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EMPLOYMENT OF WASTE HEAT FOR THERMOELECTRIC-BASED ENERGY HARVESTING

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ABSTRACT

Nowadays, there are many global warming issues as abundance of waste heat is released to the environment. A lot of machinery, electrical and electronic appliances from heavy equipment to small machines will produce waste energy in the form of waste heat. Therefore, the study on the employment of waste heat for thermoelectric-based energy harvesting that can convert heat energy directly to electrical energy is conducted. Based on thermocouple concept, the favourable material to produce more power is thermoelectric module made from Bismuth Telluride (Bi_2Te_3). The thermoelectric-based energy harvesting will convert the heat energy to electrical energy when there is a temperature difference between the hot and the cold side. This temperature difference on thermoelectric generator (TEG) plays an important role in producing a voltage output. It is found that the higher the difference in temperature, the higher the voltage produced. From the experiments, the highest temperature difference which is 10.8 ºC at the junction generated a DC voltage output of 0.92V.

Keywords: thermoelectric, energy harvesting, waste heat.

INTRODUCTION

Energy harvesting term has become a very popular term in academic and industrial world nowadays. This is due to our traditional power generation resources, such as fossil fuel which are facing global shortage crisis and simply being quite high in cost in recent years (Colomer *et al.* 2011). In contrast, the resources for energy harvesting are naturally present in our daily life such as motion from human movement, waste heat from engine combustion, and electromagnetic energy from communication (Li, 2011).

In recent years, many researchers are focusing on how to reuse energy losses (Abd Jalil and Sampe, 2013). These research consists of piezoelectric energy harvesting, electromagnetic energy harvesting, pyroelectric energy harvesting, waste heat recovery, etc. (Paolo *et al.* 2010). Among all of these researches, waste heat recovery is the most concerned due to the widespread existence and high accessibility of suitable resource which is waste heat (Ismail and Ahmed, 2009). There are a lot of waste heat recovery benefits such as reduction in the process consumption and cost, reduction in pollution and equipment sizes, and also reduction in auxiliary energy consumption (Li, 2011). Furthermore, there are numbers of devices to fulfill waste heat recovery. However, thermoelectric generator (TEG) has drawn into attention as thermoelectric effect enable direct conversion from thermal to electrical energy (Maharaj and Govender, 2012), (Assion *et al.* 2011), (Weng and Huang, 2013), Yang, 2005), (Zebarjadi and Chen, 2013), and provides an alternative source for power generation.

Thermoelectric devices utilize the Seebeck effect (Ugalde *et al.* 2011). According to the Seebeck effect, when closed circuits with two surfaces at two different temperatures, an electric potential will be developed in the circuit (Ismail and Ahmad, 2009), (Maharaj and Govender, 2012). The electric potential produced depends on the temperature gradient that exists between the hot side junction and cold side junction. Therefore, electrical potential can be used to produce an electric current in a closed circuit.

Recently, technology of portable devices such as mobile phone and Global Positioning System (GPS) has increased drastically. However, the battery of portable device does not long lasting. Eventually, the need of portable charger increased. As in nowadays, vehicles such as truck, bus and car, have their own system to recharge this portable devices. However, for motorcycle users, they do not have the built-in system to recharge their portable devices. Hence, they really need a system to recharge their portable devices, especially mobile phone during a long ride.

Nowadays, there are many issues arise due to the global warming because of abundance of waste heat released to the environment. Machines, electronic and electrical appliances; heavy and simple, release a lot of waste heat. Same goes to a motorcycle's exhaust system where most of the energy is released in the form of heat that actually can be reused as a source of energy to charge up any portable devices such as mobile phones or GPSs.

The aim of this study is to generate electricity from the waste heat harvested from a motorcycle's exhaust using TEG. TEG is a device which converts heat directly into electrical energy using a phenomenon called the "Seebeck effect" that has been introduced before. Recently, TEG is often mentioned together with photovoltaic as energy harvesting device in the future because photovoltaic has a longer history of application. However, when it comes to effective applicable time, TEG has an an advantage of not depending on factors such as daylight hour and changes of weather as compared to photovoltaic.

"Seebeck Effect" was discovered by a German physicist Thomas JK. Seebeck in 1821 (Ismail and

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Ahmed, 2009). The phenomenon occurs when there is temperature difference between the hot and cold junction that is made up of two dissimilar materials (metals or semiconductor) where voltage known as Seebeck Voltage (Ismail and Ahmed, 2009) will be generated through the junction. Thermoelectric device can act as an electrical power generator due to the Seebeck effect.

The Seebeck effect is a basic principle of thermoelectric that has been describe as the conversion of temperature differences directly into electricity. The conductor materials used to generate the Seebeck effect consist of two different types of semiconductors or metals. When there is temperature gradient on both sides of the metals or semiconductors, a voltage will be created. A schematic diagram of a simple thermoelectric power generator is shown in Figure-1.

As shown in Figure-1, Q_H is the rate transfer of heat from high-temperature heat source at T_H to the hot junction, and it rejected a heat transfer rate of Q_L to a low-temperature sink at T_L from the cold junction. Electric current will flow in the circuit and generate electrical power, $W_e = Q_H - Q_L$ when there is heat supplied at the hot junction.

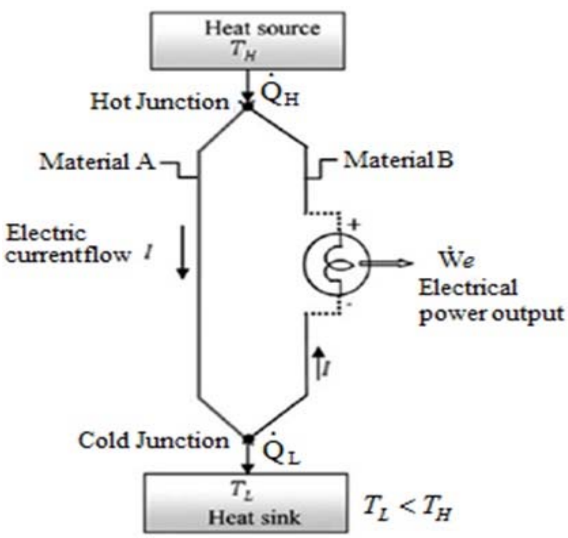

Figure-1. Basic concept of thermoelectric generator based on Seebeck effect (Ismail and Ahmed, 2009).

METHODOLOGY

The methodology of this study can be divided into three main sections: simulation, hardware development and hardware operating system.

Simulation process

For the simulation process, two softwares were used, Proteus 7.7 and PIC C Compiler. Proteus 7.7 is required to design the circuit for Thermoelectric-based energy harvesting system. Meanwhile, the PIC C Compiler is used to develop the coding for this system. Figure-2 shows the overall flow chart of how PIC controls the whole system. The developed PIC program will ultimately shows the generated voltage value harvested from the TEG and will be updated every 10 seconds to allow significant changes.

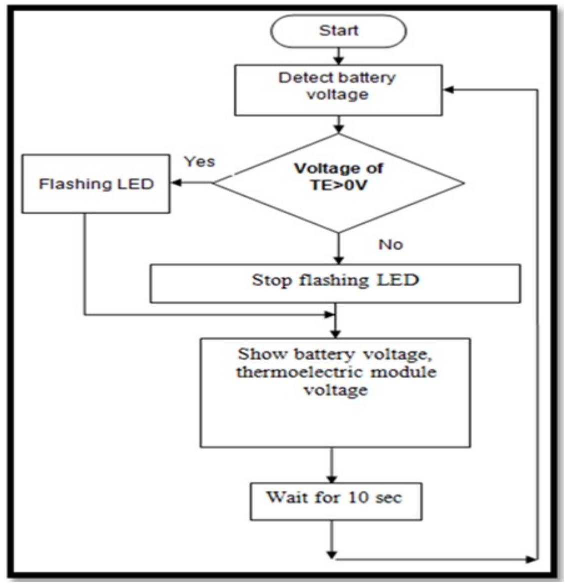

Figure-2. Flowchart of PIC program.

Hardware development process

For the hardware development process, several components are required to develop the thermoelectric-based energy harvesting system as shown in Figure-3. Figure-3 shows the block diagram for the harvesting system. The harvested energy may be directly utilized to power low power devices or may be stored in a storage system.

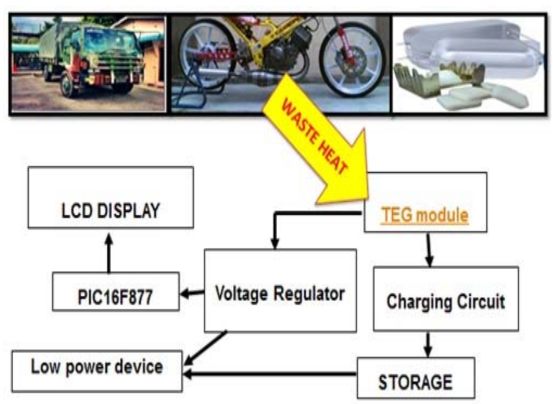

Figure-3. Block diagram for thermoelectric-based energy harvesting system.

Different size of TEG module will result in different power output even though the temperature differences are same. For this study, the main component which is a TEG module with the size of 40mm (W), 40mm (L) and 3mm (H) as shown in Figure-4 is being used since it can produce enough power for this study based on its specification.

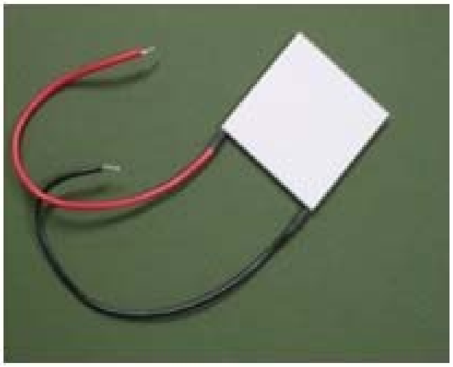

Figure-4. TEG modules (Thermoelectric module, 2009).

PIC16F877-I/P is used to control the whole system. This PIC can read/write program for more than 100,000 times (PIC data sheet, 2003). It has 40 pins and 8 kB of program memory size. An HD44780 Character LCD is an industry standard liquid crystal display (LCD) display device designed for interfacing with embedded systems (LCD data sheet, 2003). This LCD screens is limited to text only and is often used in copiers, fax machines, laser printers, networking equipment such as routers and storage devices. Figure 5 shows the instruments used to measure the voltage produced by TEG and temperature difference between the hot side and cold side of TEG, respectively.

Figure-5. Digital thermocouple and multimeter.

Hardware operating process

Hardware operating process is divided into three parts as shown in Figure-6 which are the input, output and main part.

As shown in Figure-7, the main part consists of three sub-part which are PCB board which function to run the overall process, the battery as the storage for the energy harvested and the LCD to display the voltage harvested from TEG and the voltage stored in the battery.

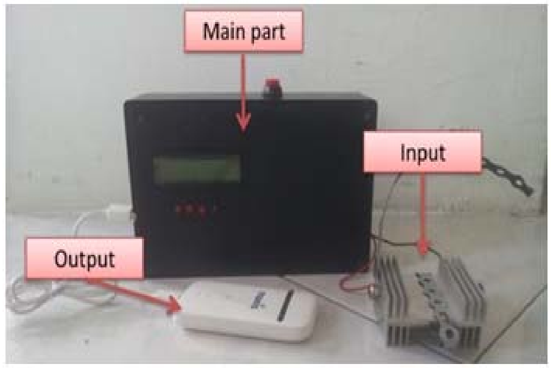

Figure-6. Hardware system.

Figure-8 shows the compartment of input and output for the study. This study of Thermoelectric based energy harvesting system is only fully functional when there is a temperature difference supplied to the input. The difference between the two sides of the TEG will produce voltage in which the voltage produced is supposed to charge the 12V rechargeable battery and optionally users may also choose to directly use the scavenged voltage for charging a low powered device at the output part. With regards to this study, the battery also serves to power up the whole system.

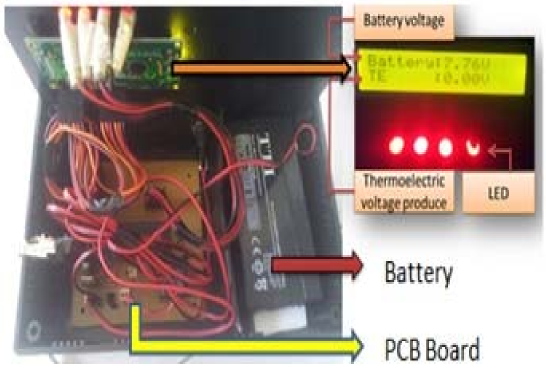

Figure-7. Main part.

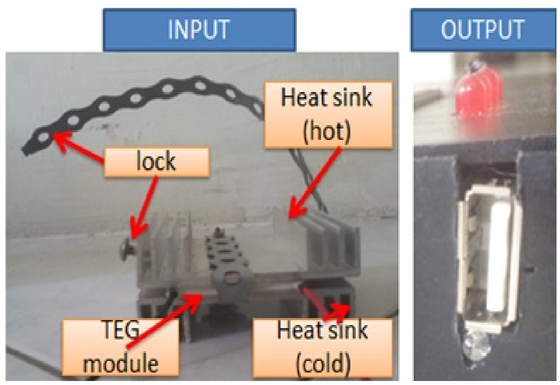

Figure-8. Input and output part.

RESULTS AND DISCUSSION

For this study, four experiments were done to observe the DC voltage being produced by the TEG when there is a temperature difference between the hot and cold sides. For each experiment, waste heat from motorcycle's exhaust is used to supply heat at the hot side of the TEG. Figure-9 shows how the input part of this system is attached to the motorcycle exhaust system. Motorcycle Yamaha LC 135cc exhaust system has been used for all the experiments conducted.

During engine start

This experiment was conducted to monitor the output voltage produced by TEG versus time when the motorcycle engine starts to operate. Based on the graph in Figure-10, it shows the highest voltage produced by TEG is 0.28V at minute 10. It indicates that the voltage increases as the time increases. This is because, as the time increases, the exhaust from motorcycle will increase in temperature due to combustion on the engine system. Therefore, higher temperature on the hot side of the TEG attached to the exhaust will increase the temperature difference between hot and cold side of TEG.

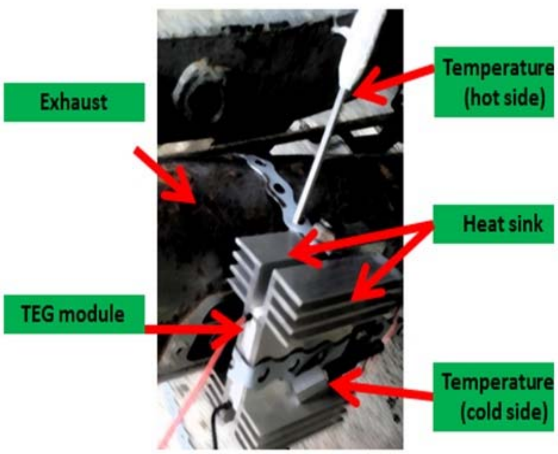

Figure-9. TEG attached to motorcycle exhaust.

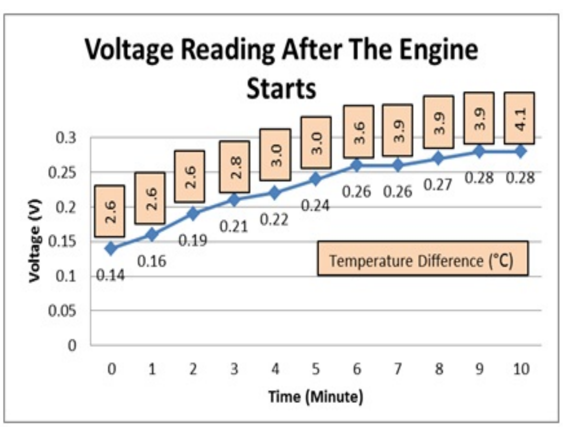

Figure-10. Graph of voltage versus time just after the engine starts.

During engine ramp

Experiment of "engine ramp" is taken when the throttle of motorcycle is turned up. Based on the graph in Figure-11, the voltage is rapidly increasing until minute 9 and the voltage produced by the TEG is 0.81V at temperature difference of 7.9 ºC. The voltage is rapidly increasing due to the increasing fuel and air intake by engine when the engine ramp thus will increase combustion and release lots of waste heat to exhaust system.

During motorcycle running

The voltages for this experiment were taken when the motorcycle was running at a constant speed of 60 km/h. Figure-12 shows that that the voltage is slowly increasing when time increases. The maximum voltage produced during this experiment is 0.92V because the combustion of engine increases and more waste heat is released to the exhaust system.

During engine stop

For the last experiment, data has been taken just after the engine of the motorcycle is turned off. Therefore, no more combustion is occurring inside the engine system. Figure-13 shows the voltage produced by the TEG for 10 minutes after the engine is turned off. Based on the graph, voltage is decreasing as the time increases. This is due to the heat released from the exhaust system to the surrounding and will result in the temperatures at cold side and hot side achieving thermal equivalent due to no more heat supplied to the hot side of TEG. Therefore it can be stated that when the temperature difference decreases, the voltage is decreasing. The highest output voltage for this experiment is at 0.78V.

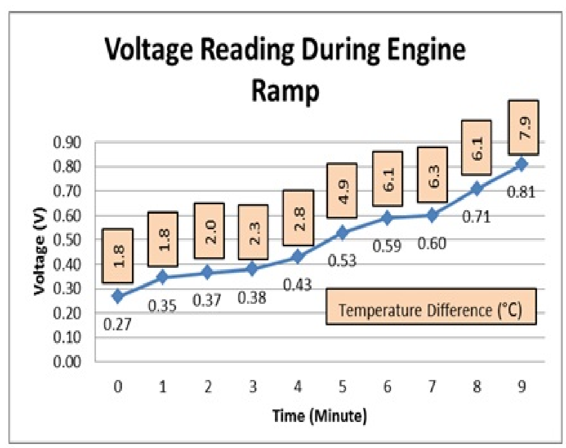

Figure-11. Graph of voltage versus time during engine ramp.

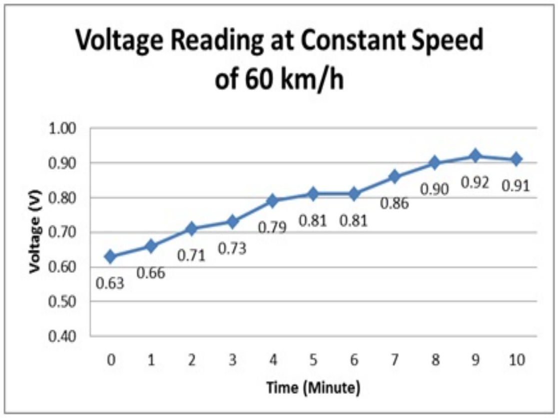

Figure-12. Graph of voltage versus time when motorcycle's engine is running.

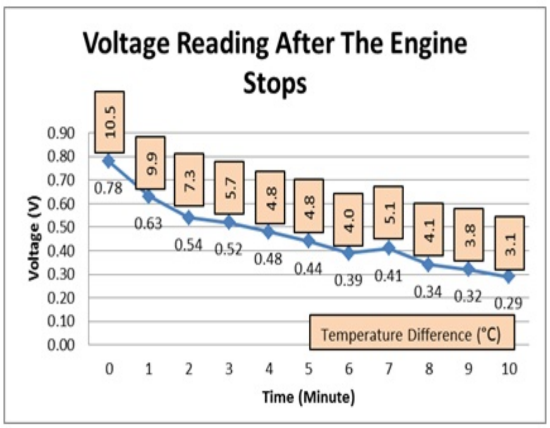

Figure-13. Graph of voltage versus time just after the engine stops running.

Based on the result of all four experiments, the graph that conclude the thermoelectric module voltage for a continuous 40 minutes is shown in Figure-14. From the graph, the maximum voltage that has been produced by this system is 0.92V at minute 31 when the motorcycle is running at a constant speed of 60km/h.

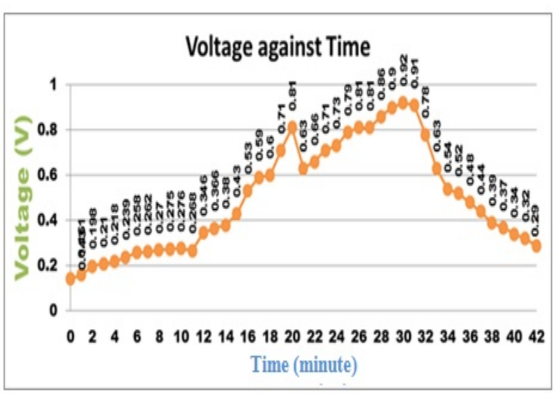

Figure-14. Overall experiments voltages versus time.

CONCLUSIONS

From this study it is shown that energy can be harvested based on waste heat from many sources such as motorcycle's exhaust system. In addition, the output voltage of thermoelectric generator depends on the temperature difference between the hot and cold sides. The higher the temperature difference, the higher the output voltage produced. During the experiments, the maximum temperature difference produced was at 10.8 ºC which generated a voltage output of 0.92V when the motorcycle was running at a constant speed of 60km/h. Therefore it can be concluded that, the temperature at the hot side influences the output voltage produced by the TEG. For future work, it is recommended that the experiments are repeated to check the repeatability of the measurement results.

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