ISSN 2616-5767 Vol.6, Issue 12: 76-82, DOI: 10.25236/AJETS.2023.061212

Extraction of Temperature Dependent Parameters for a Commercial Thermoelectric Cooler

Yang Tian*

School of Mechanical Engineering, Tongji University, Shanghai, China
**Corresponding author: tyangfight@tongji.edu.cn*

Abstract: *This study presents a simple method for extracting the performance parameters of a commercial thermoelectric cooler (TEC). Based on MATLAB, the characteristic curves of thermoelectric cooler manufactures are fitted by least square method, and the functional relationship between current and cooling capacity under different temperature differences is obtained. By the obtaining data of current, temperature, and cooling capacity, using the multivariate linear equation solves Seebeck coefficient α, electric resistance R and the thermal conductivity K. Compared with the experimental results, the extracted material parameters have the advantages of simplicity, convenience and high precision. It can facilitate engineering personnel to predict and select thermoelectric cooler (TEC).*

Keywords: *Thermoelectric cooler; Temperature-Dependent Parameters; Multiple linear regression method; Mathematical modelling*

1. Introduction

Thermoelectric refrigeration technology is a method of refrigeration based on the Peltier effect, which has many advantages: no moving parts, almost no noise, no refrigerant required, long life, fast temperature regulation and high accuracy. Usually, TEC manufacturers only provide partial parameters and corresponding performance curves for reference. However, these performance curves are often obtained where the temperature of hot side is at 27℃ or 50℃, which does not meet the actual working conditions. Therefore, in the design and development of refrigeration equipment, it is crucial to establish an effective method to determine and optimize the cooling capacity in the equipment. Palacios et al. proposed a simple analysis method to extract the internal parameters of semiconductor refrigeration components according to the performance curves provided by semiconductor refrigeration manufacturers, making it possible to predict semiconductor refrigeration performance under specified conditions[1]. Luo started from the parameter tables provided by TEC manufacturers (ΔTmax, Imax, Vmax, Qc,max) and found a simple way to calculate the physical characteristics parameters of thermoelectric module[2]. Huang et al. designed and built a fully automatic test system to test the actual performance of thermoelectric cooler, and derived the empirical formula of the thermoelectric module based on this[3]. Ciylan and Yilmaz designed a single chip computer test system to obtain the thermal end temperature, operating current, operating voltage and electromotive force of semiconductor refrigeration components or to solve the performance parameters of thermoelectric modules[4]. Rong-Yuan Jou used three estimation methods to obtain the internal parameters of the thermoelectric module, and averaged the results obtained by the three methods to obtain the numerical solution of the thermoelectric module[5]. S Nie et al. Based on the finite element method of calculating TEC's performance, non-linear least squares method is used for extracting temperature-dependent material parameters including the seebeck coefficient, electrical resistivity and thermal conductivity (α, ρ, κ)[6].

This paper proposes a method that provides the steps needed to quickly obtain TEC performance parameters. The purpose of this paper is to develop a calculation method, which can help engineers to determine the internal performance parameters of thermoelectric cooler quickly and accurately, and select suitable thermoelectric modules.

2. Modeling Approaches for Thermoelectric Cooler

Because Thomson effect is a second-order effect based on Peltier effect in thermoelectric refrigeration process, this paper does not consider Thomson effect. Based upon the principle of energy conservation, the cooling capacity formula of TEC cold side is as follows,

ISSN 2616-5767 Vol.6, Issue 12: 76-82, DOI: 10.25236/AJETS.2023.061212

$$Q_c = \alpha I T_c - \frac{1}{2} I^2 R - K\Delta T \tag{1}$$

where α, R and K are the seebeck coefficient(V/K), electrical resistance(Ω) and thermal conductance(W/K) of the module, respectively; $\Delta T = T_h - T_c$, T_h and T_c are the temperature at the hold and cold side of thermoelectric module, respectively.

2.1. Mathematical Modeling Formulation

It is assumed that all variables linear functions of temperature. In this case, the average temperature of the TEC (T_m) can be expressed as the average temperature of the cold and hot ends of the TEC. Then the TEC internal parameter can be expressed in the following way:

$$\alpha = a_1 T_m + a_2 \tag{2}$$

$$R = a_3 T_m + a_4 \tag{3}$$

$$K = a_5 T_m + a_6 \tag{4}$$

Where a_1, a_2, a_3, a_4, a_5 and a_6 are constants.

T_c can be expressed by T_m , the equation becomes,

$$T_c = T_m - \frac{\Delta T}{2} \tag{5}$$

Using (2), (3), (4), and (5), Q_c can be expressed as follows,

$$Q_c = IT_m\left(T_m - \frac{\Delta T}{2}\right)a_1 + I\Delta T\left(T_m - \frac{\Delta T}{2}\right)a_2 + \left(-\frac{1}{2}I^2 T_m\right)a_3 + \left(-\frac{1}{2}I^2\Delta T\right)a_4 + \left(-T_m\Delta T\right)a_5 + \left(-\Delta T^2\right)a_6 \tag{6}$$

If the coefficients before a_1, a_2, a_3, a_4, a_5 and a_6 are expressed by x_1, x_2, x_3, x_4, x_5 and x_6 , then equation (6) becomes,

$$a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6 = Q_c \tag{7}$$

2.2. Thermoelectric Module Fitting

In this paper, the thermoelectric cooler is from Ferrotec, Figure 1 shows the performance curve. The data sheet parameters of TEC are tabulated in Table 1.

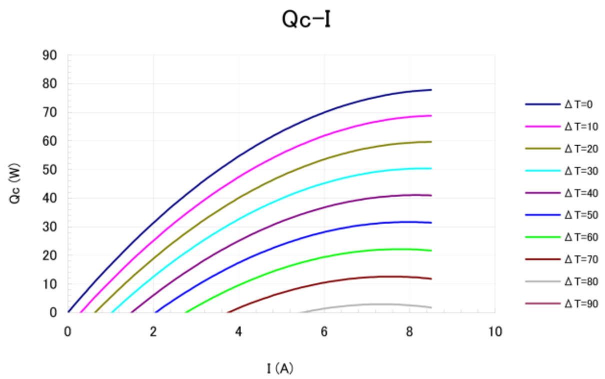

Figure 1: The performance curve of thermoelectric cooler.

Table 1: The data sheet parameters of TEC

Type	Current Imax(A)	Voltage Umax(V)	Cooling capacity Qmax(W)	Temperature difference ΔTmax(℃)	Hot side temperature Th(℃)
72003/127/085B	8.5	18.1	80	78	50

ISSN 2616-5767 Vol.6, Issue 12: 76-82, DOI: 10.25236/AJETS.2023.061212

The performance curve is read by function imread () of MATLAB, and the coordinates of several points on the performance curve are extracted by function ginput (). It can be seen from equation (1) that the cooling capacity (Q_c) is a quadratic function of current (I), so the coordinates data are fitted twice through the least square method, and Figure 2 is obtained.

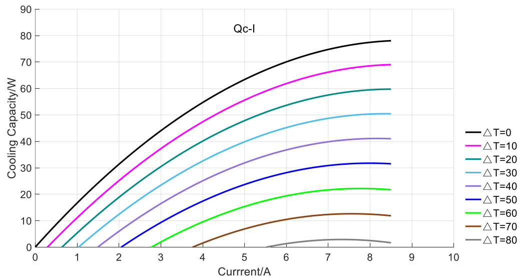

Figure 2: The simulation curve of thermoelectric cooler.

Take an average of 100 points from 0 to 8.5 for the nine curves, and remove the case where Qc is less than zero. Then 691 sets of data about the current I and cooling capacity of TEC Qc at different average temperatures can be obtained.

Plugging these data into equation (7) to get the matrix expression which is given as,

$$\begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{4} & x_{15} & x_{16} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} & x_{26} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} & x_{36} \\ x_{41} & x_{42} & x_{43} & x_{44} & x_{45} & x_{46} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{691,1} & x_{691,2} & x_{691,3} & x_{691,4} & x_{691,5} & x_{691,6} \end{bmatrix} * \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \end{bmatrix} = \begin{bmatrix} Q_{c1} \\ Q_{c2} \\ Q_{c3} \\ Q_{c4} \\ \vdots \\ a_6 \end{bmatrix} \tag{8}$$

Using the method of multiple linear regression, the coefficients of each variable can be calculated, the results show in Table 2.

Table 2: Coefficient of each variable.

intercept	0.10850362
a1	4.454679E-5
a2	0.03997626
a3	0.00572244
a4	0.12481340
a5	-0.00157995
a6	0.99673398

Therefore, the multiple linear regression model finally established is as follows:

$$\begin{aligned} Q_c = {} & 0.10850362 + (4.454679e-5)x_1 + 0.03997626x_2 + 0.00572244x_3 + 0.12481340x_4 \\ & -0.00157995x_5 + 0.99673398x_6 \end{aligned} \tag{9}$$

So seebeck coefficient α, electric resistance R and thermal conductivity K can be expressed as follows:

$$\alpha = (4.454679e-5)T_m + 0.03997626 \tag{10}$$

$$R = 0.00572244T_m + 0.12481340 \tag{11}$$

$$K = -0.00157995T_m + 0.99673398 \tag{12}$$

Using (10), (11), (12), Q_c can be expressed as follows:

$$\begin{aligned} Q_c = {} & 0.10850362 + (4.454679e-5)\left(T_m - \frac{\Delta T}{2}\right)IT_m + 0.03997626\left(T_m - \frac{\Delta T}{2}\right)I\Delta T \\ & -0.00286122I^2T_m - 0.0624067 * I^2\Delta T + 0.00157995T_m - 0.99673398\Delta T \end{aligned} \tag{13}$$

2.3. Test of Model

Statistical test is determined by statistical theory, and the purpose is to test the statistical properties of

ISSN 2616-5767 Vol.6, Issue 12: 76-82, DOI: 10.25236/AJETS.2023.061212

the model. Using mathematical statistics methods tests the equation for checking the reliability of the estimates of model parameters. It mainly includes goodness of fit test, equation significance test and so on.

2.3.1. Goodness of Fit Test

In order to check the degree of fitting between the multiple linear regression equation and the actual cooling capacity of TEC cold side, the goodness of fit is adopted to illustrate. The goodness of fit test method is to construct an index R^2 that can represent the degree of fit.

The statistic R^2 is defined as:

$$R^2 = \frac{SSR}{SST} = \frac{\sum\left(y_i - \bar{y}\right)^2}{\sum\left(y_i - \bar{y}\right)^2} \tag{14}$$

Where SSR is the sum of squares, is to describe how well the curve fits the data. SST is the sum of squared differences between individual data points and the mean of the response variable. This statistic indicates the percentage of the variance in the dependent variable that the independent variables explain collectively.

2.3.2. F Test

F test is a statistical test which is a method to check two samples are equal or not by using a hypothesis. That is, the F statistic follows the F distribution with (m, n-m-1) as the degree of freedom. Where n is the number of groups of selected data and m is the degree of freedom of the regression equation. By querying the statistical table of F distribution, the critical value of F test can be obtained under the condition of specific significance. When the value of the statistic F is greater than the critical value, it can be considered that in general, the independent variable has a significant linear relationship with the cooling capacity at the cold end.

2.3.3. Test Result

By using MATLAB multivariate regression analysis, the statistical results are shown in Table 3,

Table 3: Test of variable.

Test variable	R^2	F	P value
Result	0.99999129	13081644.97	0

From the analysis results of 691 sets of data in Table 3, it can be seen, when the degree of freedom is 6 and the significance is 0.05, the R^2 is > 95%, so it can be considered that the optimization degree of fitting of the multivariate linear equation is very good and reasonable. By searching the critical value table of F test, under the condition of 5% significance, F (6,684) =2.112, F>>F (6,684), and P value is less than 0.0001, so it can be considered that the independent variable as a whole in the equation has a significant impact on the dependent variable.

From a logical point of view, the six variables in the regression model well reflect the relationship between Seebeck coefficient α, electric resistance R and thermal conductivity K and temperature T_m. And provide a powerful reference for the performance analysis of TEC modules.

3. Experimental comparison verification

3.1. Experimental principle

The schematic diagram of the experimental test system designed in this paper is shown in Figure 3. The system consists of three parts: the main part, the power supply part and the data acquisition part. The basic principle of the system is as follows. the heating power of the ceramic heating sheet is adjusted through the DC voltage regulator power. Both ends of the TEC are in close contact with PTC heating element and heat exchanger. Thermal grease is used on the contact surface to reduce thermal resistance. The heat at the hot side of the TEC is taken away by the heat exchanger. Four thermocouples are respectively arranged on the contact surface between the TEC hot side and the heat exchanger, and the contact surface between the TEC cold side and PTC heating element. One thermocouple is provided for inlet and outlet of the liquid cold plate, respectively. The temperature information is obtained through the data acquisition, and the data is transmitted to the computer through the U disk. The liquid flowing

ISSN 2616-5767 Vol.6, Issue 12: 76-82, DOI: 10.25236/AJETS.2023.061212

through the heat exchanger is cooled by a constant temperature refrigeration equipment, so that the temperature of the hot side of the TEC is stable at 50℃. The volume flow rate of the coolant flowing through the liquid cold plate is measured by the flowmeter.

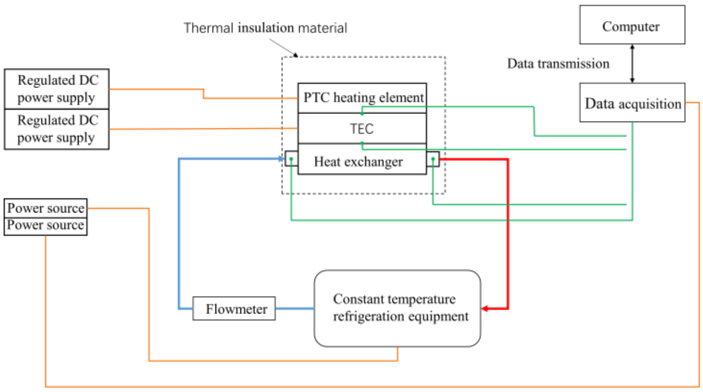

Figure 3: Experimental schematic diagram.

Thermotube is used to output a constant temperature cooling liquid, and its performance parameters are in Table 4,

Table 4: Thermocube specifications.

Operating Range	+5 to 50 °C standard range (down to -5 °C with low temp option) (up to 65 °C with high temp option)
Ambient Temperature	10 °C to 40 °C non-condensing
Repeatability	± 0.05 °C (even near ambient)
Cooling Capacity	500 Watts @ 20°C (20°C ambient) depending on model and configuration

The performance parameters of data acuisition are in Table 5,

Table 5: The parameters of data acquisition.

Type	Sampling precision
Fluke 2638A	0.1℃

3.2. Experimental test data

The experiment is conducted at room temperature of 24℃. Under different cooling capacity, the temperature of the cold side and the hot side of Peltier are recorded by the data acquisition. The experimental testing system is shown in Figure 4.

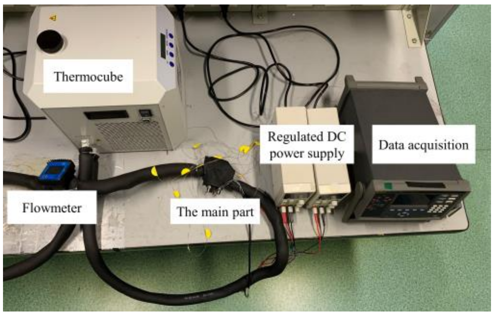

Figure 4: Experimental schematic diagram.

And The current flowing through the thermoelectric module is displayed in the DC voltage regulator power. The relationship between Qc and I is shown in Figure 5.

ISSN 2616-5767 Vol.6, Issue 12: 76-82, DOI: 10.25236/AJETS.2023.061212

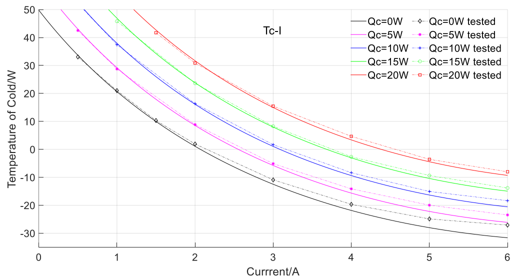

Figure 5: Comparison of experimental data with fitted curves

3.2. Experimental analysis

Table 6: The relative error of fitting current value and experimental current value.

Cooling Capacity (W)	Average relative error (%)	Maximum relative error (%)	Minimum relative error (%)
0	0.670228558	1.873350137	0.123686806
5	0.450284801	1.07098244	0.107207009
10	0.346458276	0.863942942	0.077157933
15	0.248721932	0.438967825	0.063571421
20	0.336098859	0.488094778	0.169407463

The cold end temperature and current value of TEC in stable state under different cooling power were tested experimentally. Based on Kelvin temperature, Table 6 shows the mean relative error, maximum relative error and minimum relative error of fitting current value and experimental current value. From the analysis of the results, the fitting curve is in good agreement with the experimental results. The maximum error between the experimental value and the simulated value of the cold end temperature is less than 2%, the maximum is 1.87%, and the minimum is 0.06%.

Error analysis: The main source of error in the fitting value is the simplification of the boundary conditions, such as assuming that the system is completely adiabatic, ignoring the heat transfer in the other two directions and simplifying the model to one-dimensional heat transfer, ignoring the contact thermal resistance of each contact surface. Due to the existence of contact thermal resistance, the thermocouple at both ends of TEC has deviation from the real temperature. The experimental error mainly comes from the system itself error and human error, the system error includes the data acquisition instrument recording error, the voltage regulator power supply error and so on. Human error includes thermocouple arrangement error, reading error and so on. But in general, through the experimental verification, the simulation model can accurately simulate the cooling capacity of semiconductor refrigeration components to a certain extent.

4. Conclusion

The fitting results show that Seebeck coefficient and electric resistance increase with the increase of the average temperature of TEC, and the relationship is linear; The thermal conductivity decreases with the increase of the average temperature of TEC, and the relationship is linear.

In this paper, the method obtaining TEC performance parameters has been verified by experiments, and the maximum relative error is only 6%, so it can be considered that the Seebeck coefficient, resistance and thermal conductivity obtained by this method are accurate. The method is simple and easy to implement, and no other test device is required. It can provide reference for the selection and application of TEC.

References

[1] Palacios, R. , Arenas, A. , R.R. Pecharromán, & Pagola, F. L. . (2009). Analytical procedure to obtain internal parameters from performance curves of commercial thermoelectric modules. Applied Thermal Engineering, 29(17-18), 3501-3505.
[2] Luo, Z. . (2008). A simple method to estimate the physical characteristics of a thermoelectric cooler from vendor datasheets. Electronics Cooling.

ISSN 2616-5767 Vol.6, Issue 12: 76-82, DOI: 10.25236/AJETS.2023.061212

[3] Huang, B. J. , Chin, C. J. , & Duang, C. L. . (2000). A design method of thermoelectric cooler. International Journal of Refrigeration, 23(3), 208-218.
[4] Bünyamin Ciylan, &YıLmaz, S. . (2007). Design of a thermoelectric module test system using a novel test method. International Journal of Thermal Sciences, 46(7), 717-725.
[5] Jou, R. Y. . (2012). Numerical modeling and design of thermoelectric cooling systems. Applied Mechanics and Materials, 110-116, 2639-2646.
[6] Nie, S. , Wang, M. , Gao, X. , & Liao, J. . (2019). Extraction of temperature-dependent thermoelectric material parameters of a thermoelectric cooler by the non-linear least squares method. Energies, 12.