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# Laboratory Scale Testing of Thermoelectric Regenerative Braking System

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**ABSTRACT:**

*Thermoelectric Regenerative Braking System (TERBS) employs an energy recovery mechanism by utilizing the energy conversion at the time of braking in an automobile to generate electricity accordingly. During braking, the kinetic energy of the disc rotor which is transformed into heat energy is recovered using a Thermoelectric Generator (TEG). A comparison of performance between air and water cooled heat sink is made and then the optimum way of cooling is selected for the TERBS. A customized TEG module with water cooled heat sink is designed. The experimental results are analyzed for optimum performance. TERBS evidently increased the life of a battery.*

**KEYWORDS:**

*Braking system; Thermoelectric generator; Heat sink; Electric vehicle*

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## 1. Introduction

To overcome the increasing demand for fossil fuels and other global warming crisis made by the commercial internal combustion engine vehicles, opting for electric or hybrid vehicle is the preferred solution amongst other options. But the problem with these vehicles is related to recharge the battery, e.g. several hours with a 120 volt household outlet and 1-4 hours with a 240 volt charger. A quick charge takes approximately 30 minutes to achieve 80% capacity. The distance on charge, cost of charging, and time to charge are the most influencing factors. In order for the vehicle to run on electrical power, the car alternator produces a considerable amount of electric power. The vehicle also performs the action of braking in order to generate some electricity which is widely known as Regenerative Braking System (RBS) that is purely mechanical. The reasons for inefficiency of this system are:

- The friction brake is a mandatory back-up in the event of a RBS, which drops out at lower speeds.
- Lot of moving parts and completely mechanical.
- Most cars with RBS have power generation only some of the wheels (as in two-wheel drive cars).

In this paper, Thermoelectric Regenerative Braking System (TERBS) is proposed to recover the wasted heat energy by braking to generate some electricity. First a customized Thermoelectric Generator (TEG) module with water cooled heat sink is designed and tested for its performance. Then this TEG module is assembled into a fabricated TERBS on a laboratory scale set up. Experimental results of generated voltage for various temperature gradients during braking are presented along with conclusions.

## 2. Customized TEG module with water cooled heat sink

Sivabalan [1] and Ramade et al [2] found that TEG can be used to produce power using the exhaust waste heat from IC engines. The graphical representation of working principle of TEG is shown in Fig. 1. The reasons for inefficiency of this system were:

- The process slows down the kinetic energy of exhaust gas which may cause back pressure.
- TEG gets easily damaged due to high temperature.
- Improper cooling leads to severe failure of TEG.

The exploded view of TEG model designed using CREO 2.0 software is shown in the Fig. 2. TEGs are capable of converting the heat directly into electrical energy using "Seebeck effect". TEGs are the peltier devices that are optimized for power generation. The performance specification of the SP1848-27145 TEG is given in the Table 1. In order to get sufficient output voltage, a very high seebeck co-efficient is needed. This problem is solved in some commercial devices by putting more elements in parallel and fewer in series. They are economical only at a high temperature and proper heat sink must be provided for effective performance.

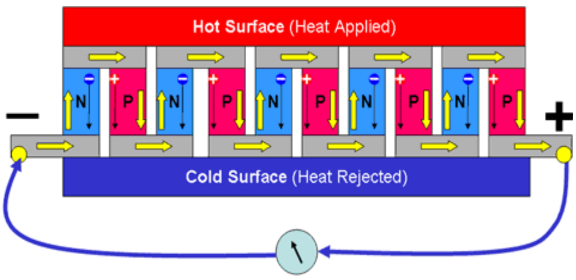


**Fig. 1: Working principle of the TEG**

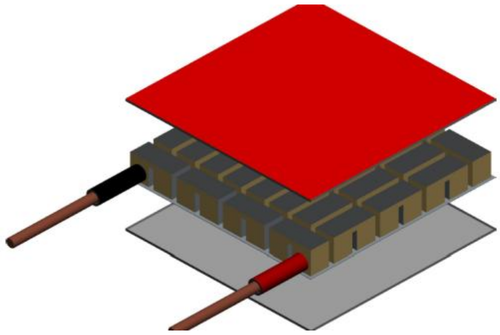

**Fig. 2: Illustration of TEG design**

**Table 1: Performance specification of SP1848-27145 TEG**

| Temp. gradient (°C) | Volts (V) | Current (mA) |
|---|---|---|
| 20 | 0.97 | 225 |
| 40 | 1.8 | 365 |
| 60 | 2.4 | 469 |
| 80 | 3.6 | 558 |
| 100 | 4.8 | 669 |

The heat initiated in the disc rotors during braking is fed to the TEG module by either tangible or intangible system. Constant feeding of heat helps to increase the efficiency of the module (i.e., generate more voltage). The modes of heat transfer [3] involved are convection (during vehicle running) and conduction (during rest). It achieves the heat transfer with the help of steam of cold water that flows inside the heat sink. The heat transfer, $q$, by conduction as per Fourier's law is given by,

$$q = kA(dT/dx) \tag{1}$$

Where $k$ is thermal conductivity of the material, $A$ is heat transfer area, $dT$ is the temperature difference across the material and $dx$ is the material thickness. The heat transfer, $q$, by convection as per Newton's law of cooling is given by,

$$q = hcAdT \tag{2}$$

Where $hc$ is the convective heat transfer coefficient, $A$ is heat transfer area, $dT$ is the temperature difference between the surface and the bulk fluid.

The TEG module is designed in the shape of 'C' where the heat generated is extreme [4-5] in the disc rotor as shown in the Fig. 3. The exploded view of the customized model of TEG and its water cooled heat sink are shown in Fig. 4. The TEG module was designed to concentrate on the entire disc area where the friction and heat will be more without disturbing the caliper. The experiments were undertaken using TEG module series SP1848-27145. Fig. 5 shows the comparison of the performance of the TEG ($16cm^2$) with air and water cooled heat sinks for selection and optimization of the best suited heat sink. The water cooled heat sink is best suited for better performance.

The TEG module and water cooled heat sink are fastened together and treated as a single component. The component is connected to the lower end of the shock absorber of the wheel by a small hinged extension rod to account for the wheel movement during irregularities in road surface. The component is placed very close to the disc so that it does not make any disturbances to the disc rotation and thus no drag force is created. The heat sink receives the water from the bottom of the radiator tank where the cooled water is accumulated and is pumped continuously by a small pump. A temperature sensor is placed at the component's hot side so that it cuts off the power supply for the pump after reaching the minimal temperature. The control switch for the pump depends on the temperature sensor. A displacement sensor is placed at the hand brake which attaches the component by hydraulic action to the disc.

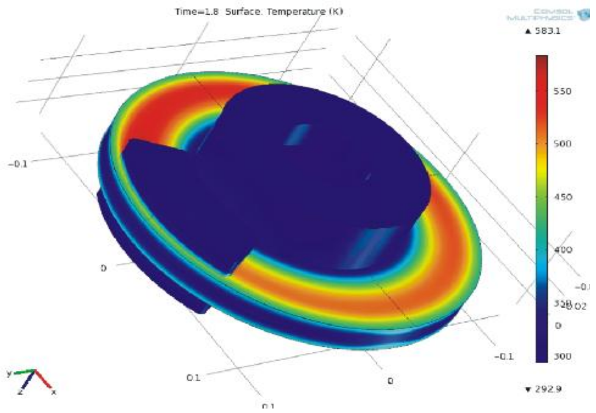


**Fig. 3: Illustration of heat generation in a cast iron disc rotor**

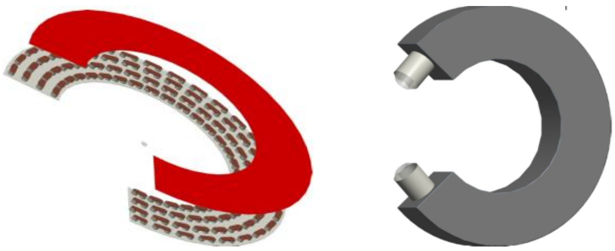

**Fig. 4: Exploded views of customized TEG (left) & heat sink (right)**

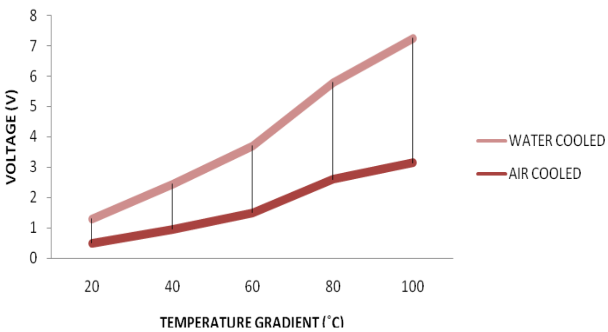


**Fig. 5: Performance of air & water cooled heat sinks**

## 3. Design, fabrication and test of TERBS

TERBS is employed with a view to produce the amount of electric power such that by the vehicle propel itself without depending on the external sources. The TERBS works by both conduction and convection. When the disc is heated during braking in a running vehicle, the heat is transferred by convection to the hot side of the TEG [6]. After a long running duration, the disc will be at a peak temperature. When the hand brake is applied after stopping the vehicle, the displacement sensor attaches the component to the disc and now the heat is transferred by direct conduction. The pump will run even after turning off the engine. The power supply is cut off by the temperature sensor which senses the attainment of minimum temperature required for a TEG to work. Fig. 6 shows the flow process of the TERBS.

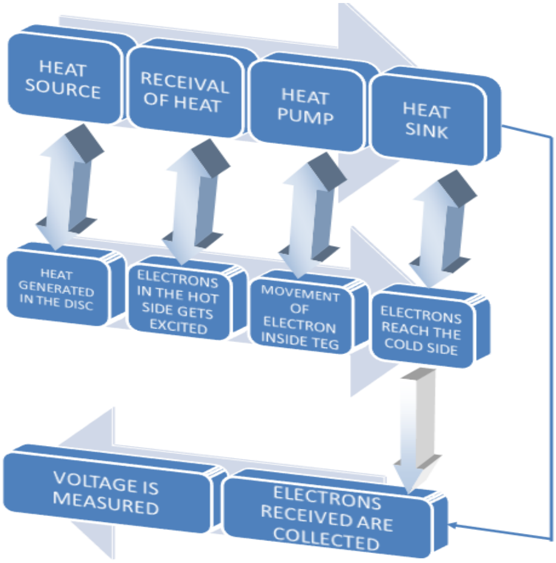


**Fig. 6: Flow chart of the working process of TERBS**

Fig. 7 shows the CREO model of the detailed TERBS laboratory test setup and a photograph of the fabricated system is shown in Fig. 8. An AC motor was used to generate the acceleration in the disc which is mounted on its output shaft and a caliper was placed at the right position to initiate the braking operation with the aid of a hand lever. The acceleration and deceleration of the disc was continued for a period of time. After attaining a considerable state, the TEG module along with the water cooled heat sink is manually made to touch the heated surface. The voltage is measured by the multimeter which is connected to the TEG terminals. The results obtained from the laboratory scale experiments are analysed. Fig. 9 depicts the performance of the custom designed TEG module of 96 $cm^2$ which is the measured area with respect to the design. It can be seen that the custom model TEG can generate voltage of 12V (which is the exact car battery voltage) with a temperature difference of 40°C.

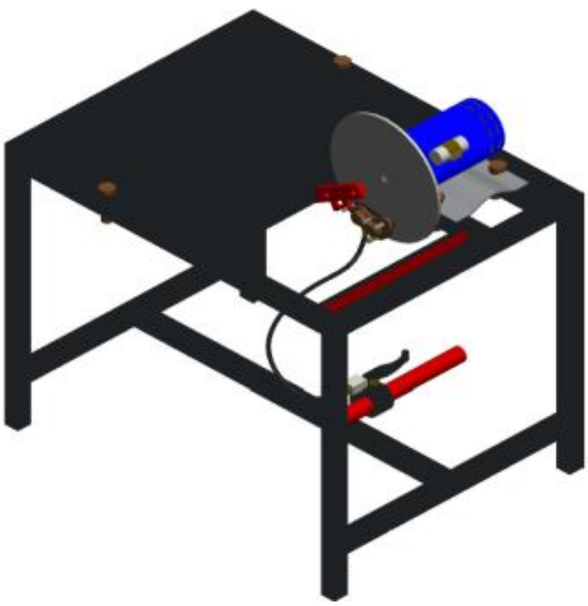

**Fig. 7: Isometric view of TERBS setup**

**Fig. 8: Photograph of the fabricated model of TERBS setup**

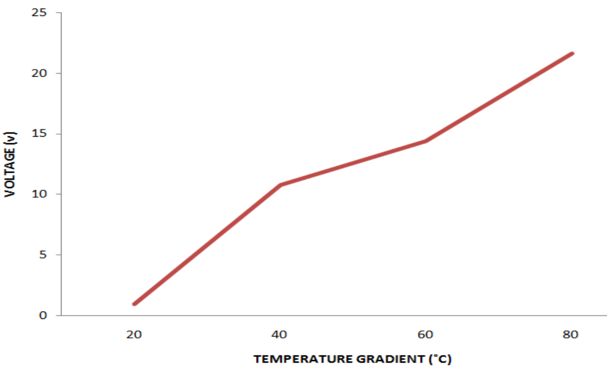


**Fig. 9: Performance of custom TEG module SP1848-27145 (96$cm^2$)**

## 4. Conclusions

Experimental results show that the custom modelled TEG module is capable of producing nearly 12V which is the optimum value of an automobile battery. This is based on the performance of a TEG attached to just one wheel. Thus, TERBS can generate almost all the electricity the vehicle needed for its travel by summing up the entire four wheels' contribution. An ultra-capacitor may be used to accumulate the charges before recharging the battery in order to avoid fluctuations. Thus, the TERBS can potentially convert the vehicle self-propelling without any external influence. The attachment width will be of the exact width of the caliper around the disc. Thus, the attachment does not require any modification except the hinged joint to the shock absorber.

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## EDITORIAL NOTES:

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