UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN AND DEVELOPMENT OF AN OPTIMISED THERMOELECTRIC COOLER FOR ACTIVE PROCESSOR COOLING

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Design) (Hons.)

by

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DECLARATION

I hereby, declared this report entitled “Design and Development of an Optimized Thermoelectric Cooler for Active Processor Cooling” is the results of my own research except as cited in references.

Signature : ………………………………………….
Author’s Name : ………………………………………….
Date : ………………………………………….

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Design) with Honours. The member of the supervisory committee is as follow:

(Signature of Supervisor)

………………………………

(Official Stamp of Supervisor)

ABSTRACT

The rising heat generation of processor have sparked many interest in active cooling solution. Current cooling solution can’t effectively cool down a higher end processor effective. Thus this where thermoelectric cooler comes into place, when voltage is applied it would create a temperature difference between the surface. This allows heat exchange to occur at a more rapid rate. However thermoelectric cooler are notoriously known for their high power consumption, high power dissipation, low coefficient of performance (C.O.P) and limitation due to inefficient system used. Therefore in this project it would be covering the optimization of the thermoelectric cooler cooling module for active central processing unit cooling. To tackle the issue several concept are proposed and weighted. A proof of concept would be designed, fabricated and evaluated. Apart from that the proof of concept serve as a guidelines and the result generated would be used in the final prototype in which it would be optimized further with the use of a PID controller designed. The final prototype is benchmarked and compared to the current cooling solution, in which it’s able to cool down an i5-2500k processor under load to 40celcius. Based on the result it’s shown that the prototype are able to achieve the intended purpose with an optimized power consumption.

ABSTRAK

Peningkatan haba yang tinggi dalam kalangan pemproses zaman sekarang telah menyemarakkan minat ramai pihak dalam mencari kaedah penyejukkan yang lebih efektif. Ini kerana kaedah penyejukkan yang sedia ada masih belum dapat menyejukkan pemproses dengan lebih cekap dan berkesan. Di sinilah pendingin termoelektrik memainkan peranan yang besar, dimana apabila voltan elektrik diaplikasikan, perbezaan suhu pada permukaan pemproses akan terhasil. Ini membolehkan perbezaan haba terjadi dalam kadar yang pesat. Walau bagaimanapun, pendingin termoelektrik agak terkenal dengan penggunaan dan pembaziran tenaga dalam kadar yang tinggi, pekali prestasi yang rendah dan juga beberapa pembatasan disebabkan oleh sistem yang digunakan tidak berapa efektif. Disebabkan itulah, projek ini akan lebih tertumpu kepada pengoptimuman pendingin termoelektrik dalam proses penyejukkan unit pemproses. Untuk menyelesaikan masalah ini, beberapa konsep akan dicadangkan dan dianalis dengan teliti. Sebagai permulaan, satu prototaip akan direka, dipasang dan dianalisis sebagai bukti bahawa konsep produk itu mampu dihasilkan. Prototaip konsep itu akan digunakan sebagai garis panduan dan hasil analisis yang diperolehi akan digunakan untuk menghasilkan prototaip akhir di mana ia akan lagi dioptimumkan dengan penggunaan pengawal PID. Prototaip akhir akan diletakkan beberapa penanda aras yang akan digunakan sebagai perbandingan dengan proses penyejukkan yang sudah sedia ada, dimana ia dapat menyejukkan pemproses i5-2500k dalam keadaan beban kepada 40 darjah celcius. Akhir sekali, berdasarkan dari hasil analisis yang diperolehi, prototaip akhir mampu mencapai objektif projek ini disamping penggunaan tenaga yang optimum.

DEDICATION

Dedicated to my beloved father, mother, sister
And not to forget my hobby community's member…

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Chapter 1

Introduction

1.1 Background

Modernisation has brought the advancement of central processing unit to a higher stage compared to the last few decades. Basically a central processing unit is an electronic chip in a computer that carries out the instruction of a computer program by performing the basic arithmetic, logical, control and input/output operation specified by the instructions. The design, form and application of central processing unit have changed over the course of history, but their fundamental operation remains unchanged.

Nowadays most modern central processing unit is called microprocessors, which mean that they are contained in a single integrated circuit. Over the course of history the advancement of central processing unit technology, the density of transistor increases as the advancement in semiconductor bring smaller transistor to into integrated circuit. According to Gordon E. Moore, the transistor count of an integrated circuit doubles approximately every two years. In 2014, the highest transistor count found in commercial central processing unit is over 4.3bilions transistor, in Intel i5-core Xeon. (Moore & Fellow, 1998)

However the advancement of central processing unit also increases the power consumption and releases more heat than their predecessor. Therefore the central processing unit need requires more heat dissipation in the form of CPU cooling solution. Normally the optimum operating temperature of a central processing unit is at room temperature, or ideally as cool as possible. A hot central processing unit would cause problems ranging from system crashes and physical damages due to overheat. Common CPU failure mechanisms tend to be mechanical (wire bond failure, die fracture, corrosion) and electrical (overstress, migration and diffusion, gate oxide breakdown) Following the Arrhenius equation, (for die temperatures operating in the range of -20ºC to 140ºC) every 10ºC decrease in temperature reduces the failure rate by approximately a factor of 2. We can therefore expect a reduction in chip failure rates with lower operating temperatures (Davis et al., 2006)

Typically heat sinks with a blower (air cooling) are attached on top of the central processing unit. However due to increasing heat load some user have opted to liquid cooling, in which the central processing unit are cooled by liquid that passed through a water block on top of the central processing unit. The liquid would be cooled down by a radiator. However liquid cooling are restricted due to the heat load they can pull.

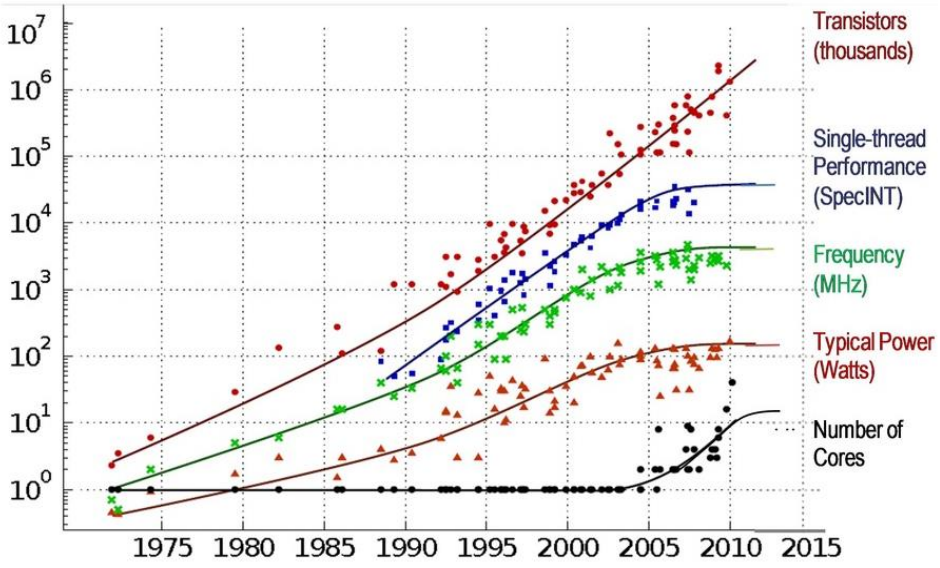

Figure 1.1: 35 Years of Microprocessor Trend Data (Sam Naffziger, AMD)

This is where thermoelectric cooler comes into place, when voltage is applied it would create a temperature difference between the surface. This allows heat exchange to occur at a more rapid rate. However thermoelectric cooler are notoriously known for their high power consumption, high power dissipation, low coefficient of performance (C.O.P) and limitation due to inefficient system used. (H Y Zhang et al.,2010)

1.2 Problem Statement

The growth in central processing unit heat generation has sparked attention in active cooling to bring the temperature down. Critical application of central processing unit in servers or a high performance computer requires an advanced cooler mechanism that would bring the temperature down to an optimum level. Thus, thermoelectric cooler would be needed to assist the cooling down of the central processing unit. However, there are many problems plaguing thermoelectric cooler. They are notoriously known for their high power consumption, high power dissipation, low coefficient of performance (C.O.P) and limitation due to inefficient system used. Thus in this project it would be covering the optimisation of the thermoelectric cooler cooling module for active central processing unit cooling.

1.3 Objective of the Project

There are three objectives that need to be achieved in this project, and they are:

i. To design an optimized thermoelectric cooler cooling module for active central processing unit cooling.
ii. To develop an optimized thermoelectric cooler cooling module for active central processing unit cooling.
iii. To evaluate the performance of the thermoelectric cooler cooling module.

1.4 Scope of Project

The scope of the project is focused on the following area:

i. Design and Analysis in Solidworks Software.
ii. Fabrication of the thermoelectric cooler cooling module.
iii. Evaluating the performance of the thermoelectric cooler cooling module.

Chapter 2

Literature Review

2.1 Introduction

In this project, the literature review serves as guide for the project. It contains the related information to proceed with the designing, analysing and the fabrication of the thermoelectric cooler cooling module prototype. In this chapter, we would be covering the thermoelectric cooler principles, design approach of the cooler, Arduino controller and the related item that would be used during the course of the project. Design approach refers to the integration of thermoelectric cooler into the cooling system of the central processing unit.

2.2 Thermoelectric cooler

Thermoelectric consisted of two dissimilar metals that are connected at two different locations or junction known as thermocouple. When temperature differences are applied to the junction a micro-voltage would be produced. This is known as 'Seebeck effect' which was found by Seebeck (1821). Inversely when voltage is applied to the thermocouple a temperature difference would be produced on the two junctions. The inverse of the Seebeck effect was discovered by a scientist called Peltier (1834), the inverse Seebeck effect was later known as 'Peltier effect'. The temperature difference would result in a small heat pump, in which later it was known as thermoelectric cooler. In practical approach the thermoelectric cooler would be consisted of several thermocouples in series. This would allow a higher amount of heat transfer to be gained. Therefore the thermoelectric cooler can be used to cool components quickly below ambient temperature which is not possible with the use of conventional air cooling or water cooling.

2.2.1 Thermoelectric Theory

When direct current (DC) voltage are applied to the module, the positive (+ve) and negative (-ve) charge carriers in the pellet array would absorb heat from one side of the ceramic plate and releases it to the opposite side of the ceramic plate. Consequently the surfaces in which the heat is absorbed become cooler and the opposite side in which the heat is released becomes hotter. When the polarities of the voltage are reversed it would result in the reserved hot and cold side. (Goupil et al., 2011)

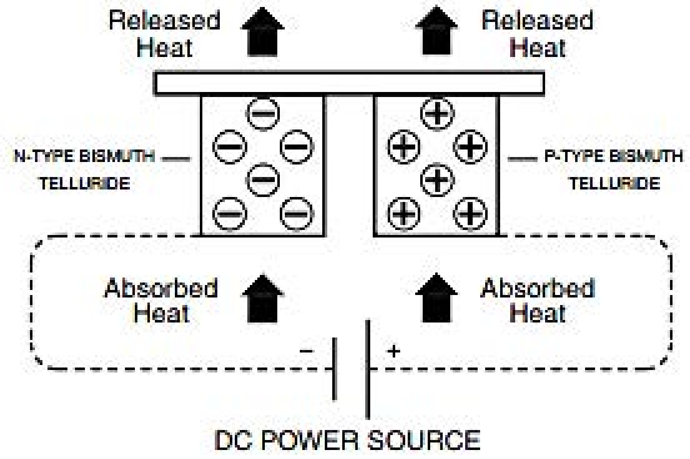

Figure 2.1: Thermoelectric module theory (Source: V-Infinity)

2.2.2 Thermoelectric cooler Construction

The thermoelectric coolers are composed of thermoelectric couples that are connected in series. They are enclosed in a ceramic plated that is sandwiched between them, in which they are parallel thermally. The two sides of the ceramic plates would be the hot or the cold side of thermoelectric cooler.

Generally, the thermoelectric cooler consisted of the following parts:

i. Pellets - usually consisted of semiconductor such as bismuth telluride, antimony telluride. These semiconductors are the best among the known material due to the complex optimal thermoelectric performance and technological properties.

ii. Ceramic Plates – used to provide mechanical integrity of the thermoelectric cooler. They must be able to satisfy the requirement of electrical insulation from an object to be cooled and the heat sink. Apart from that the plate must have a good thermal conductance to provide heat transfer with minimal resistance. Commonly aluminium oxide ceramic are used due to the optimal cost to performance ratio.

iii. Electrical Conductors – used to provide serial electric contacting of the pellet with each other and to establish contact with the leading wire. Usually on a high powered module they are made of copper tab to reduce resistance.

iv. Soldering – provides assembling of the thermoelectric cooler module. Commonly the solder used includes antimony-tin and lid-tin alloys. The solder are crucial as they are the limiting factor of operation of the module. This is because high temperature would melt the solder and damages the thermoelectric cooler module. Thus the operating temperature must be lower than the solder's melting point.

v. Terminal Wires – provides connection from the ending conductor to the direct current (DC) electrical power source

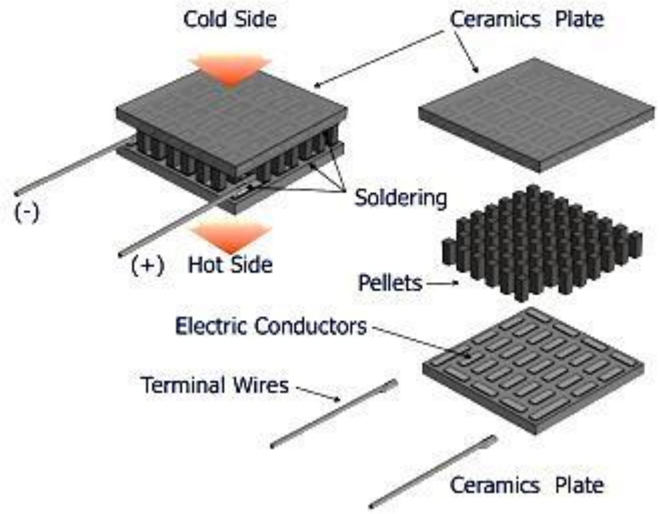

Figure 2.2: Basic Construction of a Single-Stage TEC (TEC Microsystem)

2.2.3 Thermoelectric cooler Specification

Thermoelectric cooler are specified by maximal performance parameter with a hot junction temperature. Most of the time they would be listed in standard specification of a module:

i. ΔTmax – maximal temperature difference along the module at zero heat load Q=0
ii. ΔT – operating temperature difference
iii. Q – operating cooling capacity
iv. Qmax – maximal cooling capacity corresponding to ΔTmax=0
v. I – applied current
vi. Imax – the device current at ΔTmax
vii. U – the terminal voltage
viii. Umax – the terminal voltage for Imax with no heat load

(H.Y. Zhang et al., 2010)

2.2.4 Thermoelectric Cooler Calculation

Different application of thermoelectric cooler would require specific types of thermoelectric cooler to be used. The operation parameter and restriction would dictate the requirement of an accurate selection of the optimal thermoelectric cooler types among the wide range of thermoelectric cooler module. A rough estimation can be made by the following equation. (Goupil et al., 2011)

$$Q = Q_{max}\left(1 - \frac{\Delta T}{\Delta T_{max}}\right) \quad and \quad \Delta T = \Delta T_{max}\left(1 - \frac{Q}{Q_{max}}\right)$$

The formula above would help in deciding which thermoelectric cooler module is needed. A careful calculation and consideration must be made when choosing the thermoelectric cooler module as error would lead to low system efficiency, high power consumption and damages the thermoelectric cooler module. Apart from selecting the thermoelectric cooler module the cooling capabilities must be calculated to ensure that the cooling of the hot side is adequate.

2.2.5 Thermoelectric cooler Advantages

Water-cooling and heat sink are common nowadays to cool down the central processing unit. Generally thermoelectric cooler offers plenty of unique advantages compared to other active cooling technology which includes:

i. Low cost and long service life.
ii. Low energy consumption.
iii. No special skills required for installation or servicing.
iv. Environmentally friendly and safe.
v. Compact, quiet and lightweight.
vi. Highly controllable cooling power.

(Davis et al., 2006)

However depending on how the thermoelectric coolers are implementation, some of the advantages may be lost.

2.3 Design approach of Thermoelectric cooler module

In this section we would brief on the various design approach that have been taken to integrate the thermoelectric cooler into central processing unit cooling.

2.3.1 Direct Die Heat sink TEC

Normal thermoelectric cooler design approach involves direct die cooling by attaching the TEC plate to a plate of conductive material adjacent / heat sink to the central processing unit. However heat sink has limited cooling capability, thus they would lead to higher temperature on the hot side. In which it would lead to performance degradation of the thermoelectric cooler.

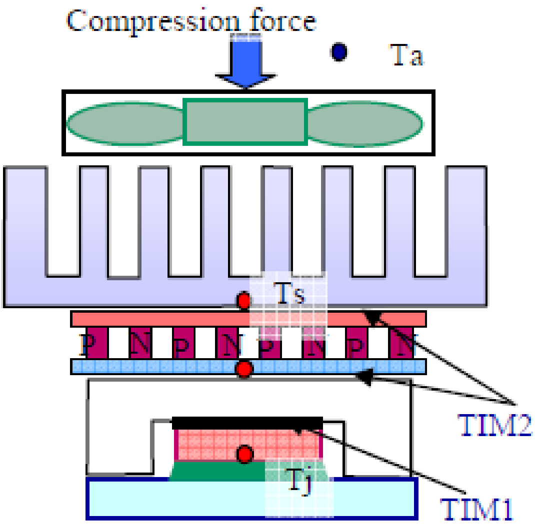

Figure 2.3: Schematic of CPU cooled by direct die TEC heat sink
(H Y Zhang et al., 2010)

2.3.2 Direct Die Liquid Cooling TEC

Alternatively direct die liquid cooling offers a better solution. The heat is dispersed by the thermoelectric cooler into a traditional water cooling system which consisted of a water block, pump and a radiator. However this solution is limited to the available space that is present in the central processing unit die area.

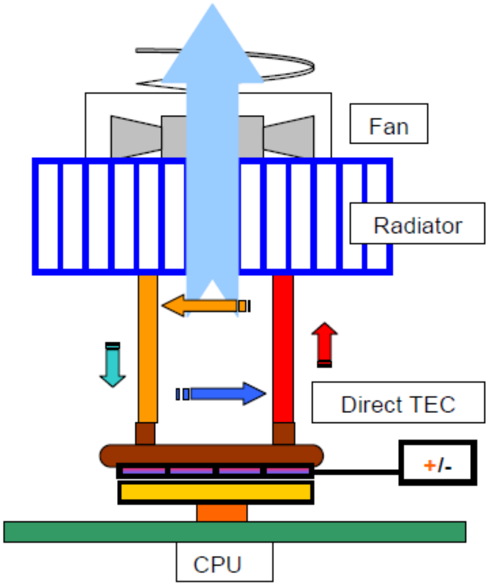

Figure 2.4: Schematic of direct die liquid cooling (Davis et al., 2006)

2.3.3 Chiller TEC

Another viable option is to use the chiller method which basically chilled water from TEC are pumped to the water block which directly cool down the central processing unit. Thermoelectric CPU chiller has several implicit advantages. They overcome the limitations of conduction resistance by lowering the temperature of the conductive medium that is adjacent to the central processing unit die, thus increasing the driving temperature differential. Both the hot and the cold side of the modules have access to highly effective heat transfer devices. Additionally they utilize the entire heat transfer surface of the module and distribute the load over several modules, allowing improved coefficient of performance (Davis et al., 2006).However this would lead to a higher cost and power consumption.

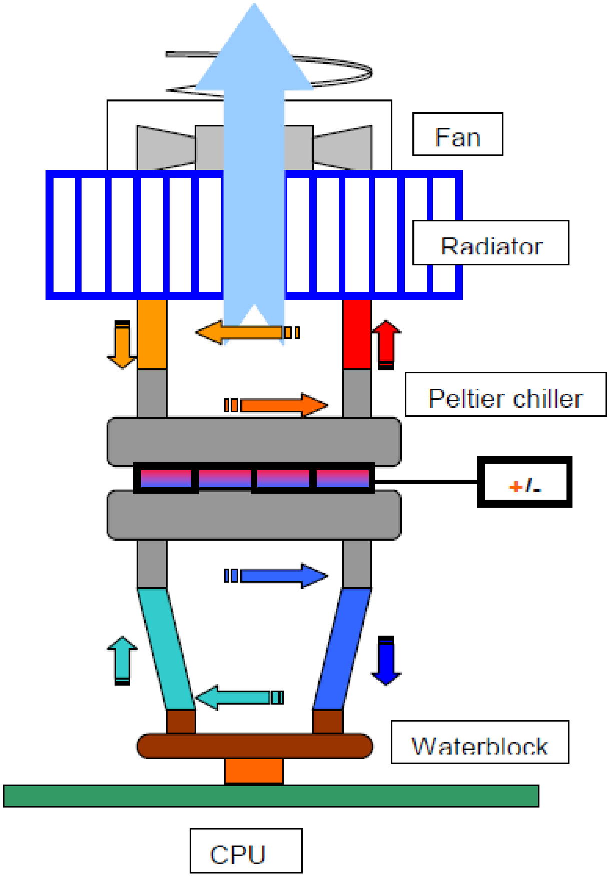

Figure 2.5: Schematic of liquid chiller thermoelectric cooling (Davis et al., 2006)

2.4 Controller

A controller is necessary to control the thermoelectric module from over-cooling the central processor unit than intended. Over-cooling of the central processing unit may cause unwanted condensation to occur without knowledge. Thus a controller is needed. Commonly there are two types of controller that can be used with thermoelectric cooler, namely thermostat and pulse width modulation. However these only provide the means of throttling the power of the thermoelectric module. Therefore a proportional-integral-derivative controller (PID controller) system would be needed to increase the effectiveness of the controller. Apart from that a platform to build the controller would be needed. (Shaojing & Qin, 2010)

2.4.1 Thermostat

A thermostat is simple control systems that act as a switch. It detects the surrounding temperature and switch off or on depending on the needs. For example a set point temperature of 25 Celsius is set, when the surrounding temperature increase beyond the set point temperature it would automatically switch on the power and switch off when the temperature drops below the set point. However the disadvantages of thermostat include huge varying temperature difference since the device is turned off and on at a slow rate simply put it can’t react with the demand fast enough.

2.4.2 Pulse-Width Modulation

Pulse-Width Modulation (PWM) is commonly known as digital pulse. PWN is a technique that is used to generate analogue signals from a microcontroller. PWM works by turning off and on a device at a rapid rate, at different frequencies and duty cycles. This would allow the control of power delivered to the device without the loss of power compared to linear power delivery by resistive mean. PWN would allow precise temperature to be achieved compared to thermostat. In thermoelectric application the PWM frequencies are suggested to be above 1 kHz are needed (Nord Ferrotech Peltier Manufacturers), this is to avoid thermal cycling to occur. (Pathak & Goel, 2013)