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Design and Fabrication of Thermoelectric Generation System

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Abstract - In recent years, an increasing concern of environmental issues of emissions, in particular global warming and the limitations of energy resources has resulted in extensive research into novel technologies of generating electric power. Thermoelectric power generators have emerged as a promising alternative green technology due to their distinct advantages. Thermoelectric power generation offer a potential application in the direct conversion of waste heat energy into electrical power where it is unnecessary to consider the cost of the thermal energy input. The application of this alternative green technology in converting waste heat energy directly into electrical power can also improve the overall efficiencies of energy conversion systems. In this paper, a background on the basic concepts of thermoelectric power generation with their important and relevant applications to waste heat energy are reviewed and discussed.

Key words: Thermoelectric sensor, Aluminium Fin and Peltier effect.

1. INTRODUCTION

The internal combustion engine (ICE) does not efficiently convert chemical energy into mechanical energy. A majority of this energy is dissipated as heat in the exhaust and coolant. Even a highly efficient combustion engine converts only about one-third of the energy in the fuel into mechanical power serving to actually drive the automobile. The rest is lost through heat discharged into the surroundings or, quite simply, leaves the vehicle as "waste heat". So rather than directly improving the efficiency of the engine, efforts are being made to improve the efficiency of the engine indirectly by using a waste heat recovery system. Thermoelectric generation technology, as one entirely solid-state energy conversion method, can directly transform thermal energy into electricity by using thermoelectric transformation materials. A thermoelectric power converter has no moving parts, and is compact, quiet, highly reliable and environmentally friendly. Therefore, the whole system can be simplified and operated over an extended period of time with minimal maintenance.

Compared to other waste heat recovery technologies, the use of TEGs in a waste heat recovery system has many desirable attributes such as silence, small size, scalability and durability. Their key attribute is that they have no moving parts and no chemical reactions therefore there is little maintenance required due to wear and corrosion.

Their efficiency is relatively low compared with a Rankine cycle waste heat recovery system but as there are no costs associated with waste heat, efficiency is not the most important factor. The most popular form of thermoelectric material is Bismuth Telluride. The use of this material in generators is limited because their maximum hot side operating temperature is relatively low. As they are widely used and mass produced, their cost is low compared to other thermoelectric materials. Other materials and techniques have been used to improve the power generation and efficiency of TEGs.

The most promising and practical materials to be used for TEGs in exhaust heat recovery systems would be materials rated for a high temperature. This means a larger temperature difference can be present and potentially more power and higher efficiency can be achieved. The use of high temperature TEGs also allows for the simplification of a design because efforts do not need to be made to prevent the TEGs from overheating.

2. METHODOLOGY

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates voltage when there is a different temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference. At the atomic scale, an applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side.

[1] Working Principle

A) Principle of Thomas Johann Seeback effect:

The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances.

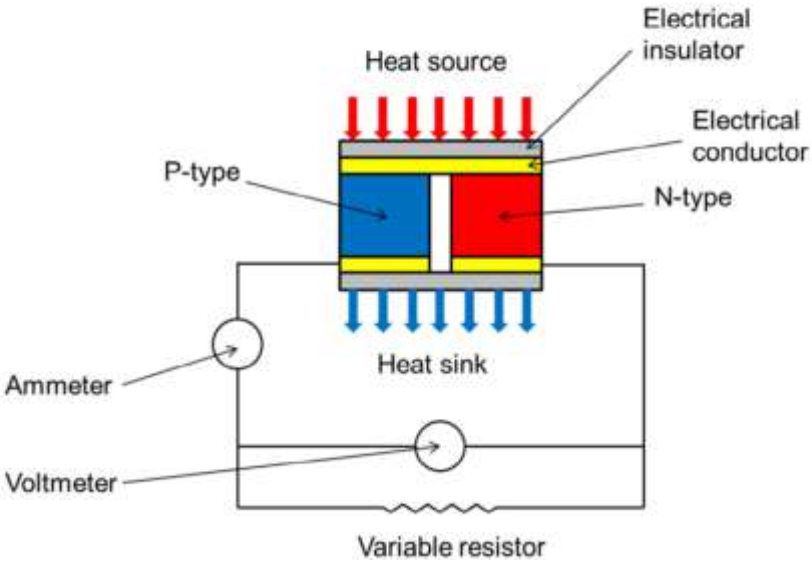


Fig 1.1: Principle of Seebeck Effect

B) Principle of Peltier effect:

The Peltier effect is the presence of heating or cooling at an electrified junction of two different conductors and is named after French physicist Jean Charles Athanase Peltier, who discovered it in 1834. When a current is made to flow through a junction between two conductors A and B, heat may be generated (or removed) at the junction.

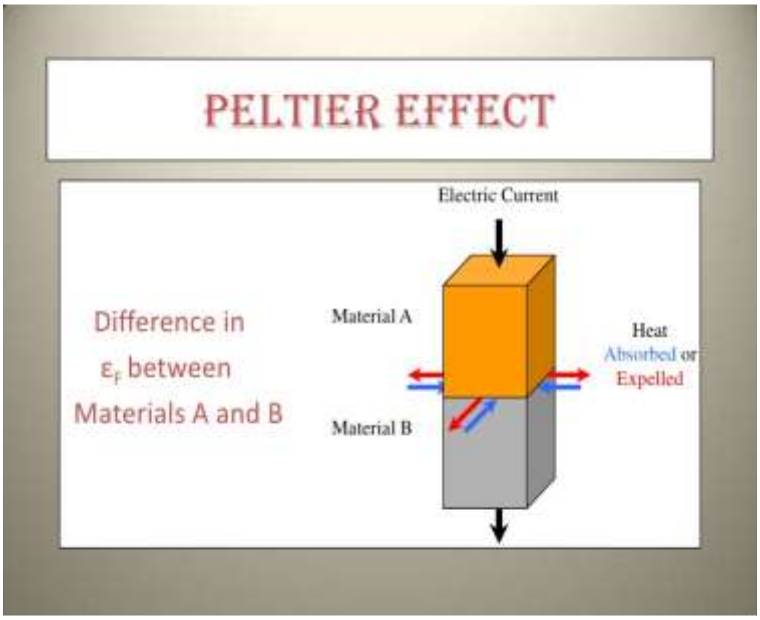
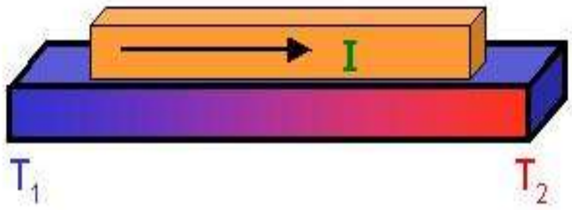


Fig 1.2: Principle of Peltier effect

C) Principle of Thomson effect:

Heat is absorbed or produced when current flows in material with a certain temperature gradient. The heat is proportional to both the electric current and the temperature gradient. This is known as Thomson effect.



$$\tau I \nabla T \equiv \text{Power evolved per unit volume}$$

Fig 1.3: Principle of Thompson Effect

[2] MATERIAL SELECTION AND DESIGN

A) Selection of the TEG modules:

During normal running conditions the exhaust pipes of an automobile reach temperatures of about 120-150°C. TEGs are specified based on their working temperature range. Based on the above mentioned working temperatures the TEGs were selected. A total of 6 TEGs were purchased.

Specifications of the TEG modules:

- PELTIER 12706 REES52 Tec1-12706 Thermoelectric Peltier Cooler 12 Volt 92 Watt
- Number of TEGs used : 4
- Temp Range : max 250 °C
- Max working temp difference : 90 °C

Fig 2.1: TEG Modules

B) Selection of Aluminum metal plate and fins:

Aluminium is an element in the boron group with symbol Al and atomic number 13. It is a silvery white, soft, non-magnetic, ductile metal. Aluminium is the third most abundant metal. Aluminium has a density around one third that of steel or copper makes it one of the lightest commercially available metal. The resultant high stress to weight ratio makes it an important structural material allowing increased pay loads and corrosion resistance. Thermal conductivity of aluminium is about three times greater than that of steel. This makes aluminium an important material for both heating and cooling application such as heat exchangers. Combined with it being non-toxic this property means aluminium is extensively used in construction of corrosion resistance devices.

Fig 2.2: NX Model of The Aluminium plate

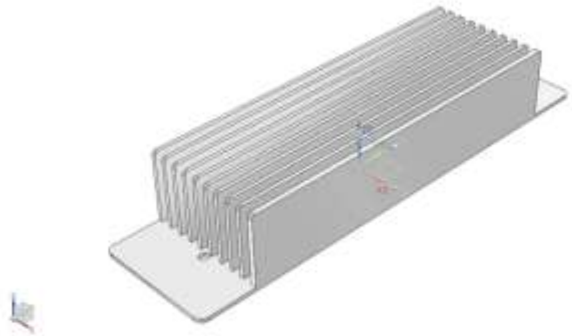


Fig 2.3: NX Model of the Aluminium Fin (Heat Sink)

C) Selection of mounting spot:

The thermal stress is more concentrated in the Elbow region and the base region of the silencer because the hot exhaust gas will directly strike the elbow region and take a diversion and so the velocity of gas will be reduced at those spots and this leads to the accumulation of more exhaust gas in those regions. Hence more amount of heat is said to be produced in those regions. However our method of cooling will not be effective because of heat radiation from the adjacent engine block. Moreover the temperature at this location will be way too high to get the required temperature difference by our cooling method. Considering the ease of fabricating the metal block we found it ideal to be mounted on the silencer itself as the silencer doesn't heat up as much. So if we place the TEG at this portion of the silencer then there would be maximum heat transfer leading to steady production of electric power.

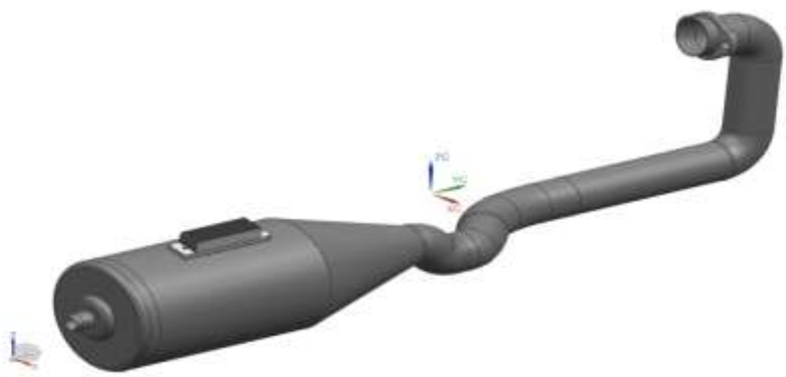


Fig 2.4: NX Model of the Exhaust Pipe with Mounted Assembly

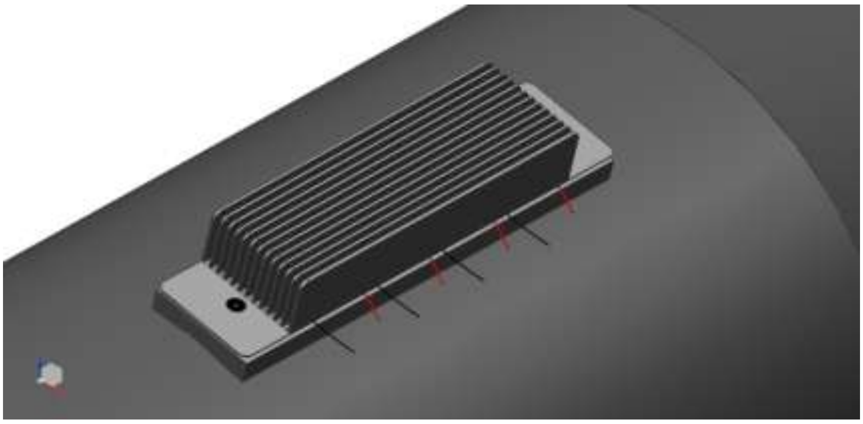


Fig 2.5: NX Model of the Mounted TEG Modules

[3] Assembly:

After machining all the required parts they were mounted on the silencer in the following manner:

1. Thermal paste was applied on the bottom curved surface of the Aluminum Block.
2. The Aluminum Block was mounted on the silencer with the two projected bolts properly aligned with the two counter bored holes machined on the metal Block.
3. A thin layer of thermal paste was applied on the surfaces of four TEGs on the side which would be exposed to hot temperatures.
4. They were then carefully placed on the Aluminum Block ensuring that there was no air bubbles trapped between the TEG modules and the Block surface.
5. The surface of the metal block left uncovered by the TEG modules was covered with asbestos threads for insulation.
6. Thermal paste was once again applied on the other "Cold" surface of the TEG modules.
7. The aluminum heat sink was mounted on top of these TEG modules with the application of pressure to attain a near perfect contact.
8. The whole setup was firmly secured to the silencer via two screws at both ends.

Fig 2.6: The Assembled System

3. WORKING

[1] Working of TEG mounted on the silencer of bike:

On to the atmosphere, the electrons and holes of the thermoelectric semiconductors will try to move towards the junction and make the flow of electric current to be possible the vehicle is started and the acceleration is to be given, so that the amount of heat leaving the exhaust will be increased. Due to this heat, the surface of the exhaust pipe and the silencer will be heated to very high temperatures. These hot surfaces will try to liberate the heat to the atmosphere, which acts as a Heat Sink. Since the atmospheric temperature is less than that of the silencer surface, a temperature difference is created and hence the surface tries to attain the equilibrium state through the heat transformation process. But this will take much longer time. Hence in order to increase the rate of heat transfer the Thermal Grease is used. The Thermal Grease is coated on the hot surface of the silencers and also in the inner surface of the fins which are present in the upper part. The fins are also used to increase the heat transfer rate. As the vehicle moves, the air flow will take place between the fins and it acts as the sink.

As the surface of the silencer gets more and more heated the heat transfer rate will increase due to the increase in the temperature difference. The Peltier module is placed between the Heat Source (Hot Silencer Surface) and the Heat Sink (atmosphere) and the fins are placed above the module. The module is made of semiconducting materials.

Hence by the principle of Seebeck Effect, the temperature difference can be directly converted into voltage by using some thermoelectric materials. Based on this effect, when the surface heat of the silencer is passed.

Fig 3.1: Experimental Setup with TEG Modules

[2] Testing 4 TEGs in series:

After running the bike for 10 minutes the desired high temperature of 120 °C was obtained on the surface of the silencer. The output voltage of the TEG modules were tested while throttling on neutral gear. Since the bike was stationary air cooling was not a possibility. Instead, water was continuously being poured on the fins to take away the heat. In actual testing the complete assembly was used i.e. all the four TEG modules were connected in series and each module supplied its own share of voltage. Since the TEG modules were connected in series the voltage across the whole circuit was the summation of the individual voltages. The following reading were obtained:

Using 4 TEGs:

T_1	T_2	T_1-T_2	VOLTS
68	37	31	1.28
76	40	36	1.50
82	45	37	1.74

Table 3.1: Voltage Readings

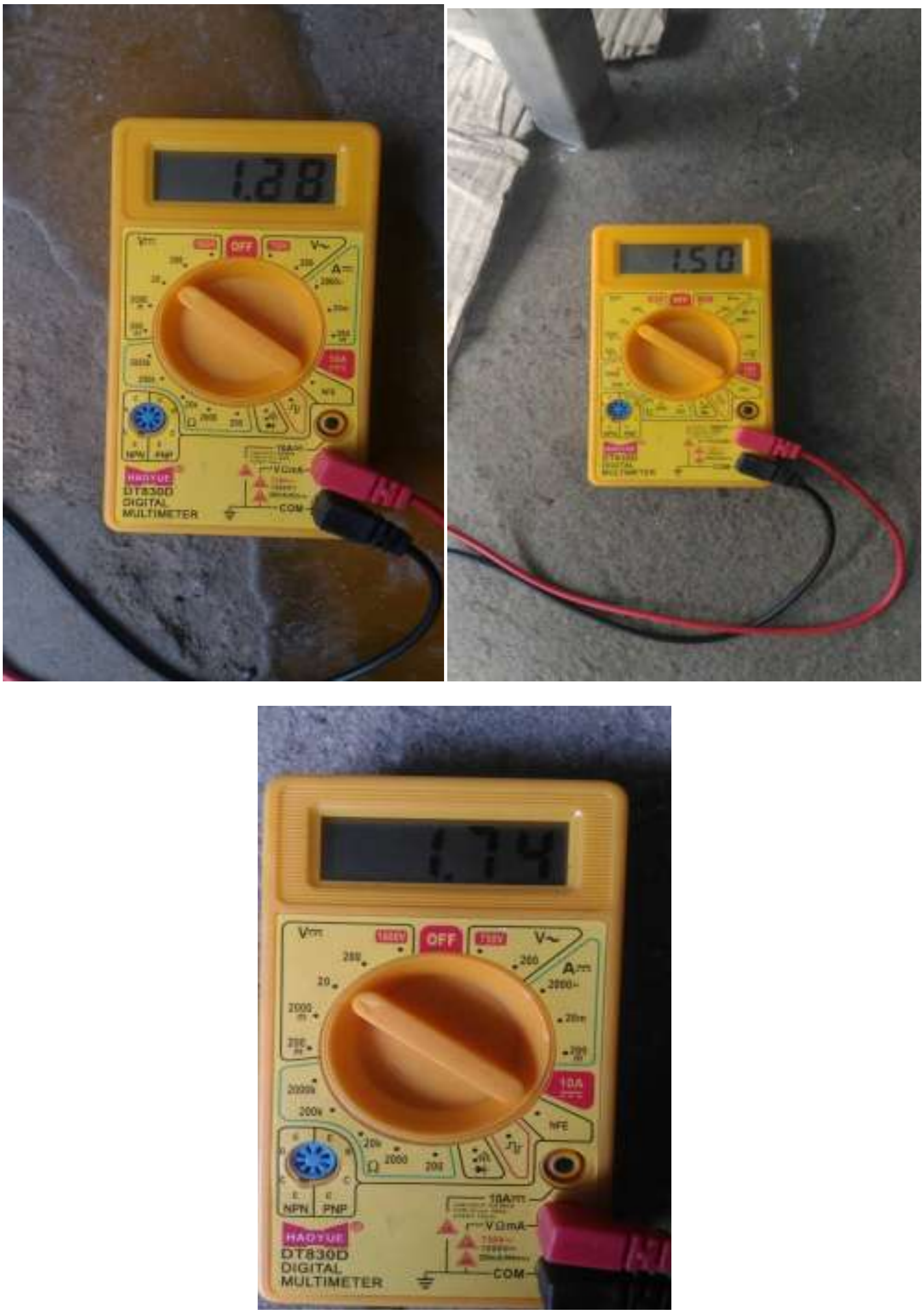


Fig 3.2: Gradual Increase of Voltage Reading

4. CONCLUSIONS

1. In this project an exhaust gas heat recovery power generator was successfully fabricated. The efficiency of the engine will not be affected because only the surface heat of the silencer is drawn out. The main objective of this project was to convert the recovered heat from the silencer to useful electric energy and plan to get voltage similar to that of Alternator voltage. This objective has been successfully accomplished in this project.
2. The TEGs were tested by mounting on engine silencer and recorded the voltage as shown in Table 3 by maintaining the temperature difference of 57°C.
3. The results were compared with that of an alternator.

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