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Heat Harvester

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Abstract: *Conventional vehicles employ an internal combustion engine as its power house. The efficiency of the engine is 30-35%, thus 65-70% of the calorific energy is lost as residual exhaust, friction and various mechanical reduction through the power-train. The bulk of this loss is in the form of residual exhaust and heat. This energy lost in the form of heat can be extracted from certain regions in the engine which provide a significant temperature gradient. This paper proposes a conceptualized mechanism using thermoelectric generators (TEGs) that employs the seebeck effect to convert temperature gradient across two continuous surfaces to electrical energy. We propose to install an array of such highly efficient TEGs in the interface of a turbo charger to capitalize on the thermal gradient offered across its two housings. The installed TEG modules readily transduce the heat energy to electric energy, about 6000 watts of energy can be converted. The electrical energy thus developed can be used to recharge on-board batteries or supply tractive energy in case of a hybrid system. This conversion of heat energy to electrical energy increases the system efficiency by at least 2-5%.*

Keywords: *Energy recovery, Seebeck effect, temperature gradient, thermoelectric generators (TEG), turbocharger.*

I. Introduction

The automotive industry is dealing with an impending energy crises. The fossil fuels used to run the combustion engines are getting exhausted at an exponential rate and we are left with about only 53 years of it [2]. All over the globe, combustion engine run vehicles are the most significant mode of transportation. The conventional combustion engine generates energy with an efficiency of 30%, thus roughly 70% of it is lost. About 35% to 45% of the energy is wasted as engine tail pipe emission and heat. [1]

By using TEG module we can recover the losses encountered at the tailpipe as heat. This heat can be directly converted to electrical energy by TEG modules. This method can create electrical energy without additionally loading the engine by making use of the heat lost in the exhaust. Creditable research has been done on TEG modules placed in the heat exchanger unit of the radiator, however this configuration other than generating insignificant amount of energy, adds a new component to the heat exchanger and hence increasing its weight and bulk. This contradicts our philosophy of optimizing the design to make vehicles compact and lighter. We propose to place the TEG modules in the cavity of the turbocharger (between the turbine housing and the compressor housing). The TEG modules needs a continuous temperature difference to work efficiently, which is provided by the high temperature gradient that exists between the two housings of a turbocharger. By making slight modifications in the design of the housing units, we can embed an array of TEG modules to generate 300 watts of Power. The basic principle of thermoelectric generator (TEG) is the Seebeck 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"*.

Using TEG modules has many advantages, the most prevalent of those is that these generators do not have any moving parts and can run unattended for thousands of hours.

II. Thermoelectric Module

A thermoelectric module is a circuit containing thermoelectric materials that generates electricity from heat directly. A thermoelectric module consists of two dissimilar thermoelectric materials joining in their ends: an n-type (negatively charged); and a p-type (positively charged) semiconductors. A direct electric current will flow in the circuit when there is a temperature difference between the two materials. Generally, the current magnitude has a proportional relationship with the temperature difference. (i.e., the more the temperature difference, the higher the current.) Refer Fig. 1

The basic principle of thermoelectric generator (TEG) is production of voltage based on temperature, Difference between two surfaces. The most appropriate TEG module for this specific application would be the one with the highest power output per temperature gradient. Hence we propose to choose "*TEGpro TE-MOD-22W7V-56"*. The Specifications of the chosen model are listed below. During the most favorable conditions, a single unit can produce up to 22 watts. The voltage obtained across the terminals at this point is 7.2V and the current supplied is 3A. Refer TABLE 1.

III. Heat Transfer Around Turbocharger

Heat transfer occurs when there is a temperature difference. In a turbocharger, a significant temperature gradient is present between the turbine housing and the compressor housing. We are harnessing the temperature difference to maximizing the efficiency of the TEG modules. To operate the TEG module we require a cold side and hot side. Cold side of TEG module is affixed to the thermally conducting extrusion which operates at 40-50 degree Celsius and the Hot side is thermally coupled to the turbine housing where the temperatures vary from 350-650 degree Celsius. We require a continuous 320 degree Celsius on the hot side to maximizing the efficiency of the TEG module, hence to maintain that temperature we propose to construct a chamber around the turbine housing. The outer surface of this Chamber should be made of 3mm thick INCONEL material that would act as the thermal medium. In this Chamber, we propose to inject fresh air to ensure that the temperature is maintained between 300 - 320 degrees C. This fresh air is allowed to escape from another orifice placed directly across the point of injection. The fresh air is used to cool the chamber and maintain the desired temperature. Refer Fig. 2.

To delivered fresh air we propose to place an orifice at the end of the compressor housing. A tube channelizes this fresh intake air from the orifice. The other end of the tube is connected to the Chamber via a one-way valve, which is actuated by a temperature sensor inside the Chamber. If the temperature on the hot side exceeds 320 degrees Celsius, the fresh air is allowed to flow from the compressor housing to the Chamber and maintain the temperature between 300 – 320 degrees Celsius.

IV. Electrical Parameters and Controlling Circuitry

The TEG modules have been arranged in 9s2p configuration electrically. A string of nine modules in series, two such strings placed in parallel. Thus, the resulting output voltage is compounded to 64 VDC and the current is compounded to 6A. At ideal operating conditions that are maintained by the Chamber and the Drain Valve, the output power is about 300 watts. This recovered energy can be used to recharge on board batteries in case of hybrid electric vehicles, or a smaller capacity TEG module array can be used to replace the alternator used to power the electronics. Refer Fig. 3.

The toggling between the battery/alternator and the TEM module occurs via the Power Switching circuitry. The switching is administered by a Power Mosfet bank represented with a single mosfet. This circuitry is hardwired. The TEM input acts as gate and Short to the output, while the input from the Auxiliary battery connects to the source. Output to the peripheral loads is drawn from the Drain. Thus, effective and automated switching is achieved.

Logic States
Digital logic inputs T and M;
Conditional Logic:
T : Temperature (T=1 when temperature>=300C & ; T=0 else)
M : Module Status (M=1 when TEG output> +ve; M=0 else)
Digital Outputs
FAULT: (1/0) High output: Indicating a Fault in the Harvesting System
STATUS: (1/0) High output: Indicating Low Energy hence switching to Auxiliary system
By employing K-Maps to derive the logic, Hence the derived feedback logic output is as follows.
The Feedback mechanism is meant for the convenience of the driver by providing with the status of working of the Heat Harvesting system. Refer TABLE 2, TABLE 3. Logic gate realization in accordance with Fig. 4.

V. Proposed Model in Automobiles

Thermoelectric modules can be placed in the cavity of the turbocharger (between the turbine housing and the compressor housing). The modules have been placed in such a manner to be able to harness the temperature difference; there exists a high temperature difference between the two housings of a turbo charger. TEG modules have two sides - the hot side and the cold side. The compressor housing of the turbocharger is extruded and filled with a thermal conducting material. We propose to use graphite since it has thermal conductivity of more than 2,000 watts per meter per Kelvin, which is five times higher than the most conductive metals such as copper [2]. The cold side of the TEG module is thermally coupled with this extrusion.

The hot side of the TEG module is affixed to the hollow Chamber which is made up of 3mm INCONEL material around the turbine housing. It contains a pair of one-way valve, one to inject the air and the other to remove the excess air from the chamber. By doing this we are maintain a temperature of 300-320 degree Celsius, the reduction in temperature is achieved by the ventilation of the chamber which is done by the fresh air taken from the compressor housing which is connected to hollow chamber by a small tube. At the other end of the tube we have a one –way valve which is actuated by the temperature requirement inside the chamber. Refer Fig. 5.

As the engine starts the turbo charge start to rotate and gradually a temperature difference builds in the turbocharge. The compressor housing attains a temperature close to 45 degree Celsius due to heat transfer and ambient conditions. The turbine housing attains a temperature of about 300 degrees Celsius due to the thermal energy present in the exhaust. The TEM module commences to converting the thermal gradient across the turbocharger housing to electrical energy. The TEM array can produce a max of 300watts at optimum operating conditions. We can directly use the 300 watts to store in an onboard battery. The Chamber attached to the turbine housing temperature is maintained between 300 – 320 degrees by using the fresh air cooling mechanism.

VI. Module Configuration and Performance Characteristics

We propose to place 18 modules around the turbocharger which can produce 300 w. The module specific characteristics are as in the GRAPH 1. The module placement can be visualiszed in accordance with Fig. 6

Applications

One possible application of TEG modules is as a replacement of the alternator in a car. Electrical loads in motor vehicles can be categorized as continuous loads (ignition, fuel injection, etc.), long-time loads (lighting, heated rear window, etc.), short-time loads (turn signals, stop lamps, electric windows, etc.) and seasonal loads (air conditioners, seat heaters in winter). The alternator is the source of this power in addition to the power required to ensure adequate energy storage in the battery. The alternator is mechanically driven by the engine and operates at an average efficiency of about 50%. Tests carried out on a medium family sedan equipped with a 4-cylinder 2.2-liter engine and 5-speed manual transmission shows that with no electrical load and full electrical load the alternator uses up to 2% and 5% respectively of the engine's output power with an alternator [3]. This indicates that the fuel consumption can be reduced by 2% to 5% if the alternator is eliminated as the main electrical power source. Thereby increasing the system efficiency.

Figures ans Tables

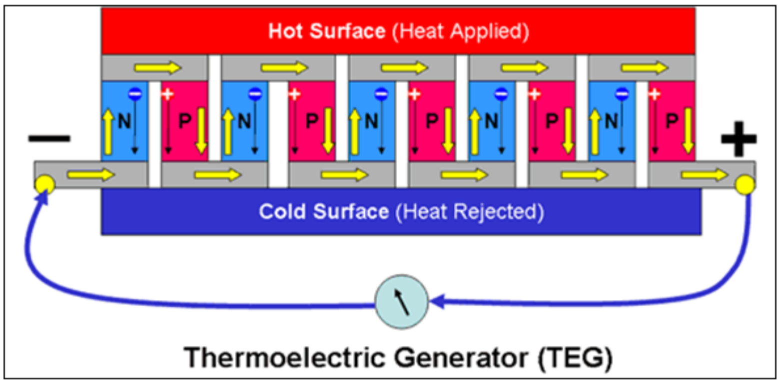
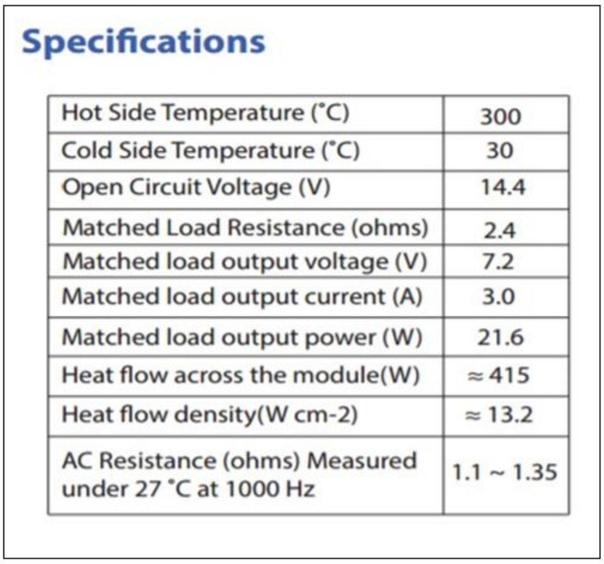


Figure 1: TEG Mechanism

Table 1: TEGpro Specifications



Specifications

Hot Side Temperature (˚C)	300
Cold Side Temperature (˚C)	30
Open Circuit Voltage (V)	14.4
Matched Load Resistance (ohms)	2.4
Matched load output voltage (V)	7.2
Matched load output current (A)	3.0
Matched load output power (W)	21.6
Heat flow across the module(W)	≈ 415
Heat flow density(W cm-2)	≈ 13.2
AC Resistance (ohms) Measured under 27 ˚C at 1000 Hz	1.1 ~ 1.35

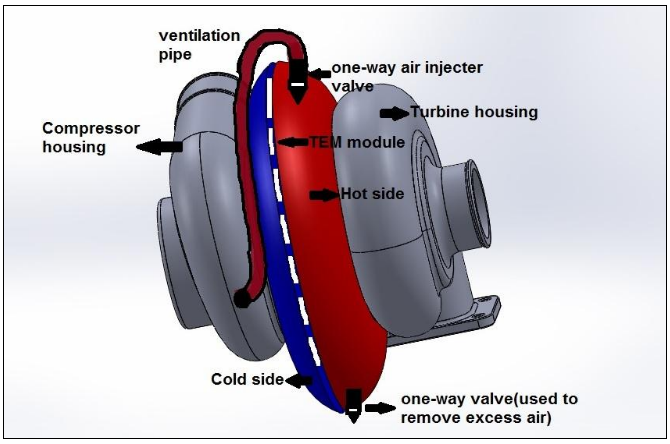


Figure 2: Construction

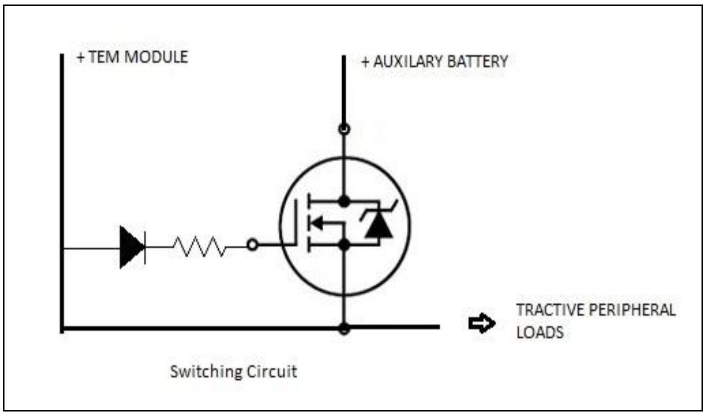
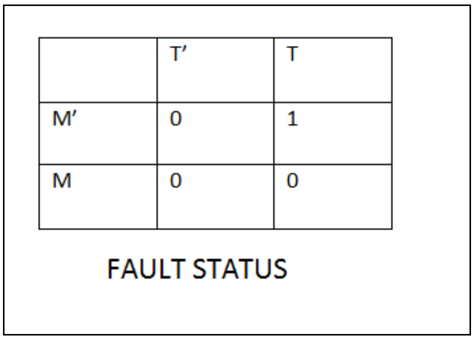


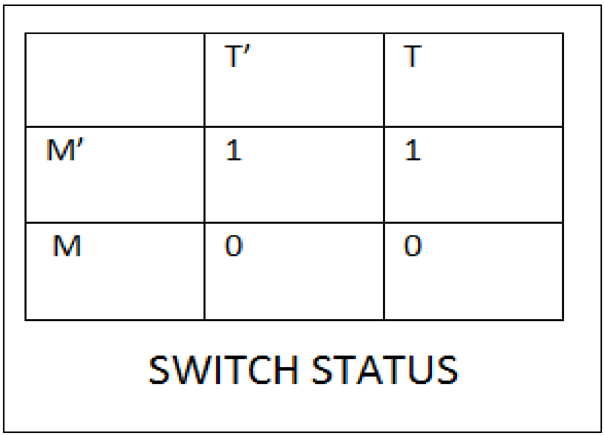
Figure 3: Mosfet power switching



	T’	T
M’	0	1
M	0	0

FAULT STATUS

Table 2: Fault Status K-Map



	T’	T
M’	1	1
M	0	0

SWITCH STATUS

Table 3: Fault Switch K-Map

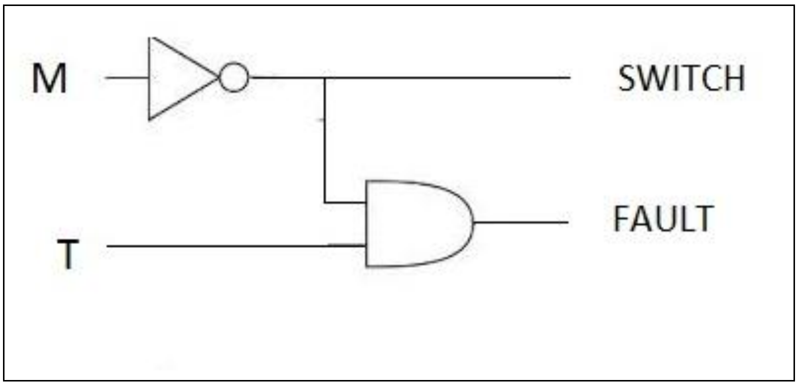


Figure 4: Gates realization

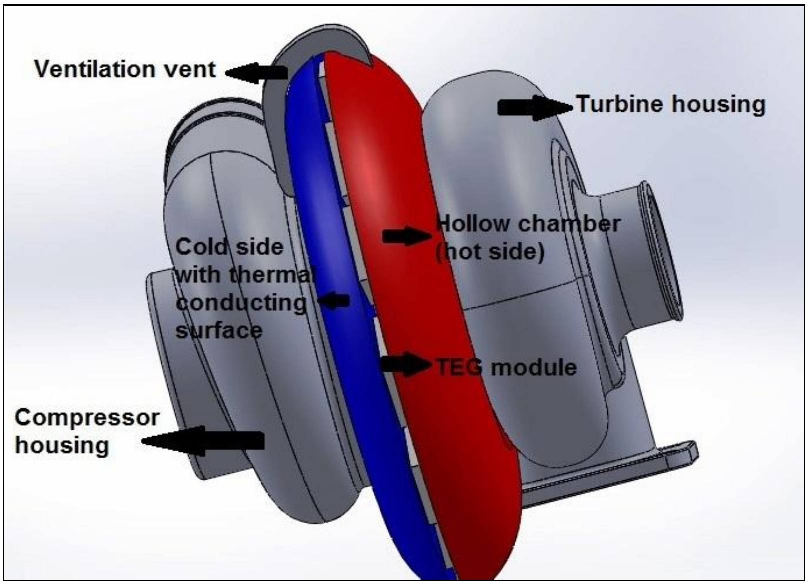
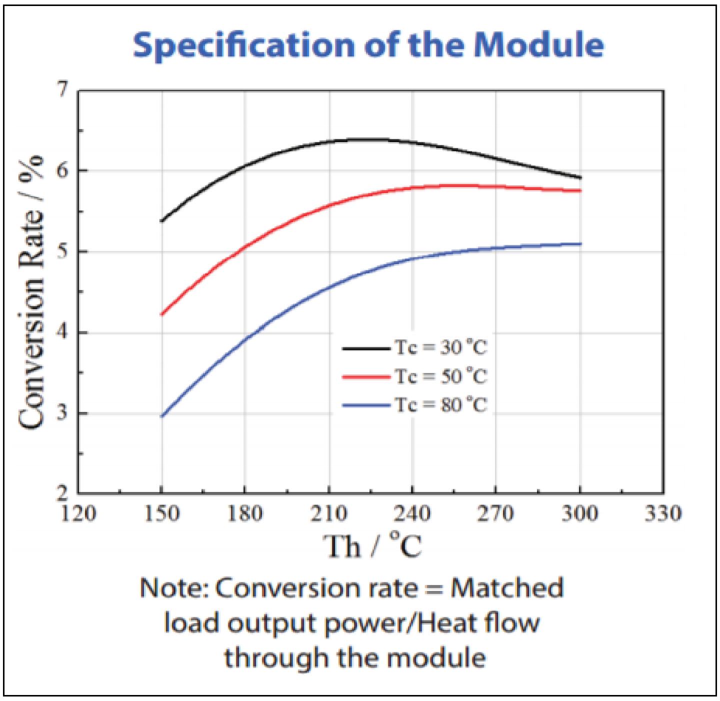


Figure 5: Final Design



Graph 1: Thermal Characteristics

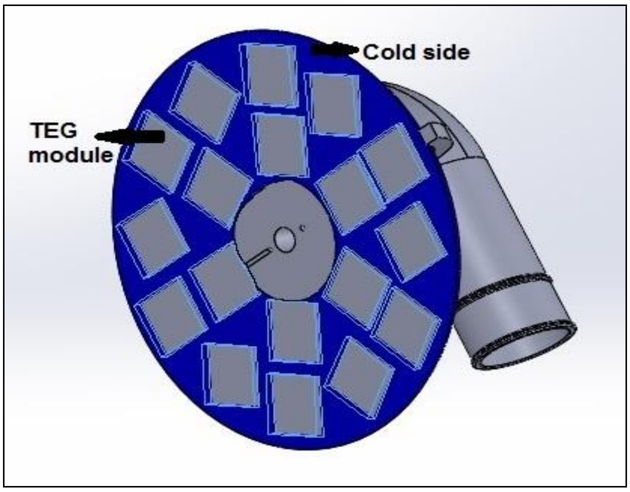


Figure 6: TEG Module placement

VII. Conclusion

In this proposal of a “Heat Harvester”, the placement of an array of TEG modules, sandwiched between the two housings of a turbocharger prove to produce enough electrical energy to be able to power the electronics of the car, and effectively replace the alternator. A max of 300 watts can be created by the current configuration of the TEG modules. TEM technology can thus bring about improvement in fuel economy by saving 2-5% of the energy that otherwise would have been consumed by the alternator. Furthermore, the energy which would have otherwise been lost in form of heat in exhaust, can be recovered to an extent. Thereby increasing the system efficiency by at least 2-5.

References

[1]. Haywood, J.B. Internal Combustion Engines Fundamentals, McGraw-Hill, 1988.
[2]. The Christian Science Monitor; BP’s annual report.
[3]. Unlikely Competitor For Diamond As Best Thermal Conductor: Boron Arsenide Potential For Cooling Applications Date: July 8, 2013 Source: Boston College
[4]. Ellis, S., Ryan, D. Application of Thermoelectricity to Waste Heat Recovery, Final Year Project, Department of Mechanical Engineering, Caulfield Campus, Monash University, 1998
[5]. Product catalogue of TEGpro INC.