PERFORMANCE CHARACTERISTIC OF THERMOELECTRIC MODULE

NAZRI BIN MD DAUD

UNIVERSITI TEKNOLOGI MALAYSIA

PERFORMANCE CHARACTERISTIC OF THERMOELECTRIC MODULE

NAZRI BIN MD DAUD

A report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

NOV 2007

ACKNOWLEDGEMENT

Firstly, I would like to express my appreciation to Dr. Mazlan Bin Abdul Wahid as my supervisor for giving a lot of guidance, advice and support. Thank you also to Mr. Hanafi, Mr. Syukri, Mr. Hafiz and Mr. Faizal for your assistance in providing some apparatus for experimental works

To my fellow postgraduate students thank you for your motivation and advices. Lastly special thanks to my beloved wife and daughters in giving such as tremendous encouragement and efforts.

ABSTRACT

The purpose of this study is to determine the physical properties and performance curves of the thermoelectric module. In order to do that a test rig has been fabricated and 2 thermoelectric modules are tested which are TEC1-12705 and CP1.4-71-06L. The voltage generated by the thermoelectric module and the temperature difference are measured and by using some equations, physical properties such as Seebeck coefficient α, Electrical resistance R and Thermal conductivity K_t are obtained. These experiments data are then compared with the manufacturer data. Performance curves are determined by testing the thermoelectric module with 3 different heat sinks which are water cooling jacket, cooling fan with fin and fin itself as a heat sink. Then by using some calculations, the values of P, Q_H and COP are determined. Optimizations have been done to improve the performance of thermoelectric module by studying the effect of different water flow rate in water cooling jacket, different power supply of cooling fan and the different number of fin and ratio between the fin area contacts to the thermoelectric module surface.

ABSTRAK

Tujuan kajian ini ialah untuk mencari sifat fizikal dan lengkung prestasi bagi modul termoelektrik. Untuk itu satu kelengkapan ujian telah difabrikasi dan 2 buah modul termoelektrik iaitu TEC1-12705 dan CP1.4-71-06L telah diuji. Voltan yang dihasilkan oleh modul termoelektrik dan perbezaan suhu akan diukur dan dengan menggunakan beberapa persamaan, pekali Seebeck α, Rintangan elektrik R dan Konduktiviti terma $K_{t,}$ telah diperolehi. Semua data eksperimen akan dibandingkan dengan data daripada pihak pembuatan. Lengkung prestasi telah ditentukan dengan melakukan ujian ke atas modul termoelektrik pada 3 pembuang haba yang berbeza iaitu jaket air penyejuk, kipas penyejuk bersama sirip penyejuk dan pembuang haba sirip penyejuk sahaja. Melalui pengiraan, nilai P, Q_H dan COP ditentukan. Prestasi modul termoelektrik boleh diperbaiki dengan melakukan kajian terhadap kesan aliran air dalam jaket air penyejuk, kesan perbezaan kuasa yang dibekalkan ke atas kipas penyejuk dan bilangan sirip penyejuk dan nisbah luas sentuhan antara permukaan sirip penyejuk dengan permukaan modul termoelektrik.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

COP	-	Coefficient of performance
I	-	current through the thermoelectric module (A)
P	-	electric power supplied to the thermoelectric module (W)
R	-	total electrical resistance of thermoelectric module (Ω)
V	-	voltage to the thermoelectric module (V)
Z	-	figure of merit of thermoelectric module ($°C^{-1}$)
ΔT	-	temperature difference (°C)
$\frac{dE_{AB}}{dT}$	-	relative Seebeck coefficient of thermo element A and B
α	-	Seebeck coefficient of the thermoelectric module ($V°C^{-1}$)
π	-	Peltier coefficient (V)
K_t	-	total thermal conductivity of thermoelectric module ($W°C^{-1}$)
Q_L	-	cooling capacity (W)
Q_H	-	heating capacity (W)
T_H	-	hot-end temperature of the thermoelectric module (°C)
T_L	-	cold-end temperature of the thermoelectric module (°C)
ρ	-	electrical resistivity (Ω-m)
A_p	-	cross section area of p type (m^2)
A_n	-	cross section area of n type (m^2)
E_{AB}	-	emf along conductor thermo element AB
T_0	-	temperature reference (°C)
T_1	-	temperature at point 1 (°C)
T_2	-	temperature at point 2 (°C)
T_3	-	temperature at point 3 (°C)
α_A	-	Seebeck coefficient at thermo element A ($V°C^{-1}$)

α_B - Seebeck coefficient at thermo element B ($V°C^{-1}$)

α_C - Seebeck coefficient at thermo element C ($V°C^{-1}$)

α_p - Seebeck coefficient of p type ($V°C^{-1}$)

α_n - Seebeck coefficient of n type ($V°C^{-1}$)

ρ_P - electrical resistivity of p type (Ω-m)

ρ_n - electrical resistivity of n type (Ω-m)

λ_n - thermal conductivity of n type ($W°C^{-1}$)

λ_p - thermal conductivity of p type ($W°C^{-1}$)

CHAPTER 1

INTRODUCTION

1.1 Background

Basically thermoelectric module is a simple and unique device that converts electrical energy into thermal energy or reverse. It has been used in various applications such as to cool infrared detectors and to stabilize the temperature of solid-state lasers. Furthermore thermoelectric is also one of the famous field in the university courses and many researchers have been studied about it.

Yaakov [1] studied the Seebeck and Peltier effects in simple experiment with thermoelectric module and data acquisition system. The experiment has a simple method in order to determine the Seebeck coefficient, Peltier coefficient, efficiency of thermoelectric generator and maximum temperature difference provided by Peltier cooler.

Xu Xu et al [2] studied the performance of thermoelectric modules in active building envelopes (ABE). Thermoelectric modules are tested as single thermoelectric unit and in an assembly of eight thermoelectric units. For single unit tests, two types of commercial thermoelectric modules are used which are CP1.4-127-045L and PT4-12-40. Then each type is tested separately in a cooling and heating mode at 3, 5 and 7V. The changes in current and temperature are measured over a period of 2 until 12 hours.

The thermal performance of thermoelectric module depends on physical properties such as the Seebeck coefficient α, the electric resistance R and the thermal conductivity, K_{t}. B.J. Huang et al [3] reported that the manufacturer of thermoelectric module usually does not provide the correct physical properties of thermoelectric module to their customer. An automatic test apparatus has been designed to find the correct physical properties. From that experiment data and by using several equations, then the performance curves of thermoelectric module are obtained.

Y.J.Dai et al [4] studied on the thermoelectric refrigerator that driven by a solar cells. The experiment is conducted by making a prototype which consist a solar cell driven, thermoelectric refrigerator, controller, storage battery and rectifier. In the end it focused on testing the performance of the daytime used solar driven thermoelectric refrigerator without the need of battery.

S.Maneewan et al [5] reported about the investigation of the thermoelectric roof solar collector (TE-RSC) for power generation using solar energy. Ten thermoelectric cooling modules (model: TEC1-12708) are used in that experiment.

A optimization of heat and cold sink extenders has been studied by Paul G. Lau et al [6] in thermoelectric cooling assemblies. The thermoelectric module is tested by using heat sink extender and cold sink extender.

Instead of experimental investigations, several numerical studies also have been conducted by other researchers such as L.N Vikhor et al [7], A Chakraborty et al [8] and Lingen Chen et al [9].

L.N Vikhor et al [7] used the methods of optimal control theory to determine the optimal parameter values for thermoelectric coolers BiTe-based with single, double and three-segmented legs.

Meanwhile, A Chakraborty et al [8] studied the temperature-entropy analysis starting from the principle of thermodynamics of thermoelectricity, differential governing equations that describing the entropy and energy flows in the thermoelectric element.

The effects of heat transfer on the performance of thermoelectric generators are analyzed by Lingen Chen et al [9]. The paper reported that the heat transfer irreversibility does affect the performance of thermoelectric generator.

In U.K and Lebanon, R.Y. Nuwayhid et al [10] designed a low cost stove-top thermoelectric generator with unreliable electric supply to be used especially during the winter. The current generator that using peltier module has been re-designed in order to produce the maximum power.

K.A. Moores, Y.K. Joshi and G. Miller [11] examined the performance of thermoelectric coolers for used in electronic system and applications in high temperature conditions. A commercially available thermoelectric cooling has been used and the experiment it shows that the differential temperature decline slowly and steadily due to test durations. The type is similar for module voltage as well.

Gao Min and D.M. Rowe [12] conducted the experiment to evaluate the prototype thermoelectric refrigerators in terms of heat-pumping capacity, cooling-down rate and coefficient of performance. The results indicate that the COP increases if the module contact resistance, thermal interfaces and heat exchangers are effective and in the good conditions.

1.2 Objectives

The objectives of this project are

1. To determine the physical properties and performance curves of thermoelectric module
2. To optimize the operation of thermoelectric module experimentally

1.3 Scopes

This is an experimental study where the test rig has to be fabricated in order to achieve the objectives of the project. The scopes are covered by 3 parts and listed as follows:

1. Study on the thermoelectric module principle theory.
2. Determination of performance curve and physical properties of the thermoelectric module by using some related equations. Comparison between the experimental data and manufacturer data will be made.
3. Optimize experimentally some parameters that important to increase the performance of thermoelectric module such as power applied, size, cooling system that involved in the experiment or thermoelectric material itself.

1.4 Problem statement

Theoretically thermal performance of thermoelectric module depends on the physical properties such as the Seebeck coefficient α, the electric resistance R and the thermal conductivity, K_t But usually the manufacturer of thermoelectric module does not provide this kind of data for their customer or the given data are not accurate because of the variation of manufacturing process. So in order to determine the physical properties of thermoelectric module, an experimental apparatus has been fabricated. Finally by knowing that data we can measure the thermal performance of the thermoelectric module by using some equations that related. Optimization need to be done experimentally to increase the performance of thermoelectric module.

REFERENCES

[1] Yaakov Kraftmakher, Simple experiment with a thermoelectric module, Eur. J. Phys. 26 (2005) 959-967

[2] Xu Xu, Steven Van Dessel and Achille Messac, Study of the performance of thermoelectric modules for use in active building envelopes (2005)

[3] B. J. Huang, C.J Chin and C.L Duang, A design method of thermoelectric cooler, International Journal of Refrigeration 23 (2000) 208-218

[4] Y.J.Dai, R.Z.Wang and L.Ni, Experimental investigation on a thermoelectric refrigerator driven by solar cells, Renewable energy 28 (2003) 949-959

[5] S.Maneewan, J. Khedari, B. Zeghmati, J. Hirunlabh and J. Eakburanawat, Investagation on generated power of thermoelectric roof solar collector, Renewable energy 29 (2004) 743-752

[6] Paul G. Lau, Todd M.Ritzer and Richard J. Buist, Thermodynamic optimization of heat and cold sink extenders in thermoelectric cooling assemblies, TE Technology Inc.

[7] L.N.Vikhor and L.I.Anatychuk, Theoretical evaluation of maximum temperature difference in segmented thermoelectric coolers, Applied Thermal Engineering 26 (2006) 1692-1696

[8] A.Chakraborty, B.B.Saha, S.Koyama and K.C.Ng, Thermodynamic modeling of a solid state thermoelectric cooling device: Temperature-entropy analysis, International Journal of Heat and Mass Transfer 49 (2006) 3547-3554

[9] Lingen Chen, Jianzheng Gong, Fengrui Sun and Chih Wu, Effect of heat transfer on the performance of the thermoelectric generators, Int. J. Therm. Sci. 41 (2002) 95-99

[10] R.Y. Nuwayhid, D.M. Rowe and G.Min, Low cost stove-top thermoelectric generator for regions with unreliable electricity supply, Renewable energy 28 (2003) 205-222

[11] K.A. Moores, Y.K. Joshi and G.Miller, Performance assessment of thermoelectric coolers for use in high temperature electronic application, International Conference on thermoelectric, Baltimore, MD, September 1999.

[12] Gao Min, D.M. Rowe, Experimental evaluation of prototype thermoelectric domestic-refrigerators, Applied energy 83 (2006) 133-152

[13] D.M. Rowe, CRC Handbook of thermoelectrics, 1995

[14] www.ferrotec.com

[15] Goldsmid, H.J., Electronic Refrigeration, Pion, London, 1986

[16] Ioffe, A.F, Semiconductor Thermo elements and the Thermoelectric Cooling, Infosearch, London, 1957

[17] www.melcor.com

[18] H.J. Goldsmid, Thermoelectric refrigeration, 1964

[19] Drabble, J.R. and Goodman, C.H.L., J. Phys. Chem. Solids 5, 142 (1958)

[20] Harman, T.C., Logan, M.J., and Goering, H.L., J. Phys. Chem. Solids 7, 228 (1958)

[21] Specifications of TE Module Model TEC1-12705

[22] Specifications of CP1.4-71-06L

[23] S.B. Riffat and Xiaoli Ma, Improving the coefficient of performance of thermoelectric cooling systems: a review, Int. J. Energy Res. 2004; 28:753-768

[24] S.B. Riffat and Xiaoli Ma, Optimum selection (design) of thermoelectric modules for large capacity heat pump applications, Int. J. Energy Res. 2004; 28:1231-1242