THE EFFECT OF THERMOELECTRIC POWER GENERATOR (TEG) BASED HI-Z THERMOELECTRIC MODULES ON THE PERFORMANCE OF 1.3L 4G13 WIRA ENGINE

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APPROVAL OF SUPERVISOR

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DECLARATION

I declare that this thesis entitled *"The effect of thermoelectric power generator (TEG) based Hi-Z thermoelectric modules on the performance of 1.3L 4G13 Wira Engine"* is the result of my own research except as cited in the references.

Signature :..

Author : AZMIN BIN AHMAD

Date : 19 MAY 2010

To My Parent And My Family

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ABSTRACT

Waste heat recovery from car engine coolant provides an opportunity to significantly improve the overall car engine efficiency. One approach of recovering waste heat is by using thermoelectric power generator with a main component of thermoelectric module. A thermoelectric module is solid state device. It is reliable energy converters and have no noise or vibration as there are no mechanical moving parts. The capability of TEG is proven but the effect of TEG to the performance engine is questioned. In this project, the best location to install the TEG was identified. The next step is to determine the effect on the performance engine with and without using the TEG. Theoretically, the TEG will produce small value of power and torque to the engine after installation. By using the Engine Dyno test, the result from this project will show that the installation of TEG to the engine system are practical or not.

ABSTRAK

Penggunaan semula haba terbuang daripada pendingin enjin kereta boleh meningkatkan kuasa kecekapan enjin. Salah satu cara untuk mendapatkan tenaga elektrik adalah menggunakan tenaga haba terbuang untuk menjana kuasa elektrik melalui Penjana Kuasa Thermoelektrik (PKT). Peranti Termoelektrik adalah peranti keadaan pepejal. Ia adalah tenaga boleh dipercayai dan tidak mempunyai bunyi bising atau getaran serta tiada penukaran alat mekanikal. Keupayaan PKT telah terbukti tetapi kesan PKT terhadap enjin masih menjadi persoalan. Sementara itu, tempat terbaik untuk pemasangan PKT haruslah dikenal pasti dahulu. Langkah seterusnya adalah menentukan kesan pada enjin kereta sebelum dan selepas pemasangan PKT. Ini dapat dibuktikan dengan menggunakan ujian enjin Dyno. Secara teori, PKT akan menghasilkan nilai yang kecil kepada kuasa dan daya kilas enjin. Hasil daripada kajian ini akan menunjukkan samaada penggunaan PKT adalah praktikal atau tidak dalam sistem enjin kereta.

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CHAPTER I

INTRODUCTION

In this chapter there will be an explanation of this project. This chapter consist briefly the introduction of this project, the problem statement, main objectives and scope of this project.

1.1 Introduction into General Topic.

All thermoelectric power generators have the same basic configuration. A heat source provides the high temperature, and the heat flows through a thermoelectric converter to a heat sink, which is maintained at a temperature below that of the source. The temperature differential across the converter produces direct current (DC) to a load (R_L) having a terminal voltage (V) and a terminal current (I). There is no intermediate energy conversion process. For this reason, thermoelectric power generation is classified as direct power conversion.

According to D.M Rowe (2006), this reversibility distinguishes thermoelectric energy converters from many other conversion systems, such as thermionic power converters. Electrical input power can be directly converted to pumped thermal power for heating or refrigerating, or thermal input power can be converted directly to electrical power for lighting, operating electrical equipment, and other work. Any thermoelectric device can be applied in either mode of operation, though the design of a particular device is usually optimized for its specific purpose.

Systematic study began on thermoelectricity between about 1885 and 1910. By 1910 Edmund Altenkirch, a German scientist, satisfactorily calculated the potential efficiency of thermoelectric generators and delineated the parameters of the materials needed to build practical devices. Unfortunately, metallic conductors were the only materials available at the time, rendering it unfeasible to build thermoelectric generators with an efficiency of more than about 0.5 percent.

By 1940 a semiconductor-based generator with a conversion efficiency of 4 percent had been developed. After 1950, in spite of increased research and development, gains in thermoelectric power-generating efficiency were relatively small, with efficiencies of not much more than 10 percent by the late 1980s. Better thermoelectric materials will be required in order to go much beyond this performance level.

1.2 Problem Statement

According to D.M Rowe (2004), the energy flow path of an internal combustion engine in which only 25% of the fuel combustion can be utilized for vehicle operation, whereas 40% of the fuel energy is waste in exhaust gas, 30% in engine coolant and 5% in friction and parasitic losses. The installation of TEG can recovery heat loss to electricity and also increasing efficiency of internal combustion engine. The effect to the engine should be investigate to justify the advantages and disadvantages to the engine performance. Therefore, to propose this project.

1.3 Objectives of the Study

The objective of this project is to determine the effect of thermoelectric power generator (TEG) based Hi-Z thermoelectric modules on the performance of 1.3L 4G13 engine.

1.4 Scopes of the study:

The scopes of this project are given as follows:

1. Literature review on TEG and related topics.
2. Conduct analysis to chose the best location for TEG.
3. Conduct experimental study on 1.3L 4G13 engine by using ready to used TEG.
4. Analysis data collected from the experiment study to determine the effect of thermoelectric power generator (TEG) based Hi-Z thermoelectric modules on the performance of 1.3L 4G13 engine.

CHAPTER II

LITERATURE REVIEW

Thermoelectric generator (TEG) theoretically may offer many advantages such as being highly reliable, having no moving parts, and being environmentally friendly, when compared with conventional electric power generators. Owing to these advantages, there have been considerable emphases on the development of the small TEG for a variety of aerospace and military applications over the past years. More recently, there is a growing interest for waste heat recovery TEG, using various heat sources such as combustion of solid waste, geothermal energy, power plants, and other industrial heat-generating processes.

2.1 A Brief History of Thermoelectric

According to Brooks (2006), the study of thermoelectric began in 1822 when Thomas Johann Seebeck , a German physicist, noticed that two dissimilar metals in a closed loop caused a compass needle to deflect when the two metals were held at different temperatures. This meant that an electric field was created between the two metals, thus inducing a magnetic field to deflect the needle. Seebeck later discovered that some metals were able to create stronger fields with the same temperature difference, and that the amount of deflection in the needle was proportional to the temperature difference between the two conducting metals. These principles make up the foundations of thermoelectric, and for his discoveries the Seebeck coefficient (the voltage produced between two points of a conductor where a uniform temperature difference of 1K exists between those two points) was named after the founding father of thermoelectric.

In 1834,a French watchmaker named Jean Charles Athanase Peltier discovered that thermoelectric materials could also work in reverse. That is, an applied voltage could create a temperature difference between the two dissimilar metals. Although Peltier is generally credited with the discovery of thermoelectric cooling, he did not fully understand the physics of the phenomenon. The full explanation was given four years later by Emil Lenz, who showed that a drop of water on a bismuth-antimony junction would freeze when electrical current was applied one way, and melt again when the current was reversed.

As knowledge of thermoelectric increased, the most important discoveries were related to material properties. In 1911, Altenkirch derived the thermoelectric efficiency, now known simply as or the thermoelectric figure of merit.

According to Brooks (2006), Altenkirch and others realized that ideal thermoelectric materials would have a high electrical conductivity to minimize Joule heating and a low thermal
conductivity to prevent the backflow of heat from the hot side to the cool side. The thermoelectric efficiency can be non-dimensional by multiplying by the absolute temperature , which yields the most common form of thermoelectric efficiency, also known as the dimensionless.

Beginning in the late 1930's and continuing into the 1970's, there was a surge of discoveries that showed semiconductors exhibited the best thermoelectric properties. Until then metals such as bismuth and antimony alloys were the state of the art with a value of around 0.1 at room temperature. The implementation of semiconductors such as bismuth telluride (Bi_2Te_3) helped to increase that number by tenfold because semiconductors are moderate conductors of heat and electricity.

Recent advancements in nanoscale physics have allowed researchers to begin manipulating materials at the molecular level. This means that new materials may be created that can conduct electricity very well while insulating against heat transfer. This area of research will be discussed in more detail in the next section.

2.2 Waste Heat Recovery

In the case of TEG for waste heat recovery power generation, there have been many conceptual designs of a power conversion system which are potentially capable of obtaining application in this area. These designs involve the consideration of the maximum power output and conversion efficiency with different thermoelectric heat exchanger. Furthermore, performance evaluations of the thermoelectric generators have been theoretically carried out by modeling approach. The results show that the thermoelectric generators are promising devices for waste heat recovery. Although the economic viability of a TEG may be improved significantly when used for waste heat recovery, desirable TEG technologies for waste heat recovery are those that could reduce the device cost and increase the conversion efficiency of a device. Therefore, one of the more attractive options for waste heat recovery is to construct the TEG device by incorporating the relatively simple parallel-plate heat exchanger with the commercially available thermoelectric modules.

According to Crane (2004), the TEG module to optimize TE waste heat recovery by integrating efficient cross flow heat exchangers with thermoelectric modules for conversion of waste heat to electricity. Numerical heat exchanger models are integrated with models for Bi_2Te_3 TE modules, which are positioned between the hot and cold flow streams as shown in the schematic of a heat exchanger sub-section in Figure 1. It indicates fins on the air side passages, which are often louvered (not shown in the illustration) to enhance heat transfer, since air side cooling typically presents the highest resistance to heat transfer. The TE modules are electrically isolated by thin passivating oxide layers on both the outer surface of the metal tubes, which hold the hot fluid, and the inner surface of the outer metal wall, which supports the fins for air side cooling.

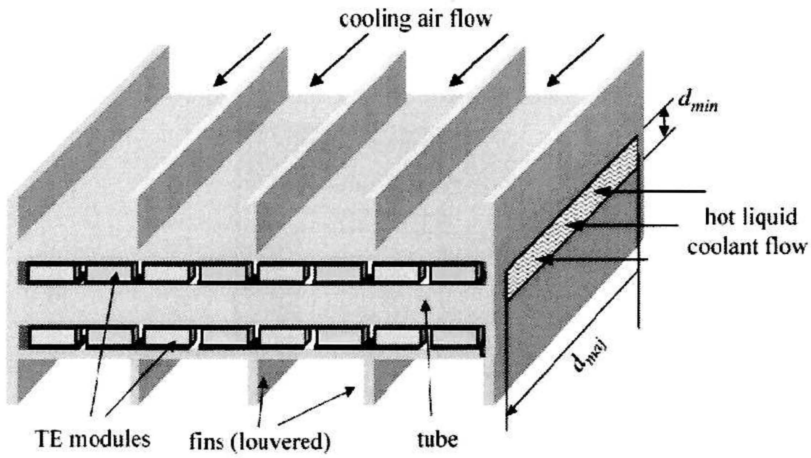

Figure 2.1 : Sub-section of thermoelectric heat exchanger
(Source : Crane, (2004))

2.3 Thermoelectric Device

There are two types of thermoelectric devices are thermoelectric generation and thermoelectric cooling.

2.3.1 Thermoelectric Generation

The simplest thermoelectric generator consists of a thermocouple (thermopile) comprising a p-type and n-type semiconductor connected electrically in series and thermally in parallel. Heat is pumped into one side of the couple and rejected from the opposite side. An electrical current is produced, proportional to the temperature gradient between the hot and cold junctions. a thermoelectric generator utilizing semiconductors could achieve a conversion efficiency of 4% (the ratio between the useful output of an energy machine and the input, in energy terms = Pout /Pin. Generally, conversion efficiency is a dimensionless number between 0 and 1.0 or 0 to 100%). The thermoelectric generator shows further possible improvement in his performance. (Source : Gaffar, (2007))

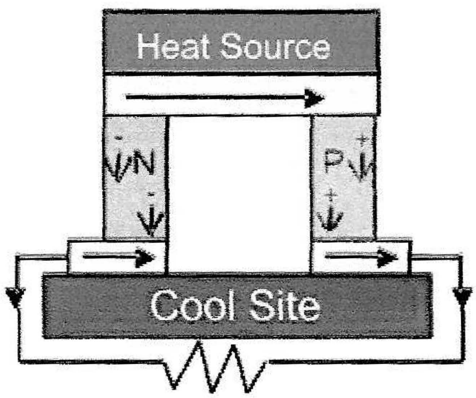

Figure 2.2 : Principle of Thermoelectric Generation (Source : Gaffar, (2007))

2.3.2 Thermoelectric Cooling

If an electric current is applied to the thermocouple as shown, heat is pumped from the cold junction to the hot junction. The cold junction will rapidly drop below ambient temperature provided heat is removed from the hot side. The temperature gradient will vary according to the magnitude of generation current applied (Seebeck effect).

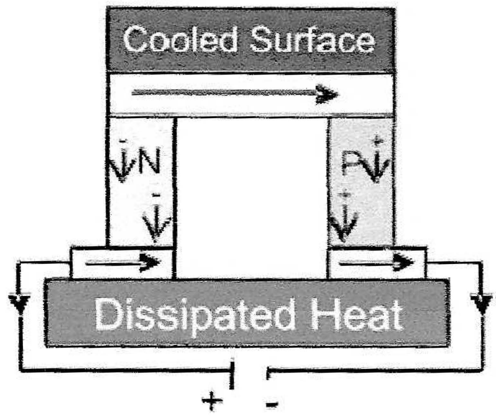

Figure 2.3: Principle of Thermoelectric Cooling (Source : Gaffar, (2007))

2.4 General Concept of Thermoelectric Generators for Vehicles

A well-known rule of energy balance in internal combustion engine that the power available for driving the vehicle is one third at the most , the remaining two thirds are evolved rough equally as waste heat in the exhaust stream and latent heat in the coolant system.

According to Rowe (2006), for a typical 100 hp engine generating 75 kW in terms of electric power, roughly 50 kW is evolved as waste heat energy. Evidently even if only a small fraction of this can be recovered, a substantial amount of electrical power could be generated.

The Figure 2.4 shows the amount of heat per hour (kW/h) versus temperature for a 2000cm^3 class passenger car. It is shown that the exhaust gas possesses high heat energy corresponding to 10 kW/h at exhaust gas temperature 400°C and 100 kW/h at 620°C when running at 32.4 miles an hour (60 km/h) on a flat road. The heat energy of exhaust gas is extracted through a heat exchanger and is converted into electric power through a thermoelectric stack (TE Stack) which is a united system of thermoelectric modules and a heat exchanger.

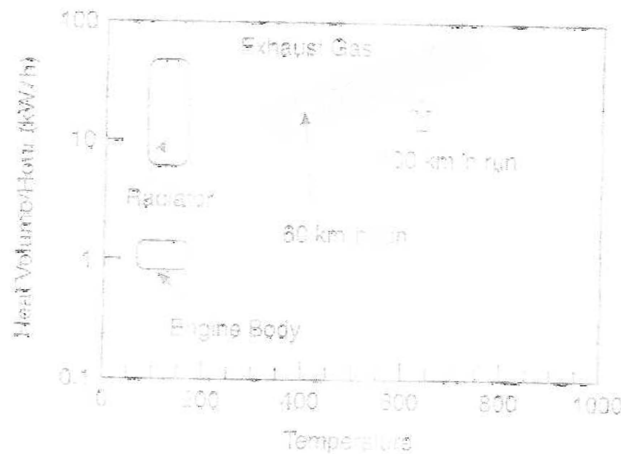

Figure 2.4 : Exhaust heat volume per hour temperature for a 2000cc car.

(Source : Rowe, (2006))

The Figure 2.5 shows the basic structure of a TE Stack and its heat balance. In this system, the overall efficiency of the TE Stack can be obtained as a product of the efficiencies of the thermoelectric modules and heat exchanger. In this heat balance model, $Q_{gas\text{-}in}$ and $Q_{gas\text{-}out}$ are the amounts of heat at the inlet and outlet of heat exchanger, respectively Q_1 and Q_2 are the radiation losses from the side of the legs , and P is the electrical output power. If we assume that $Q_{gas\text{-}out}$ is 45% and Q_2 (the radiation heat loss from the side of the heat exchange) is 10%, the net amount of heat (Q_e) , which is represented as the sum of P, Q_0 and Q_1 is 45% (about half of $Q_{gas\text{-}in}$)

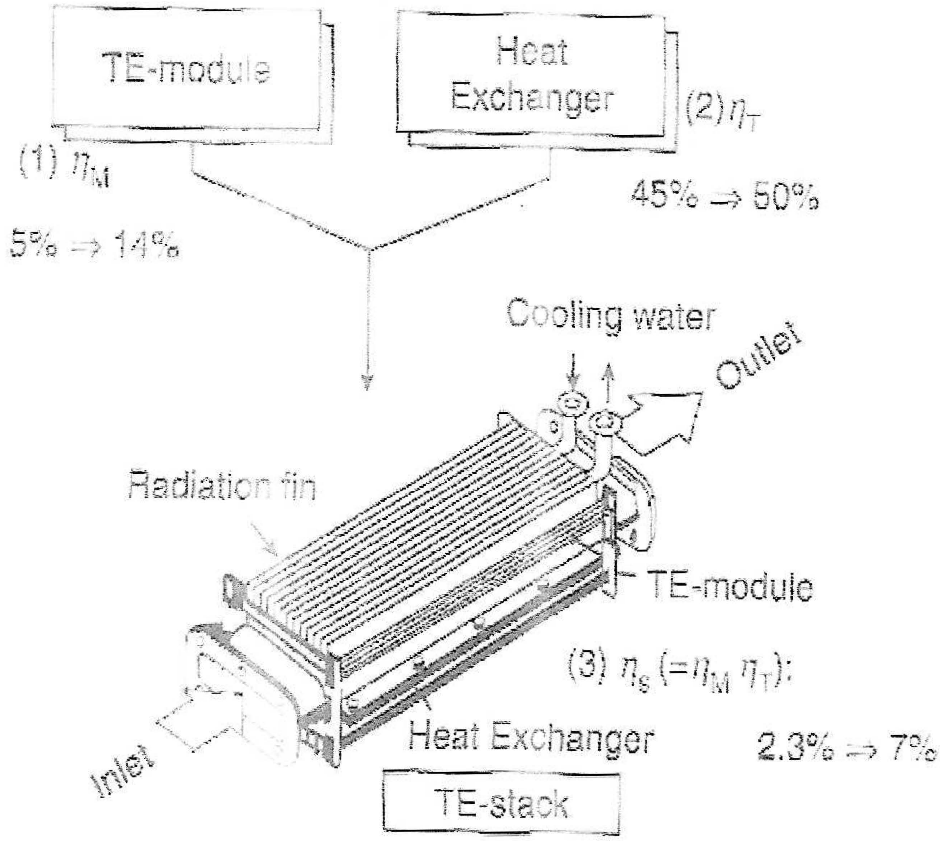

Figure 2.5 : Structure of thermoelectric with a heat exchanger
(Source : Rowe, (2006))

2.5 Automotive Waste Heat Energy Recovery

According to Yu and Chau (2009), a practical automotive waste heat energy recovery system consists of an exhaust gas system, a heat exchanger, a TEG system, a power conditioning system, and a battery pack. There are various considerations and alternatives:

- A typical exhaust gas system for internal combustion engines is composed of the exhaust manifold, exhaust pipe, catalytic converter, center muffler and rear muffler. It is a natural choice that the heat exchanger should be installed at the location with the highest temperature, namely at the exhaust manifold. Taking into account the working temperature of the TEG device and the convenience of mounting the heat exchanger, a compromise may be required on the selection of heat exchanger location.

- The TEG system is governed by the selected TE materials which need to offer high energy conversion efficiency. In recent years, the characteristics of thermoelectric materials have been significantly improved in terms of both the ZT value and the temperature range. For example, the p-type and n-type Bi-Te materials offer the optimal ZT values at the temperature range of exhaust gas.

- Rather than directly connecting the TEG system to the battery pack, a power conditioning system needs to be installed between them. This power conditioning system functions to regulate the power flow in such a way that the maximum power transfer can be achieved. The two key issues are the design of a proper power converter and the devise of an effective control algorithm, which will be discussed later.

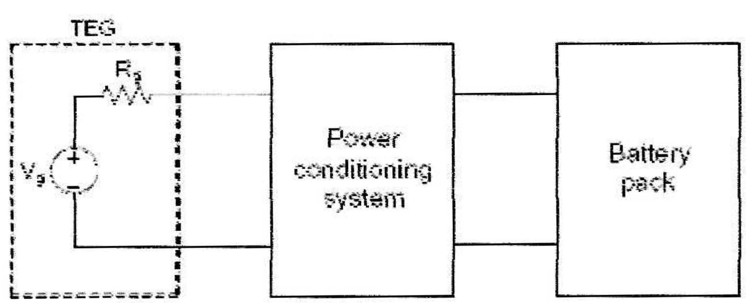

Figure 2.6 : TEG Power System (Source : Yu and Chau, (2009))