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AN EXPERIMENTAL INVESTIGATION IN GENERATION OF ELECTRICAL ENERGY FROM TEG (Bi_2 Te_3)

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Abstract

With the increasing in price on petroleum products due to the depletion in source of availability and also increase in the rate of consumption as automobiles are increasing in quantities day by day. When the fuel is burnt, 20% to 25% of the heat generated in the fuel combustion process is converted into useful mechanical work and remaining heat is emitted to the environment through the exhaust gases and the engine cooling systems, resulting in an enormous waste of energy. If we can trap such unused heat energy and try generating electric power using Thermoelectric Generator we can store that electrical energy and can be used as power backup or can run the electrically operated equipments. The increasing amount of electrical and electronic devices on vehicles provides more comfort and convenience for users, while places higher requirements on vehicle power supply.

In this paper an effort is made to prepare a lab scale model setup and has conducted an experimental study of the characteristic behavior of TEG (Bi_2 Te_3) using copper as a base plate of 5mm thick & generates electrical energy under three different variable conditions.

1. Varying the thickness of aluminum supporting block at different mechanical loading condition
2. Varying the thickness of aluminum supporting block at maximum constant mechanical loading without TIM or Thermal Grease.
3. Varying the thickness of aluminum supporting block at maximum constant mechanical loading with TIM or Thermal Grease.

   And understand at what condition the maximum power can be generated.

1. Introduction

TEGs are devices which convert heat (temperature differences) directly into electrical energy, using a phenomenon called the "Seebeck effect" (or "thermoelectric effect").

Automotive industry is one of the main application fields of TE technologies. Among all the possible applications of TEG technologies, vehicle waste heat harvesting by thermoelectric generator (TEG) is generally believed to be a feasible trial. The reasons for this belief is straight-forward and intuitive. One of the main reasons is that a large portion of all generated energy from combustion engine is emitted as waste heat. For a typical gasoline fueled internal combustion engine vehicle, only about 25% of the fuel energy is utilized for vehicle mobility and accessories; the remainder is lost in the form of waste heat and coolant, as well as friction and parasitic losses (Figure 1.1) which provides possibility of desired large temperature gradients for TEGs. Exhaust gas system is an example of waste heat harvesting location.

From another perspective, many other industrial developments urge the development of TEGs for automotive applications. The increasing amount of electrical and electronic devices on vehicle provides comfort and convenience for users, while places higher requirements on vehicle power supply. Furthermore, the global gasoline shortage gives rise to the necessity of the development of hybrid engine vehicles (HEV), which entails more efficient, economic and environment-friendly method of providing power sources for vehicles. These facts greatly spark research interests on TEG for vehicles

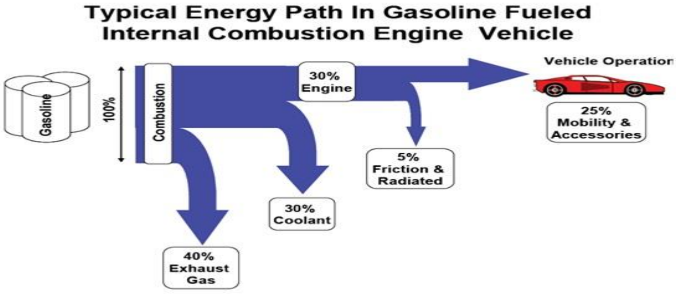


Figure 1.1: Typical energy path in gasoline fueled internal combustion engine vehicles [8].

Consequently there are two general ways to reduce vehicle fuel consumption:

1. Increase the overall efficiency of the power train
2. Waste heat from the exhaust gas from the vehicle accounts for a considerable portion of the fuel energy that is not utilized, about 40% from figure (1.1).

Therefore a means to improve the fuel economy is to increase the overall efficiency of the Power train by recovering waste heat from the exhaust gas of the vehicle.

2. Lab setup model

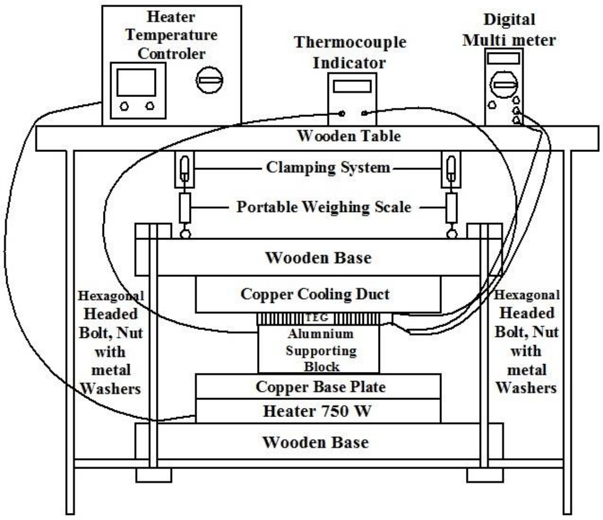


Figure 1.2 Line diagram of lab setup Model

The subparts of the Setup are as follows:

1) Heater with controller, 2) Two Wooden plates with 12mm bolts of 4 numbers,
3) Copper base plate (5mm thick), 4) Aluminum supporting block of Variable thickness (5mm, 10mm, 15mm, 20mm & 30mm thick), 5) Thermo electric Generator device (Bi_2 Te_3), 6) Cooling duct made of Copper, 7) Portable weighing scale, 8) Thermocouple Indicator, 9) Silicon based grease loaded with Zinc oxide.

A wooden plate is clamped by a pair of 12mm bolts at the bottom of the frame. Over it a mica heater is placed and it is connected to the heater controller unit (HCU). A thermocouple is placed above the heater to sense the temperature in order to control the heating at set temperature. Above the heater a Copper base plate of 5mm thick is placed because of its high thermal conducting ability. An aluminum supporting block is placed over the plate to safely control the heat at the bottom of thermoelectric generator, as well as to increase the gap between the heating and the cooling sides. A cooling duct in which continuously water is circulating is placed above the TEG so as to increase the temperature difference on either sides of TEG. The entire set up is placed in this order and again clamped by a Hexagonal Headed bolt, Nut and metal washers on all 4 corners.

3. Methodology & results

Figure 1.3: Lab setup

The experiments are conducted based on 3 major variables and the details are as follows:

Copper as base plate of 5mm thickness having aluminum supporting blocks of variable thickness of 5mm, 10mm, 15mm, 20mm & 30mm

CASE A: Varying the thickness of aluminum supporting block at variable mechanical loading.

CASE B: Varying the thickness of aluminum supporting block at constant maximum mechanical loading without application of Thermal Grease

CASE C: Varying the thickness of aluminum supporting block at constant maximum mechanical loading with application of Thermal Grease

<u>CASE A: Power generation at variable thickness of aluminum supporting block at variable mechanical loading.</u>

The experiment proceeds as follows:

STEP 1: Note the Weight of the cooling duct (with water) and the top most wooden plate.

STEP 2: Place it as per the specified order and lock the nut till it touches the surface.

STEP 3: By adjusting the height of weighing scale in the top, set the reading to zero.

STEP 4: Mark a reference point on all the 4 nuts and a reference lines on the wooden plate at an angle of 90^o each.

STEP 5: Using wrench or spanner need to tighten all the 4 nuts by rotating the diagonally opposite nuts at an angle of 90^o simultaneously and note down the mass applied.

STEP 6: Allow water to flow through the cooling jacket at a rate of 2 LPM

STEP 7: Switch on the console of controller and set the value to some temperature and make it constant.

STEP 8: Once it reaches a steady state, note down the voltage and current showing in the multimeter and also the hot and cold side temperature from the digital temperature indicator.

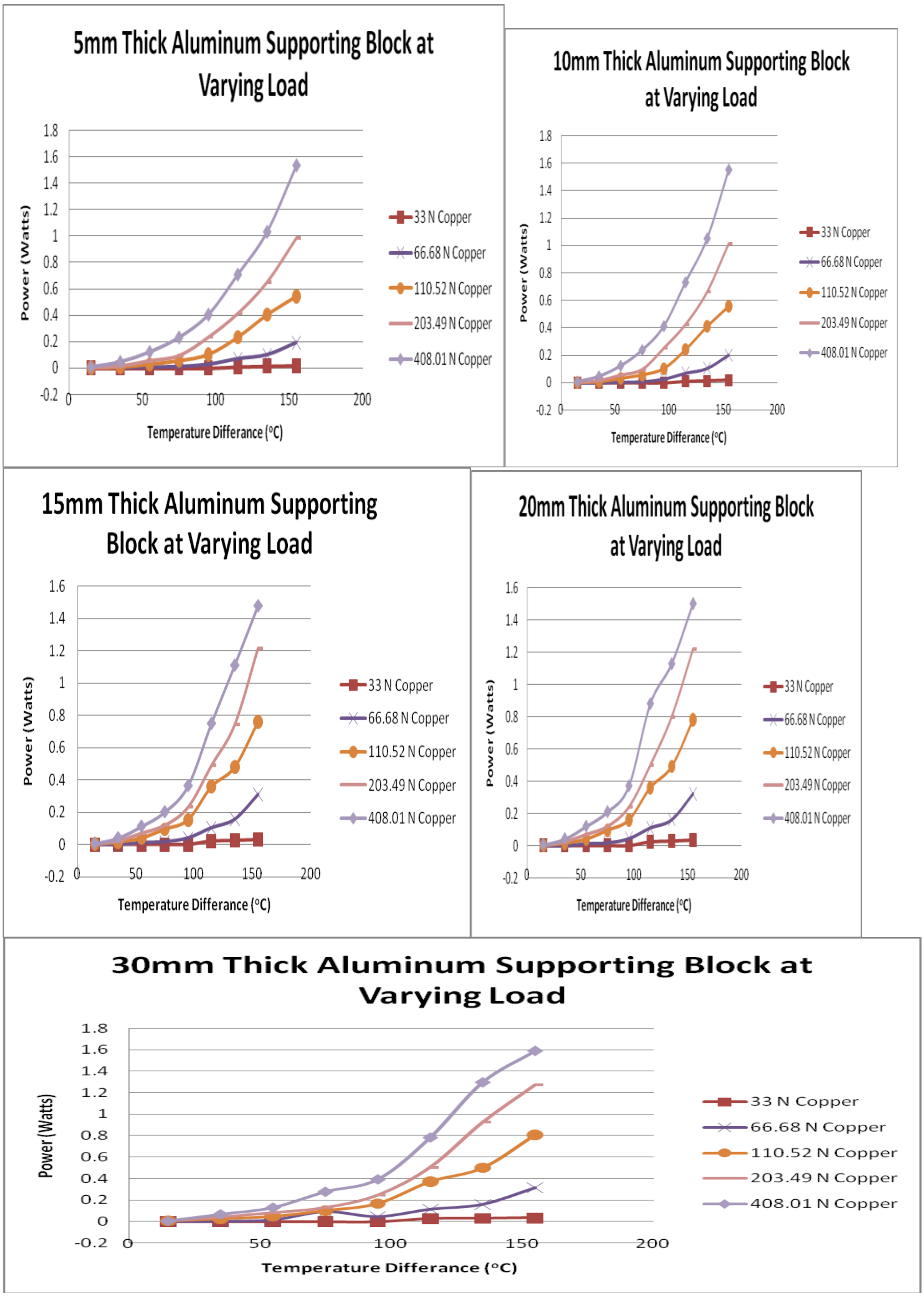
STEP 9: Repeat the STEP 5 & STEP 8 procedure and continue till we attain maximum tightening and note down the required details.

STEP 10: Increase the temperature for the next 10^oC and repeat the STEP 5 & STEP 8 respectively

MECHANICAL LOAD CALCULATION:

NOTE: Here Total load applied = [mass of cooling duct with water (Kg)+ mass of wooden plate (Kg)+ mass applied by rotating all 4 nuts] X 9.81 m/s^2

- At 0^o Rotation the total load was 33 Newton[(2.335 + 1.035 + 0) X 9.81]
- At 90^o Rotation the total load was 66.68 Newton[(2.335 + 1.035 + 3.427) X 9.81]
- At 180^o Rotation the total load was 110.52 Newton[(2.335 + 1.035 + 7.897) X 9.81]
- At 270^o Rotation the total load was 203.49 Newton [(2.335 + 1.035 + 17.37) X 9.81]
- At 360^o Rotation the total load was 408.01 Newton [(2.335 + 1.035 + 38.22) X 9.81]



Graph 1.1: Power (Watts) vs Temperature difference (°C)

From graphs we can analyse that more the load we applay, more the power gets generated and in our setup we were able to reach maximum power generation at maximum load of 408.01N hence at that particular load we performed the CASE B & CASE C.

CASE B: Power generation at Variable thickness of aluminum supporting block at maximum constant mechanical loading 408.01 N without TIM or Thermal Grease.

STEP 1: Note the Weight of the cooling duct (with water) and the top most wooden plate.

STEP 2: Place it as per the specified order and lock the nut till it touches the surface.

STEP 3: By adjusting the height of weighing scale in the top , set the reading to zero.

STEP 4: Using wrench or spanner need to tighten all the 4 nuts by rotating the diagonally opposite nuts simultaneously to the maximum and note down the mass applied. (408.01 Newton)

NOTE: Here Total load applied = (mass of cooling duct with water + mass of wooden plate + mass applied by rotating all 4 nuts) X 9.81 m/s^2

STEP 5: Allow water to flow through the cooling jacket at a rate of 2 LPM

STEP 6: Switch on the console of controller and set the value to some temperature

STEP 7: Once it reaches a steady state, note down the voltage and current showing in the multimeter and also the hot and cold side temperature from the digital temperature indicator.

STEP 8: Repeat the STEP 7 after increasing the set temperature for next 10^{o}C.

CASE C: Power generation at Variable thickness of aluminum supporting block at maximum constant mechanical loading 408.01 N with TIM or Thermal Grease.

As if we see the readings of case A, we can understand more the tightening is done more the power is getting generated and reason is the reduction in air gap formed between the plates due to the 2 reasons:

- Due to less tightening
- Due to uneven of surfaces in microscopic level.

These air gaps which are formed between the Base plate to aluminum block, between the aluminum block to the TEG and between the TEG to the cooling jacket, in all these junctions the air gap is acting as a insulator due to thermal contact resistance. This drops the performance of TEG (Figure 1.4)

The tightening can be overcome by applying appropriate torque. But the uneven surface of the plates in microscopic level should be concentrated. they consist of “hills”, “peaks” and “valleys”. When these two surfaces are brought into contact with one another, only the peaks make contanct. It has been calculated that the average amount of contact between any two smooth surfaces is in reality only 5%. The other 95% are voids.

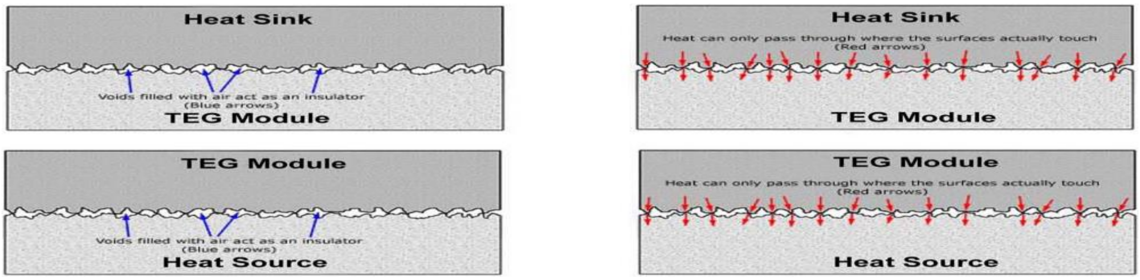


Figure 1.4: Effect of peaks and valleys when assembled [12]

Figure 1.4 shows how the remaining valleys creates voids through which heat energy can barely pass through, in effect creating an insulated area not the ideal thermal interface.

To avoid this Thermal contanct resistance, A third party interface material is needed since it is all but impossible to achieve ideal flat and smooth surfaces. The purpose of using Thermal Grease is to fill the valleys and gaps with a material that has a much higher thermal conductivity (ability to transfer heat) than the air gaps it replaces. This essentially makes the entire interface transfer heat instead of just where the peaks were contacting. The following image shows how the situation has been dramatically improved.

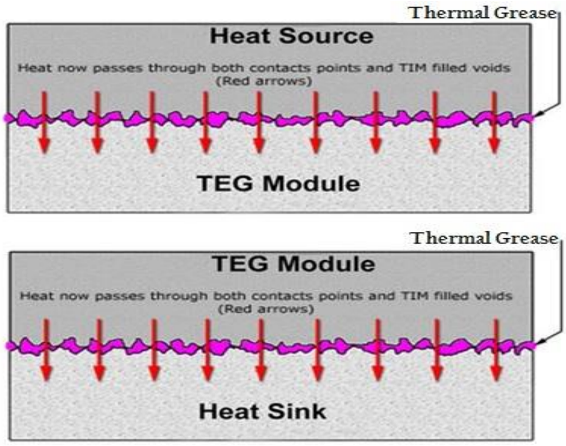
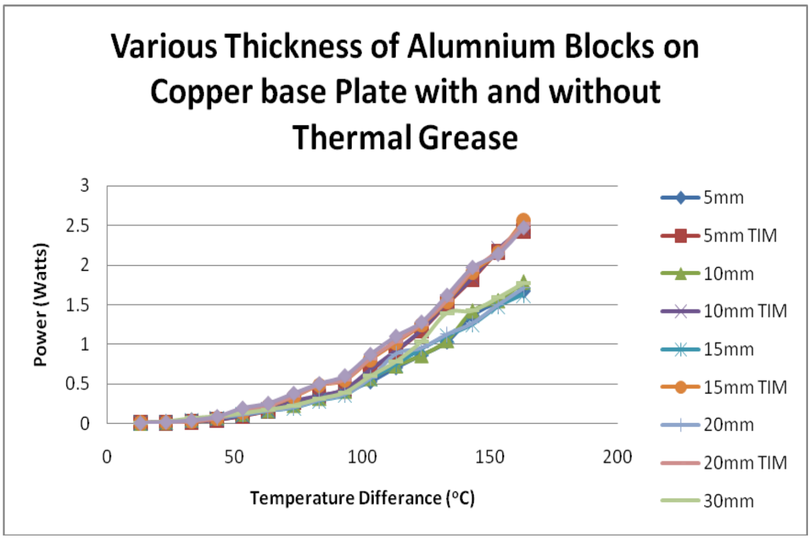


Figure 1.5: Effect of peaks and valleys after applicatiion of Thermal Grease [12]

By the application of Thermal grease in between the TEG Module, Heat source & Heat sink, this will enchance heat transfer between two surfaces by filling in the microscopic voids casued by surface roughness. Most thermal greases are also known as Thermal interface material (TIM) or transistor heat sink compound or thermal joint compound which are made up of silicon grease loaded with zinc oxide. Non silicone based compound are also available which in most cases are superior but more expensive than silicone based alternatives.

Apply Thermal Grease on the Base plate, Alumnium blocks, TEG, Cooling duct and press it firmly in order to remove air gaps and then follow the steps of CASE B.

Now comparing the readings obtained from the procedure of CASE B & CASE C with aluminum as base plate or the copper as a base plate, the graph is as follows.



Graph 1.2: Power (Watts) vs Temperature difference (ºC)

4. Conclusion

There are several significant opportunities for thermoelectric recovery of waste heat. Through this work a thermoelectric generator has been used and characterized that produces enough power for a high intensity LED. An in depth analysis has been performed in selecting each component of the system to maximize power. A high temperature Bi_2Te_3 has been selected as the most cost effective module for this application.

With referance to the graph we can see 15mm Thick Aluminum supporting block with the application of Thermal grease curve gives maximum power output with respect to temperature difference with Copper as a base plate at maximum mechanical loading of 408.01 Newton.

Hence thermoelectricity is a promising method of harvesting low-grade waste heat in applications where traditional methods are impractical.

The efficiency of the system or the power requirement of any electrically operated equipments can be met by adding up more number of thermoelectric modules in the set up. A Series and parallel connections between numbers of modules can also improve the efficiency of the system and generate more voltage, Current and power.

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