Shuttle Contamination Measurement* – Faraday Laboratories, La Jolla, CA.

COOLING CONFIGURATION	DESCRIPTION
Radiative Case QMC Cooling with TEM	Radiative/Conductive cooling action from the cold side of the module and Crystal's heating for the regeneration of the balance.
Conductive Case Cell Based Support	Conduction through the supporting blades connected to the TEC, in order to transmit the refrigeration power to the crystal.
Conductive Case Direct Link Cell-Crystal	Conduction using a new component as conductive link beneath the crystal and the cold side of the TEC.
Radiation Case Double Crystal QMC	Use of two quartz crystals to decouple the measuring effects associated to the mass deposition and to temperature changing.

Table 1-1 Cooling Configurations

In simple terms, the requirements that we want to fulfill with these arrangements can be summarized as:

- Spacecraft environmental temperature varying between 150°C and -200°C.
- Cool down requirement: temperature difference of 30°C between 130 and -50°C.
- Expected heat to be removed, 70 mW from thermal design.

Simulations with thermal models performed in a previous studyshowed that the cooling action is clearly better with TEC usage. To recall, every configuration that has been used to test the conductivity allowed the system to reach the required temperatures. Uniformity around the electrodes is improved.

Moreover, as far as mechanical and thermal characteristics are concern, new requirements are born, which will be described next.

1.1.2 Requirements

Mechanical

The mechanical requirements, needed to be fulfilled by the QCM design and its cooling system involve: Size and weight of the model should be kept at a minimum; this shouldn't be a major problem since the QCM itself won't experience any change. The metal sheet that insulates the lower side of the crystal, for it to have better thermal exchange with the cell, will be kept as well as the titanium blades for system insulation; Plus, coating the crystal's upper surface to make it less emissive, and have better temperature gradients on the lower face.
The TEC mechanical characteristics are required to properly evaluate the system dynamic behavior. Besides the quasi-static loading, random excitation is expected and in order to avoid high stresses, larger natural frequency for the TEC element shall be provided.

For space missions, not only we find space restrictions, but all the equipment has to be able to resist the acceleration loads due to spacecraft launching. As long as the TEC remains unharmed, that is, it holds its physical integrity, we can concentrate on the thermal results. Only the later results will indicate if a new TEC is needed and, of course, tested for mechanical load resistances.

Thermal

Previous thermal requirements demanded to achieve two main objectives: the radiative or conductive cooling action from the cold side of the TEC, and the crystal's heating in order to regenerate the microbalance. Having tested and proven that the use of two crystal QCM with conductive link was the best solution, it is imperative for the project the characterization of the TEC (its thermal control) between 130 °C and -50 °C, temperature range in which the active control should be provided.

It is important to remember the basic principles of the thermoelectric cell in order to understand its behavior at much lower temperatures. So, we will briefly describe the different effects that take place inside the cell, in order to have a better picture for the future test and pass on to the experimental phase on the next chapter.

1.2 Cooling System – TEC Application (Thermoelectric Cell)

A thermoelectric cooler (TEC), also known as a Peltier cooler, is a semiconductor-based electronic component that works as a small heat pump. When DC power is applied to a TE module, heat moves through the module from one side to the other proportionally to the applied voltage. Thermoelectric modules are solid state devices well-known to be reliable energy converters that are virtually maintenance-free. They are also noise-less and vibration-free as there are no mechanical moving parts. They are also smaller and lighter than comparable mechanical cooling systems and do not have vibrating elements. Their solid-state construction ensures high reliability, which is an advantage when used in systems that are not easily accessible after installation. TECs used in air-conditioners offer significant advantages over other conventional cooling devices, because they show better performance in active cooling, precise control, and reliability, as well as being environmental friendly. They are widely used to cool electronic devices because of the advantages mentioned above.

1.2.1 Physical Phenomena

Four basic physical phenomena can be associated with the operation of thermoelectric devices: The Seebeck effect, the Peltier effect, the Thomson effect, and the Joule effect. The Seebeck effect is the voltage generated when a temperature change is maintained between the two sides of a TEC. The Peltier effect can be described as the heating or cooling effect obtained when an electrical current is passed through two dissimilar junctions. The Thomson effect is heating or cooling effect in a homogeneous conductor observed when an electrical current is passed in the direction of a temperature gradient. The Joule effect is the heating effect observed in a conductor as an electrical current is passed through the conductor.[4] A typical TEC module consists of two ceramic plates with several p-

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[4] Xu Xu, Steven Van Dessel, Achille Messac – *Study of the Performance of Thermoelectric Modules for use in active building Envelopes* - Mechanical and Aeronautical Eng. Renselaer Polytechnic Institute, 110 English Street, Troy, NY 12180, USA

and n-type semiconductors materials connected electrically in series and thermally in parallel, see in Fig. 1.1.

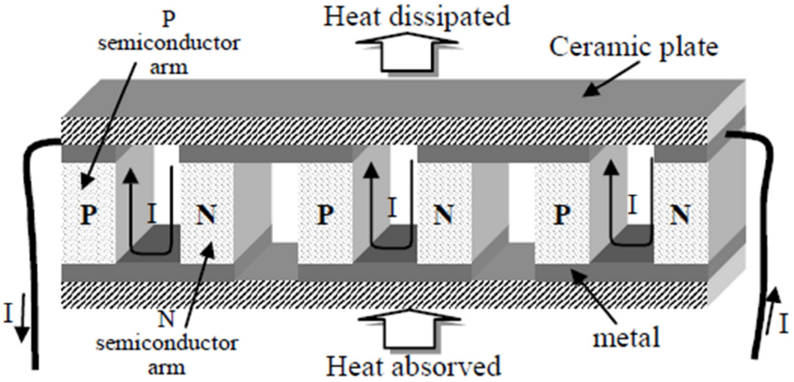

Figure 1-1 TEC module Schematic

If we only consider a semiconductor bar having a different temperature at each end (see Fig 1.2) through which the current is flowing, such that:

T_c is the cold side temperature,
T_h is the hot side temperature,
q_c is the absorbed heat in the cold side,
q_h is the generated heat in the hot side, and
I is the electrical current.

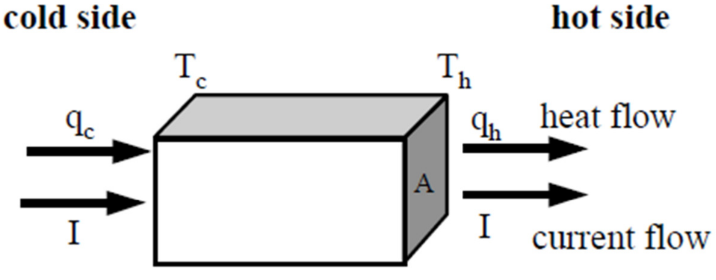

Figure 1-2 Current and Heat Flows

We’ll have, under steady state conditions, the contribution to the energy flow through a unit volume of the phenomena associated with thermoelectric devices described by the following differential equation:

$$TJ\frac{d\alpha}{dx} + \tau J\frac{dT}{dx} - \rho J^2 - \frac{d}{dx}\left(k\frac{dT}{dx}\right) = 0 \tag{1}$$

Where:

T is the absolute temperature (K),
J is the electrical current density (A/cm$_2$),
α is the Seebeck coefficient (V/K),
τ is the Thomson coefficient (V/K),
ρ is the electrical resistivity (Ω cm) and
k is the thermal conductivity of the material.

where k_N, τ_N and ρ_N are averaged properties.
The equation corresponding to heat flow at the junction of two dissimilar conductors, at the cold side, is:

$$q_c = \alpha T_c I + \frac{1}{2}\tau_m I \Delta T - \frac{1}{2}I^2 R_m - K_m \Delta T \tag{2}$$

And, at the hot side:

$$q_h = \alpha T_h I - \frac{1}{2}\tau_m I \Delta T + \frac{1}{2}I^2 R_m - K_m \Delta T \tag{3}$$

Where τ_m,(Thomson coefficient of the metal)
R$_m$ (metal Resistance)
K$_m$ (Thermal Conductivity of the metal)
all of which are average properties of a couple.

The electrical power is equal to the difference between heat flow at the hot side and heat flow at the cold side:

$$P_e = q_h - q_c = \alpha(T_h - T_c)I - \tau_m I \Delta T + I^2 R_m \tag{4}$$

The electrical behavior is only due to Seebeck and Joule effects. Thus, the voltage at the thermoelectric terminal is:

$$V_p = \alpha(T_h - T_c) + IR_m \tag{5}$$

In the next section, the model equations due to the thermoelectric phenomena will be described.

1.2.2 Electro-Thermal Model of a Peltier device

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junction of two different types of materials. A Peltier device can be modeled using a three port system: two thermal and one electrical port as shown in the figure 1.3. The voltage of thermal ports corresponds to the temperature of the cooled surface, T_c, and the temperature of the heated surface, T_h. The current corresponds to the thermal power absorbed from the device being cooled and from heat generated because of Joule effect.

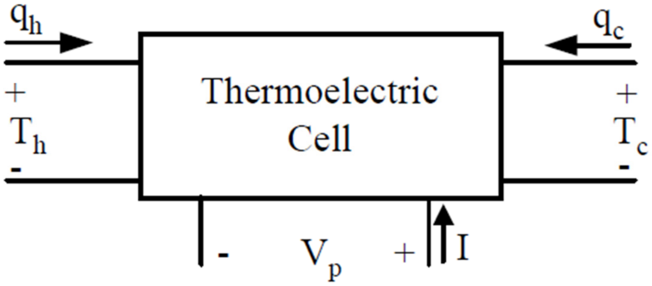

Figure 1-3 Three Port Model for a TEC

The next table lists the analogies between electrical and thermal variables that will be used ahead.

Thermal Variable	Electric Variable
Heat Flow (W)	Current (A)
Temperature (C°)	Voltage (V)
Thermal Conductivity (W/mC°)	Electrical Conductivity (Ω/m)
Thermal Mass (J/K)	Electrical Capacity (F)

Table 1-2 Electrical and Thermal Variables Analogies

According to it, an electrical current source models a heat flow source, and a voltage source models a temperature source. A resistor with value $l\ k_{m\ -1}A_{-1}$ represents a thermal loss, where l (m) is the length of the material and A (m^2) is the section. And, a capacitor with value mc_o is a thermal mass, where m (g) is the mass of the material and c_o (Jg$_{-1}$K$_{-1}$) is the specific heat. Thus, according to the thermal-electrical analogies and the thermal equations, the proposed thermal model results in the circuit shown next.

The proposed model is equivalent to the model presented in the left figure, where we have taken into account the electrical input power (P_e) and the heat flow absorbed at the cold surface.

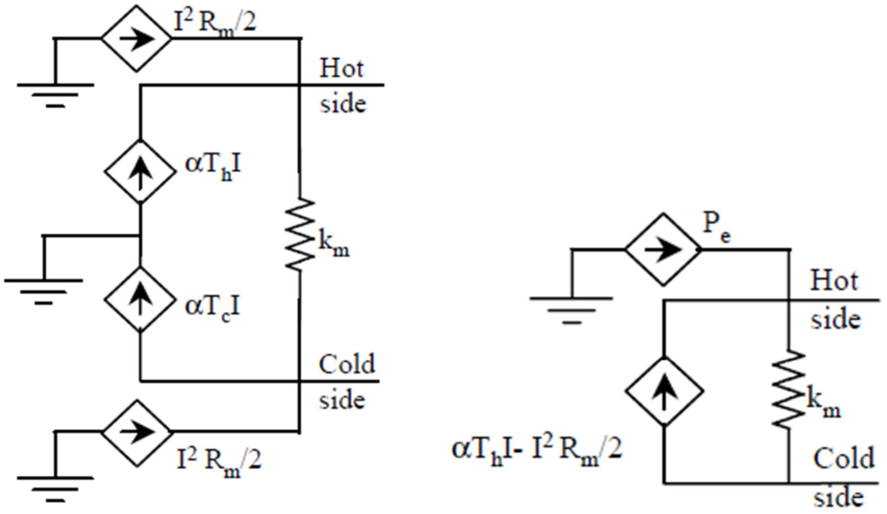

Figure 1-4 a) Proposed Thermal Model. b) Thermal Equivalent Circuit

Now, we can add two capacitors to take into account the thermal mass of every side of the TEC module. Next figure (right side) shows the complete model, C_h is the capacitor for the hot side and C_c is the capacitor for the cold side. Measurements have shown that the capacitance values C_h and C_c are around 2 J/K[5].

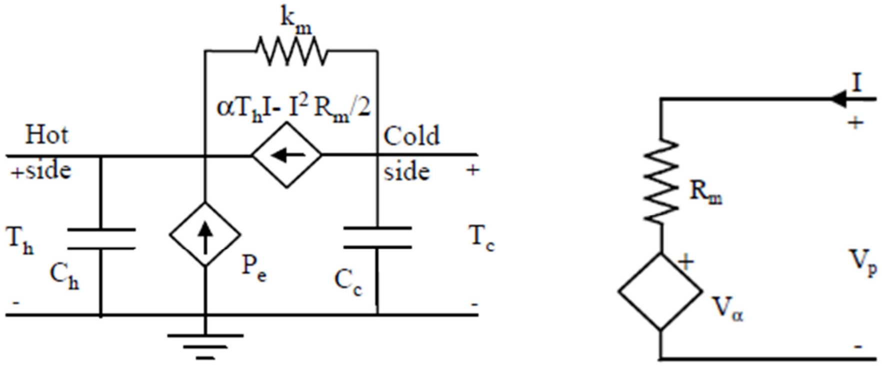

Figure 1-5 a) Modified Thermal Circuit. b) Proposed Electrical model

The thermal circuit consists of two voltage-controlled current sources, a thermal resistance and two thermal capacitors. Current sources model the heat flow between cold surface and hot surface.

The electrical behavior can be modeled with a voltage source depending on temperature difference between hot and cold surfaces, and a resistance for the Joule effect. Figure 1.5 (left) shows the proposed electrical circuit, where *V* is the Seebeck voltage produced by two dissimilar conductors.
As it can be seen, figure 1.6 shows the structure of the equivalent circuit for a TEC element, consisting of a thermal and an electric circuit.

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[5] Marc Hodes – *Thermoelectric Modules: Principles and Research "InterPACK 2011 Tutorial"*

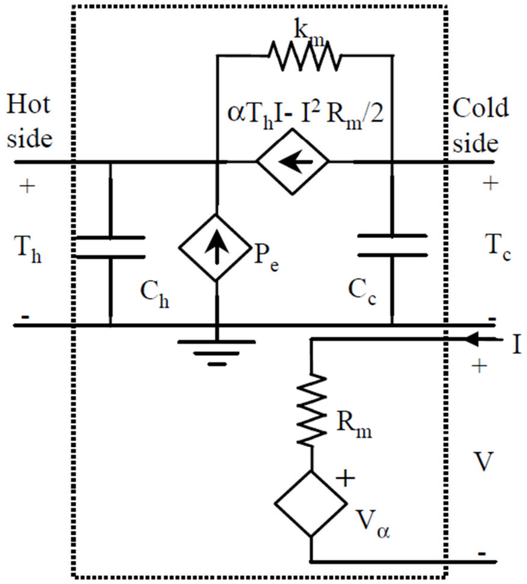

Figure 1-6 Proposed Complete model

The Peltier Coefficient is dependent on temperature and the materials the TEC is made of. Decreasing temperature dramatically changes effectiveness of the elements. As long as heat pumping should overcome heat produced by the flow of current which produces this pumping, going to low temperatures is a challenging task.

1.3 Thesis Objectives

The experimental characterization of the Thermoelectric Cell will be fundamental part of this work, since a reduction of the cooling performance is expected.

CAM project requires at least 30°C of temperature difference when the heat sink reads 50°C below zero and with 70 mW heat load, i.e. 30 °C difference provided by the TEC including heat losses also. Thus, testing is required within expected environment, and indeed, our main objectives will be to test the performances of the TEC putting it through close-to-space working conditions, and control if its cooling capacities are adequate to the project purposes. For this matter, an optimal design of the setup will be pursuit also. In fact, keeping stable cryogenic temperatures will be a challenge, when testing the TEC, as well as ensuring that parasitic heat load on the TEC cold surface is minimized.

2 Chapter

THERMOELECTRIC CELL TESTS

A better understanding of the current TEC performances is necessary in order to choose a new device. Several methods for installing thermoelectric modules have been developed, including: mechanical clamping, epoxy bonding, and direct solder bonding. The individual requirements of the application will determine which method is most appropriate, mechanical clamping is by far the most common. This chapter will cover the tests carried out on the TEC currently used to cool down the QCM.

2.1 TEC Testing Setup Design

In order to reproduce certain thermal ambient and pressure conditions around the tested cell, a metal chamber, able to hold vacuum conditions, will be used. This chamber, equipped with spiral coils on the lower half, can also bring the inside temperature down, letting cold water or even liquid nitrogen flow through them. Also, proper serial ports have been installed to weld the necessary electrical connections for our purposes.

The TEC will be sandwiched between two aluminum plates. The lower (bigger) one will be the bottom part of the cryostat and responsible to hold the TEC and transmit the coolant liquid temperatures when necessary. The upper smaller one (12x12x3mm plate) will be attached to the TEC upper face and will be on charge of transferring the heating power directly to the cell's cold face.

Two sensors will be placed, one on the TEC's bottom face, and the other on the upper face of the aluminum plate on top of the TEC. Each one of these will have a thermocouple glued to them to help us read both faces temperatures.

In order to fix the cell and thermo-resistances together, thermal grease will be used. The upper heater will be shielded with a silver adhesive coating, strongly reflective, that will keep the heating power from flowing into the ambient.

Finally, the whole group will be kept pressed down, onto the bigger aluminum plate, by a metal band screwed to the plate itself.
The test will consist on the Cell's characterization at room and low temperature, this last one using liquid Nitrogen

2.1.1 Setup Concept and Uncertainty Budget

In testing a thermoelectric system, one of the most important requirement is reaching an understanding of the thermal load. This information should be known in order to select the thermoelectric device and heat exchangers for the job. To start one has to arrive at a good, solid estimate of how much thermal load must be removed from the object to achieve the performance objectives.
In our case, expected load is 70mW, coming from thermal design.

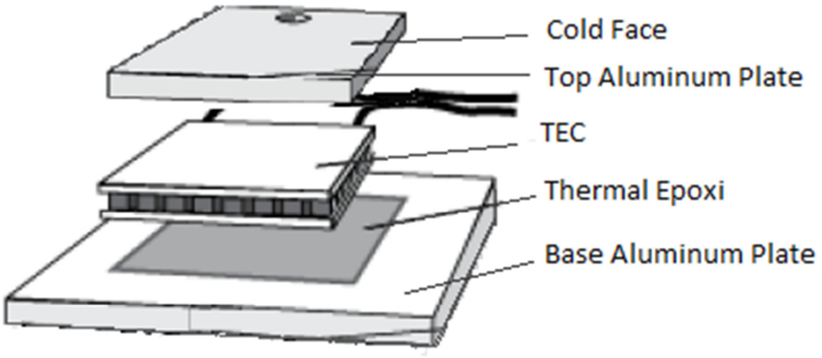

Figure 0-1 TEC Setup

The principal objective of the model's arrangement is to reproduce, as best as possible, the expected environmental conditions outside earth atmosphere.

Having understood the way a thermoelectric cell works, what we will do is bring the cell's hot side temperature down, using the liquid nitrogen cooling power, and keep track of this temperature with the help of a resistance temperature detector placed in the base aluminum plate. In this way, we will be able to monitor the *simulated space temperature* at which the TEC pumps the absorbed heat[6].

The TEC, placed on top of the base aluminum plate, will be tested simulating different environments, being Room and Cold temperatures. With the cold side facing up, and being this the one that interests us the most, we will observe its behavior when applying different current values and reading the heat pumping power when subjected to periodic ON/OFF sequences.

A second, smaller aluminum plate, on top of the cell, will simulate the link between the cell and the quartz crystal; it will hold an RTD sensor on its upper face that will measure the temperature of the connection of the QMC at the cold TEC face.

Being 70mW the energy supplied by the heater on top of the TEC, our objective is to maintain this value from the only source of parasitic power, coming from the ground connections of the wires attached to the heater and the PT100 (2 and 4 respectively). Maximizing the thermal resistance (R) of the wires is key to keep this from happening, and since this is a function of the cross section, length and thermal conductivity of the wire material, a quick analysis between the two bests material candidates, Cooper and Manganina, will be made.
The longer the wire, the higher the resistance and the conductivity, but a larger area also means lower thermal irradiance. Therefore, the length of the wire has to be such that these three parameters find a common minimum value. From the concepts of conductivity and irradiance, we can build the following table:

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[6] *Thermoelectric Handbook* – LAIRD Technologies

Radiative Heat transfer $Qrad = \sigma\varepsilon A(Tcry^4 - Ttec^4)$

Conductive Heat transfer $Qcond = \frac{KAdT}{L}$

In obtaining the surface area, for the first equation, and the section area for the second, we will use the same wire diameters used in previous experiments. That is, 0.2mm for cooper and 0.152mm for Manganin.

The area for the relative heat transfer is calculated using equivalent diameter factors, taken from radiation-between-surfaces diagrams, when several wires are used, all of this of course, multiplied by their length. Temperatures for the TEC and its Cryostat will be -80°C (193.15K) and -25°C (248.15K) respectively.

On the other hand, the area involved in conductive heat transfer is the one transversal to the wire. All other values are constants, as follow

Stefan – Boltzmann constant	σ = 5.6703E-8 [W/(m^2*K^4)]
Emissitivity	ε = 0.1
Cooper Thermal Conductivity	Kcu = 390 W/mK
Manganina Thermal Conductivity	Kman = 23 W/mK

L [mm]	Qrad [mW]	Qcond [mW]	Qerr [mW]	% Error Cu
10	0,6	220,5	221,1	315,9
15	0,9	147,0	147,9	211,3
20	1,2	110,3	111,5	159,2
25	1,5	88,2	89,7	128,2
30	1,8	73,5	75,3	107,6
35	2,1	63,0	65,1	93,0
40	2,4	55,1	57,5	82,2
45	2,7	49,0	51,7	73,9
50	3,0	44,1	47,1	67,3
55	3,3	40,1	43,4	62,0
60	3,6	36,8	40,3	57,6
65	3,9	33,9	37,8	54,0
70	4,2	31,5	35,7	51,0
75	4,5	29,4	33,9	48,4
80	4,8	27,6	32,4	46,2
85	5,1	25,9	31,0	44,3
90	5,4	24,5	29,9	42,7
95	5,7	23,2	28,9	41,3
100	6,0	22,1	28,0	40,1

Table 0-1 Cooper Thermal behavior

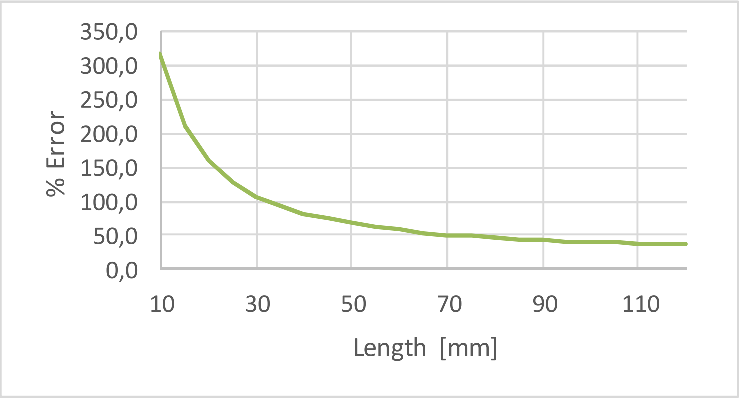

Figure 0-2 Cooper Thermal behavior

Once we have calculated the values of Radiative and Conductive Heat Transfer for several lengths of the wires, they plot two lines that describe the heat load as function of the conductor's length. The downwards line describes how the radiation contribution to the heat error decreases when the wire is longer, and the upwards line shows how conduction error increases proportional to the wire length. These two should cross at a point that represents a point of equilibrium between them, and the minimum longitudinal value we should work with. Moreover, summing up both heat quantities and finding the proportional percentage with the 70 mW value of heat load, we come out with a single line graph that showing our optimal connector length as its minimum value.

L [mm]	Qrad [mW]	Qcond [mW]	Qerr [mW]	% Error Mn
10	0,45	10,0	10,6	15,1
15	0,68	6,7	7,5	10,7
20	0,91	5,0	6,1	8,7
25	1,14	4,0	5,3	7,6
30	1,36	3,3	4,9	7,1
35	1,59	2,9	4,7	6,8
40	1,82	2,5	4,6	6,6
45	2,05	2,2	4,6	6,6
50	2,27	2,0	4,7	6,7
55	2,50	1,8	4,8	6,8
60	2,73	1,7	4,9	7,0
65	2,96	1,5	5,0	7,2
70	3,18	1,4	5,2	7,4
75	3,41	1,3	5,3	7,6
80	3,64	1,3	5,5	7,9
85	3,87	1,2	5,7	8,2
90	4,09	1,1	5,9	8,5
95	4,32	1,1	6,1	8,7
100	4,55	1,0	6,3	9,1

Table 0-2 Manganin Thermal behavior

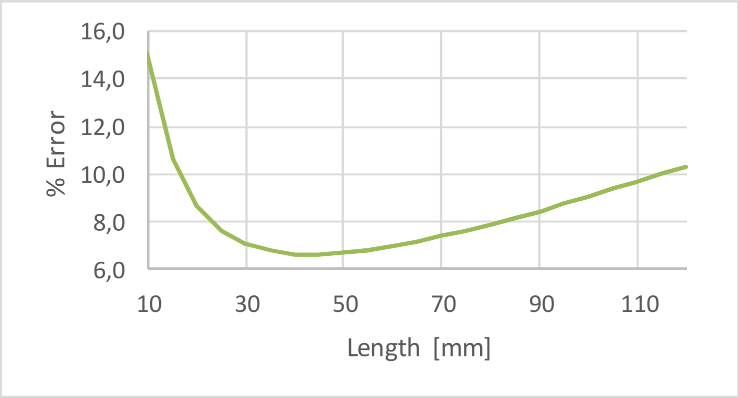

Figure 0-3 Manganin Thermal behavior

Quick glance to the pictures and we can conclude that our best options are 40-45 mm long manganin wires.

All aluminum plates and cryostat were made according to the TEC dimensions, the resistances and thermocouple glued to the cell, the whole device attached to the base and covered with the cryostat inside the vacuum chamber as can be seen on the following pictures, so as to have the final setup ready for testing.

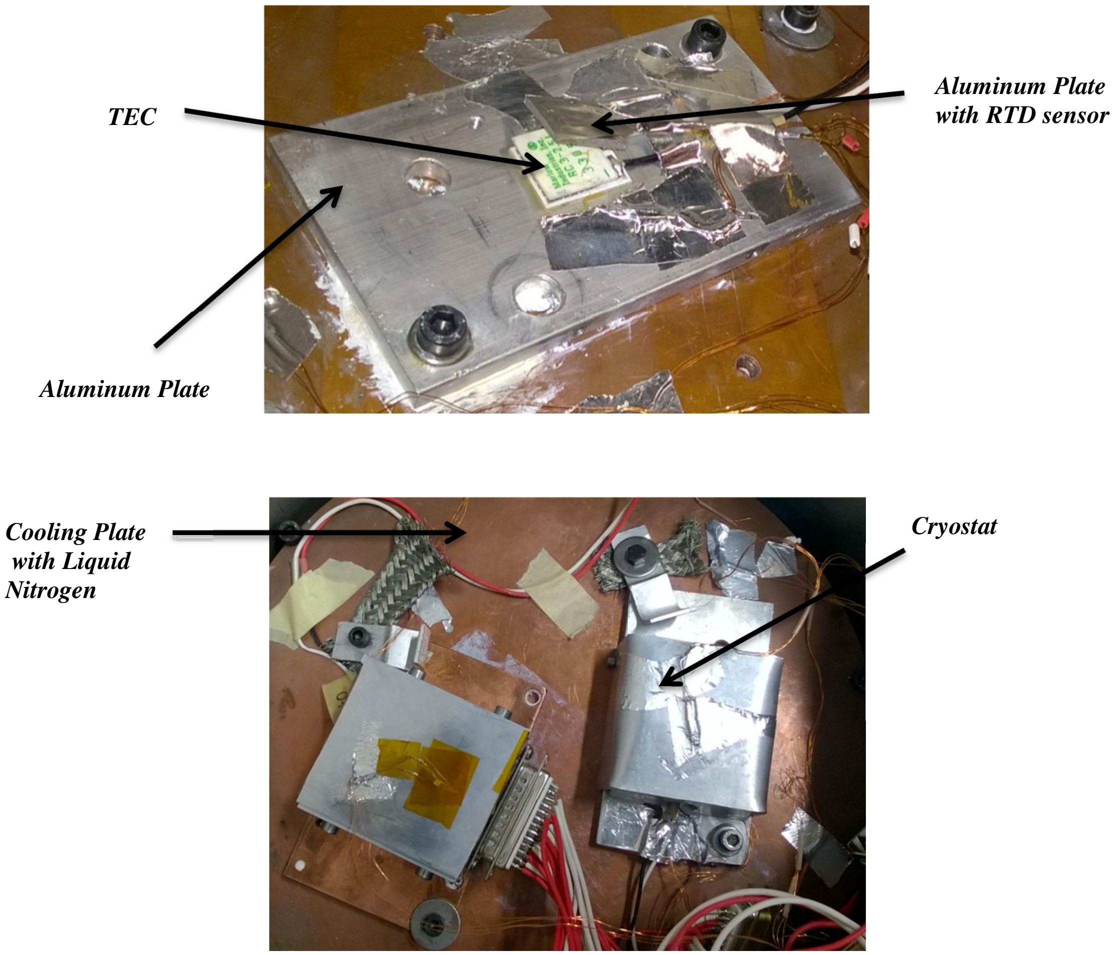

Figure 0-4 TEC setup

As for the necessary equipment to make the environmental changes inside the chamber, supply power, read and collect data, the following picture shows the physical arrangement.

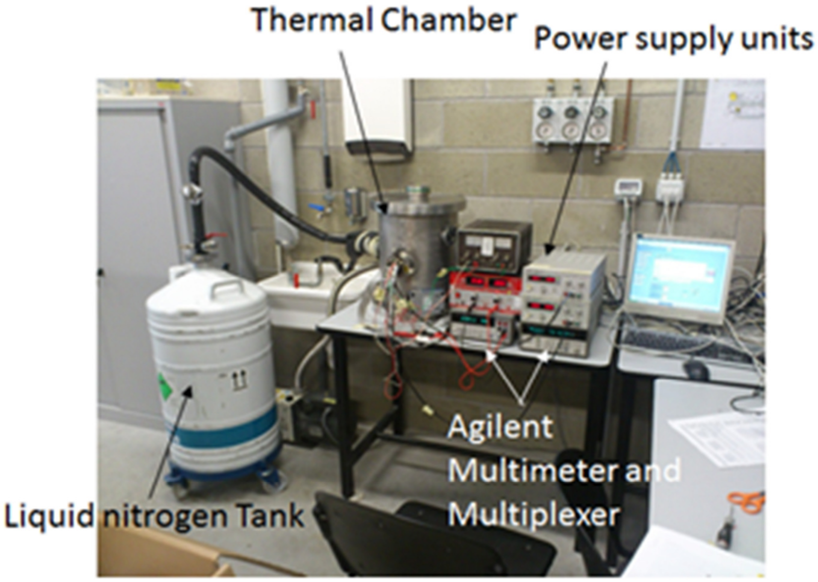

Figure 0-5 Equipment Setup

The measurements we will take can be listed as:

- Temperature 1 Heat Sink (TH1c)
- Temperature 2 Heat Sink (TH2c)
- Temperature Cold Side (Tc)

Since we want to know how much is the temperature difference we can get, either at room temperature or colder environments, and if this suffers any change over repetitive cycles, our test will consist on feeding the TEC with different current values. These are held until it reaches stable temperature values[7].

In doing so, we aim to find out heating up and cooling down times, i.e. how much time does it take for the TEC to reach a stable point in which it creates a desired temperature difference between its faces, and how fast does it return to starting conditions. It is worth to say that, for the sake of reliable equipment re-

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[7] Wang XiaoQun, Zhao ZhenLu, Liao FangPing, Wei DiSheng, Du, ShanYi – *Parameter Determination and Experimental Verification of Thermoelectric Cooling for a Low Temperature Chemical Reactor.*

sults, the thermoelectric cell has to fulfill certain requirements and/or behave inside predefined limits. In fact, the cell shall provide 30°C temperature difference, with -50°C cold side. The later requirement comes from thermal design results.

2.2 TEC Performances

Test on the thermoelectric cell will be done under three different environmental conditions. Room and Cold temperatures.

2.2.1 Room Temperature Testing

The test at room temperature allows us to compare our data with that of the manufacturer's, control the work of the TEC at room temperature in order to have a validation of the setup.

The TEC will be covered with its cryostat surrounded by insulating material, the vacuum chamber cover set on place and the test sequence will carry on as follows:

a) Turn ON the vacuum pump, power supply, multimeter, multiplexer and computer.
b) Set the multiplexer reading acquisition time to 5 seconds.
c) Set the feeding voltage until the multimeter reads our first value of current.
d) Start the data collecting software and connect the power supply.
e) Observe the temperature rising and wait stabilization. Take note of the scan time, let it run for another 20 s and unplug the power.
f) Observe the temperature drop and wait until stabilizes. Reconnect the power supply with the next value and repeat the previous steps.

The next table shows the temperature changes of the cold side of the TEC, when it uses 0.5W, and the difference respect to the average value of the crystal's temperature. Here, TH1 and TH2 are the TEC hot side temperatures and Tc is the old side temperature. We used four values of currents in order to reconstruct TEC performance curve.

I [A]	Scan	TH1 c [°C]	TH2 c [°C]	Tc [°C]	ΔT [°C]
0,80	142	21,28	21,42	-8,71	30,05
1,60	249	24,18	24,34	-26,34	50,60
2,11	360	28,97	29,14	-28,71	57,77
2,40	409	31,19	31,39	-28,39	59,68

Table 0-3 Test with 0.5W Power

From the following figure, we can conclude that the TEC behaves as expected and measured temperature differences match the graphs of the TEC datasheet, where it has been obtained a maximum ΔT of 60°C and 30°C below zero on the cold side of the TEC:

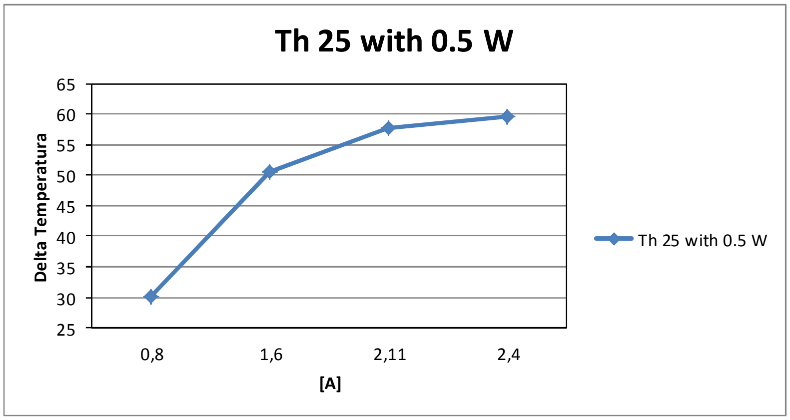

Figure 0-6 TEC Performance under vacuum

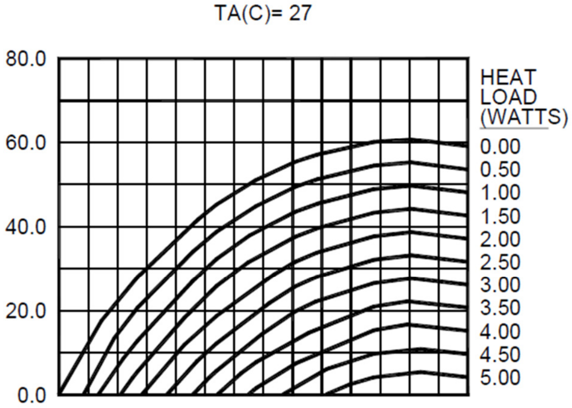

Figure 0-7 Datasheet Performance Curve

2.2.2 Cold Temperature Testing

Cold temperature testing will refer to the model being tested at temperatures of -50°C±10, with the help of the liquid nitrogen. Most cells are tested to work at room or hotter environments and little information about their behavior at low temperatures is available. From previous tests conclusions[2], we can outline our starting considerations.

- Thermal conductivity decreases at low temperatures
- Electric resistance also decreases as temperature does.

All though, not a behavior of the sensor as such, the sensor could not remain attached to the aluminum plate at low temperatures. Therefore, better ways to keep it fixed should be tried.

The procedure of the test follows quite the same steps as the room temperature testing, with the obvious adding of the liquid nitrogen flowing underneath the cooper plate that holds the setup. Therefore, between steps c) and d) we should:

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[2] Julien Cornali, *Thermal Design of a Microbalance for Space Application,*

- Open the manual valve to allow the liquid nitrogen enters the test chamber.
- Control the double QCM temperature until it reaches -50°C, and then close the manual valve.

Be aware of the thermal inertia phenomena, for we will still see a drop on the temperature after closing the valve. Since it becomes difficult to keep a steady value of temperature, we will allow a fluctuation of ±5°C during the test[8].

Thus, once the four tests have been carried out with different heat loads, we shall be able to study the behavior of the TEC as function of different supplied currents and power.

I [A]	Scan	TH1 c [°C]	TH2 c [°C]	Tc [°C]	ΔT [°C]
0,8	1500	-56,21	-56,42	-76,69	20,38
1,6	1582	-56,40	-56,51	-86,62	30,17
2,1	1630	-52,32	-52,41	-86,59	34,23
2,4	1729	-51,00	-51,25	-85,60	34,48

Table 0-4 Test with 0 Power

I [A]	Scan	TH1 c [°C]	TH2 c [°C]	Tc [°C]	ΔT [°C]
2,4	1759	-51,38	-51,61	-84,18	32,68
2,1	1909	-51,76	-51,92	-83,94	32,10
1,6	1982	-52,81	-52,95	-81,96	29,08
0,805	2115	-55,78	-55,93	-74,19	18,34

Table 0-5 Test with 0.07W Power

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[8] L. Yershova, V Volodin, T. Gromov, D. Kondratiev, G. Gromov – *Thermoelectric Cooling for Low Temperature Space Enviroment*.

I [A]	Scan	TH1 c [°C]	TH2 c [°C]	Tc [°C]	ΔT [°C]
2,4	1805	-50,80	-51,04	-80,41	29,49
2,1	1859	-51,92	-52,12	-80,79	28,77
1,6	2028	-53,05	-53,19	-78,71	25,59
0,805	2079	-54,92	-55,09	-70,24	15,24

Table 0-6 Test with 0.201W Power

I [A]	Scan	TH1 c [°C]	TH2 c [°C]	Tc [°C]	ΔT [°C]
0,783	279	23,07	23,40	-7,13	30,37
1,476	355	25,34	26,04	-23,44	49,13
2,108	423	28,37	29,60	-28,96	57,95
2,349	494	30,95	32,46	-28,44	60,14

Table 0-7 Test with 0.5W power

The ΔT[°C] column on each table reads the difference of temperature between the TEC cold side temperature and the average value of the TEC hot side. Following:

$$\Delta T = \left| Tc - \frac{TH1c + TH2c}{2} \right|$$

Figure 2-5 shows the delta temperature on the ordinates and the current applied on the abscissas and gathers the behavior of all four tests. Noticed that the last test, with 0.5W power has been done at room temperature, and not at bellow temperature conditions; we can see a clear distinction of the power curve respect to the others, which does not follow the relatively equal behavior, but spikes to 60°C of delta temperature. It would be something positive, for heat removal purposes, if it would take place at lower temperatures.

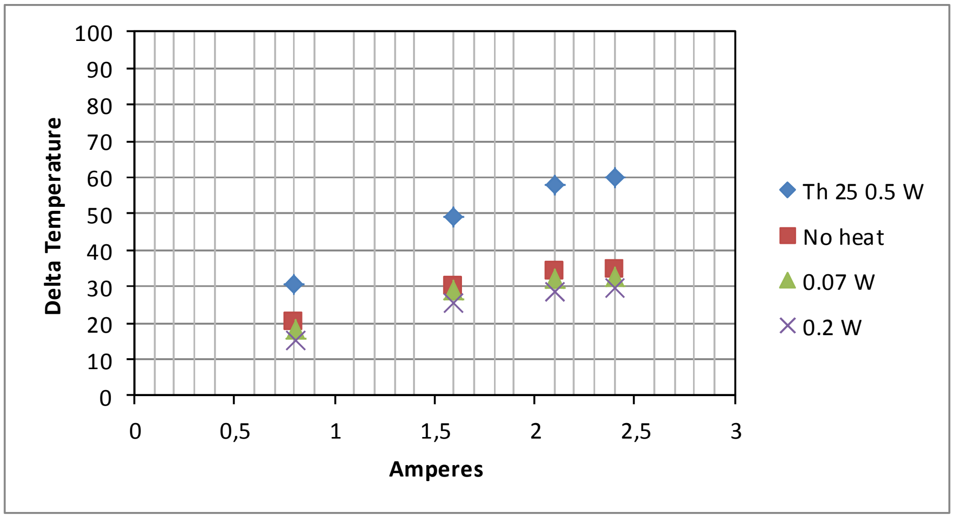


Figure 0-8 TEC Behavior Changing Feeding Current

2.2.3 Discussion

Agreement between measured and expected performances at ambient temperature is satisfactory. The error between measured and theoretical performance is never above 8%.
Testing results evidence that, the performance of the TEC decreases as the temperature drops, been able to reach the required difference in temperature at -50°C, only by very little.

We evidence that having the cold side of the TEC at -50°C, we can only reach a delta temperature of 34°C, which is more than what we need, but does not give us additional heat removal power in the case that environmental conditions get worse. This means that we can ensure this maximum difference of temperature in this case between the TEC and the double QCM, as long as the surrounding temperature does not drop lower that -50°C.

Conclusions

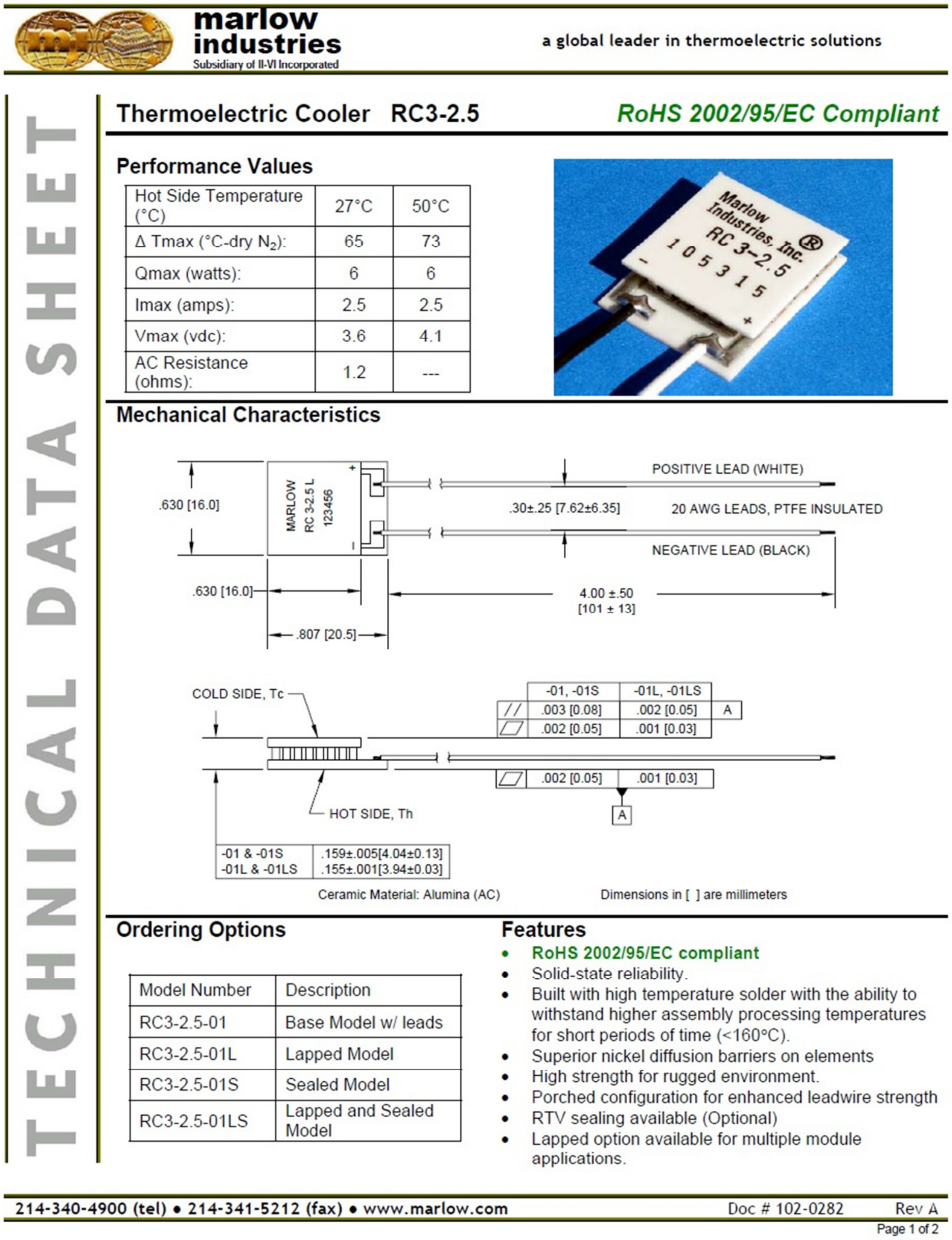
This work has allowed us to assess the feasibility of the thermal control system of a Double Quartz crystal microbalance using a Thermoelectric Cell at low temperature, i.e. -50°C. We were able to reproduce the expected working conditions, so as to replicate the behavior and results of the manufacturer. Taking the later result as validation of the designed setup, we can drive out some final conclusions:

- Although our thermoelectric cell achieves the desired heat removal values, it will struggle to do the same if temperatures drop further. An optimization of the cell is required if better performances would be achieved.
- The TEC performances are near to the one provided by the manufacturer at ambient temperature, validating the designed setup;
- The parasitic heat load due to the working in cryogenic condition has been minimized by proper setup design.

Next steps of this activity will be the testing of the TEC module with the CAM crystals, to measure the TEC performances with the complete instrument and the fulfillment of the project requirements.

ANNEX

A.1.MARLOW INDUSTRIES DATASHEET



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TECHNICAL DATA SHEET

Thermoelectric Cooler RC3-2.5

RoHS 2002/95/EC Compliant

Performance Values

Hot Side Temperature (°C)	27°C	50°C
Δ Tmax (°C-dry N_2):	65	73
Qmax (watts):	6	6
Imax (amps):	2.5	2.5
Vmax (vdc):	3.6	4.1
AC Resistance (ohms):	1.2	---

Mechanical Characteristics

	-01, -01S	-01L, -01LS	
//	.003 [0.08]	.002 [0.05]	A
⏥	.002 [0.05]	.001 [0.03]	

⏥	.002 [0.05]	.001 [0.03]

-01 & -01S	.159±.005[4.04±0.13]
-01L & -01LS	.155±.001[3.94±0.03]

Ceramic Material: Alumina (AC)

Dimensions in [ ] are millimeters

Ordering Options

Model Number	Description
RC3-2.5-01	Base Model w/ leads
RC3-2.5-01L	Lapped Model
RC3-2.5-01S	Sealed Model
RC3-2.5-01LS	Lapped and Sealed Model

Features

- **RoHS 2002/95/EC compliant**
- Solid-state reliability.
- Built with high temperature solder with the ability to withstand higher assembly processing temperatures for short periods of time (<160°C).
- Superior nickel diffusion barriers on elements
- High strength for rugged environment.
- Porched configuration for enhanced leadwire strength
- RTV sealing available (Optional)
- Lapped option available for multiple module applications.

214-340-4900 (tel) • 214-341-5212 (fax) • www.marlow.com Doc # 102-0282 Rev A
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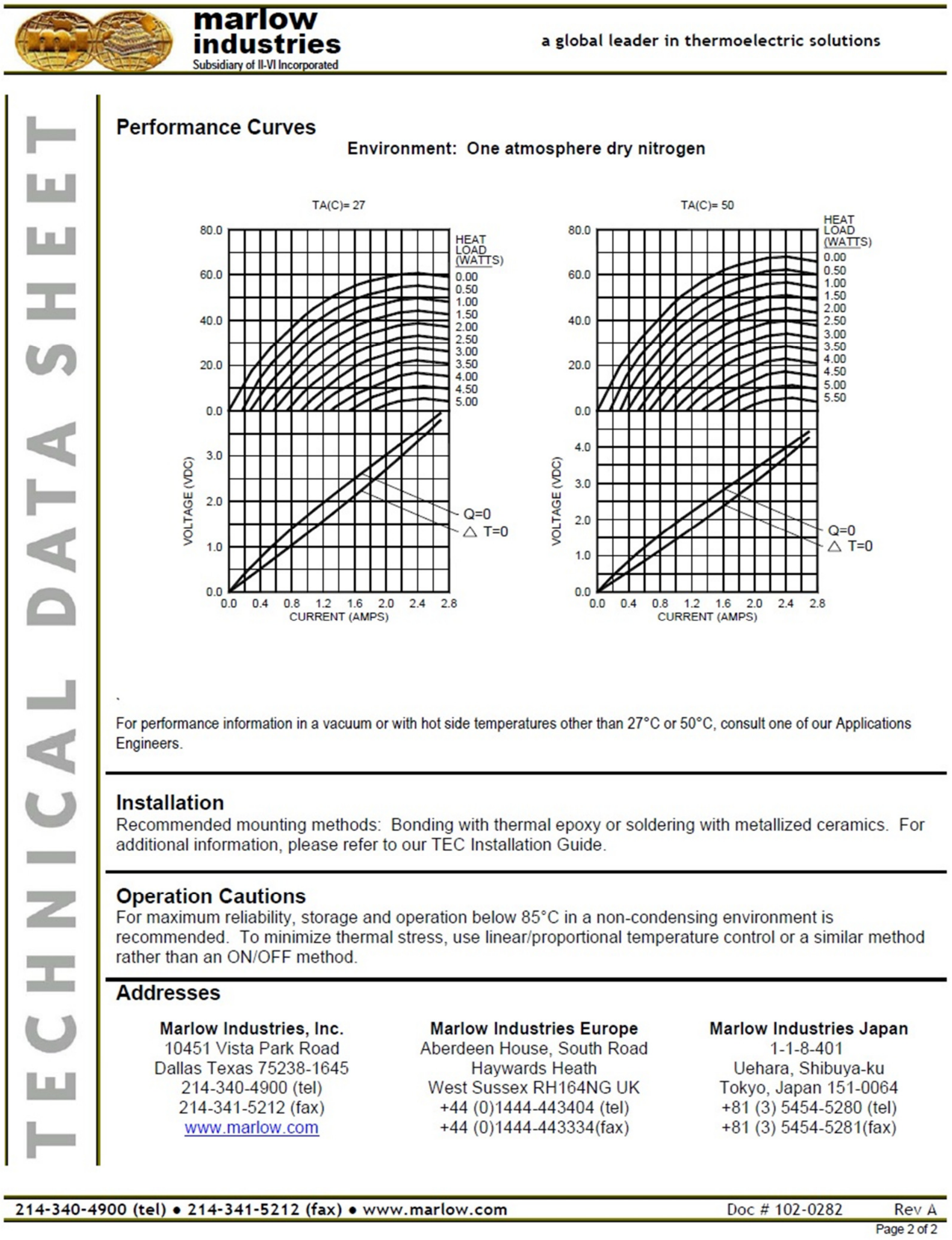

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TECHNICAL DATA SHEET

Performance Curves

Environment: One atmosphere dry nitrogen

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For performance information in a vacuum or with hot side temperatures other than 27°C or 50°C, consult one of our Applications Engineers.

Installation

Recommended mounting methods: Bonding with thermal epoxy or soldering with metallized ceramics. For additional information, please refer to our TEC Installation Guide.

Operation Cautions

For maximum reliability, storage and operation below 85°C in a non-condensing environment is recommended. To minimize thermal stress, use linear/proportional temperature control or a similar method rather than an ON/OFF method.

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