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Thermo-Electric Generator in Turbocharged Diesel Engine - A Review

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Abstract: Almost every type of internal combustion engine works on the principle of Heat Engine. It's impossible to design 100% perfect Heat Engine. It converts the chemical energy into thermal energy and in the form of pressure of air carrying the heat, piston movement is done. Traditionally, only 25 to 30 percent of energy is being utilized to run the vehicles and accessories mounted on the engine and left amount of energy is wasted in various ways like in the form of exhaust and cooling of engine components. The useful energy is used to run the engine as well as generator. So the efficiency of those engines were very low. If any means energy is recovered, then the efficiency can be increased.In the current trend, based on this concept only waste energy is being recoveredin different methods. Removing the load on the engine increases the engine efficiency. Generator generally draws power from the engine through a belt drive, in turn it affects the engine efficiency. So by recovering the energy from the exhaust which contains 40% (approx.) of total amount of energy present in the fuel depending on the load on the engine. This paper describes about the thermal energy converted into electrical energy directly without any moving parts. This will help the engine to work on less load with a better fuel economy.

Keywords: *Thermoelectric generator, turbocharger, exhaust gas*

1. Introduction

Automobile engines works on variable loading condition which is having less efficiency than other type of machines. As this kind of engine works on heat engine concept. Heat energy is the source for the conversion of energy to various forms for different purposes. This paper is about the waste heat recovery coming out of the Internal Combustion engine as exhaust gas. This can be achieved by utilizing the heat energy to convert into electrical energy and store in a battery along with of using a DC generator. When the engines run, within 5 to 10 second, the exhaust gas carrying heat having a temperature range of 300^{o}C to 600^{o}C after passing through the catalytic converter. So the thermoelectric generator can be applicable with in this range of heat of exhaust gas of any type of IC Engine.A thermoelectric power generator is a solid state device that provides direct energy conversion from thermal energy due to a temperature gradient into electrical energy based on the concept of "Seebeck effect". This is effective because the exhaust gas having no role forany purpose. Installing this small device, with no moving parts, will definitely enhance the efficiency of the engine. Unlike traditional dynamic heat engines, thermoelectric generators contain no moving parts and are completely silent. Such generators can be used reliably for over 30 years of maintenance-free operation. The use of waste heat from the mobile heat conversion process to optimize power generation.

Ongoing research and advances in the semiconductor materials and technology enables to develop a static device to generate electricity. Commercial thermoelectric modules can be used to generate power, typically in mW or μWrange if the temperature is maintained between two terminals of a thermoelectric generator. Thermo electric modules work on the principle of heat pump. The focus is to review on the turbocharger technology and thermoelectric power generation technology and based on this concept modification of the power production unit in the vehicles. Combining the turbocharger unit with the thermoelectric generator power generation can be enhanced.

2. Literature Review:

Thermoelectricity utilizes the See beck, Peltier and Thomson effects that were first observed between 1821 and 1851. Practical thermoelectric devices emerged in the

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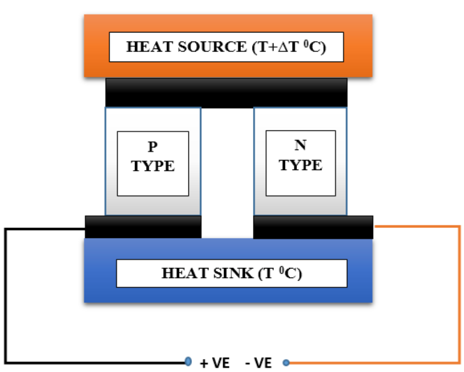
1960's and have developed significantly since then with a number of manufacturers now marketing thermoelectric modules for power generation, heating and cooling applications. Research activities in energy recovery from waste heat have considerably increased since the 1990s although there were many historical applications of TEGs using heating systems. There are recently reported researches such as thermoelectric power generation from CPU waste heat, Si-Ge based TEGs applied to gasoline engine vehicles, bismuth telluride based TEGs applied to diesel engines.

Ongoing research and advances in thermoelectric materials and manufacturing techniques, enables the technology to make an increasing contribution to address the growing requirement for low power energy sources typically used in energy harvesting and scavenging systems. Commercial thermoelectric modules can be used to generate a small amount of electrical power, typically in the mW or µW range, if a temperature difference is maintained between two terminals of a thermoelectric module.

3. Construction of thermoelectric generator:

Compared to large, traditional heat engines, thermoelectric generators have lower efficiency. But for small applications as well as co-generation electricity, thermo-electrics can become competitive because they are compact, simple (inexpensive) and scalable. Thermoelectric systems can be easily designed to operate with small heat sources and small temperature differences. Such small generators could be mass produced for use in automotive waste heat recovery.



POWER GENERATION

Figure - 1 (Thermoelectric Generator)

A single thermoelectric couple is constructed from two 'pellets' of semiconductor material usually made from Bismuth Telluride (Bi_2Te_3). One of these pellets is doped with acceptor impurity to create a P-type pellet; the other is doped with donor impurity to produce an N-type pellet. The two pellets are physically linked together on one side, usually with a small strip of copper, and mounted between two ceramic outer plates that provide electrical isolation and structural integrity. For thermoelectric power generation, if a temperature difference is maintained between two sides of the thermoelectric couple, thermal energy will move through the device with this heat and an electrical voltage, called the Seebeck voltage, will be created. If a resistive load is connected across the thermoelectric couple's output terminals, electrical current will flow in the load and a voltage will be generated at the load. Practical thermoelectric modules are constructed with several of these thermoelectric couples connected electrically in series and thermally in parallel. Standard thermoelectric modules typically contain a minimum of three couplesrangesup to one hundred and twenty seven couples for larger devices. A schematic diagram of a single thermoelectric couple connected for thermoelectric power generation, and a top view of a thermoelectric generator is shown in Figure-1.

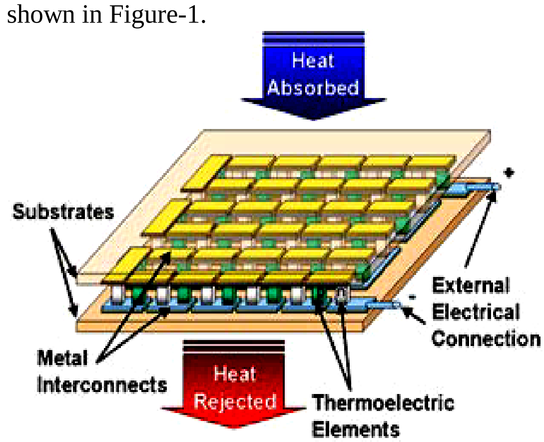


Figure - 2 Compact Thermoelectric Device (Source: Google)

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exchangers were modeled using computer aided design and analysis was done using a computational fluid dynamics code which is commercially available to study the flow and heat transfer characteristics. From the simulated results it was found that rectangular shaped heat exchanger met our requirements and also satisfied the space and weight constraint. A rectangular heat exchanger was fabricated and the thermo electric modules were incorporated on the heat exchanger for performance analysis. Commercially available thermoelectric generator is shown in the Figure 2. Heat source as shown in the figure 1, are the plates exposed to the high temperature zone i.e. exhaust of the engine after passing through the Turbocharger and Catalytic Converter and the heat sink is connected with the cooling circuit attached to the main radiator (Heat Exchanger). In the radiator the heat absorbed by the sink is released to the atmosphere there by maintaining a constant temperature at the sink side.

4. Heat Flow In Thermoelectric Generator (Teg)

A thermoelectric produces electrical power from heat flow across a temperature gradient. As the heat flows from hot to cold, free charge carriers (electrons or holes) in the material are also driven to the cold end (Fig. 1). The resulting voltage (V) is proportional to the temperature difference (ΔT) via the Seebeck coefficient, α, ($V = \alpha\Delta T$).By connecting an electron conducting (n-type) and hole conducting (p-type) material in series, a net voltage is produced that can be driven through a load. A good thermoelectric material has a Seebeck coefficient between 100 µV/K and 300 µV/K; thus, in order to achieve a few volts at the load, many thermoelectric couples need to be connected in series to make the thermoelectric device.A thermoelectric generator convertsheat (Q) into electrical power (P) with efficiency η.

$$P = \eta Q$$

The TEG consists of an exhaust gas heat exchanger, counter flow coolant cooling chamber and 18 Thermo-electric module connected in series. The amount of heat transferred from the exhaust gas to the Thermo-electric module depends on the design of the Thermo-electric module and the critical parameter is the heat flux which crosses the Thermo-electric module.

$$Q_{Lost} = Q_{Gain}$$

$$Q_{Lost} = m\, C_p\, \Delta T = m_{exhaust} \times C_{pe} \times (T_{ei} - T_{eo})$$

$$Q_{Gain} = m_{water} \times C_{pw} \times (T_{wo} - T_{wi})$$

The total heat flow from the exhaust gas side to the coolant side:

$$Q = \frac{1}{\frac{1}{h1A1} + \frac{L1}{K1A1} + \frac{L2}{8K2A2} + \frac{L3}{K3A3} + \frac{1}{h2A2}} \times \frac{(Th2 - Tc1) - (Tc2 - Th1)}{ln\frac{(Th2 - Tc1)}{(Tc2 - Th1)}}$$

Mass flow rate of water is calculated by;

$$Q = m_{water} \times C_{pw} \times (Tc_2 - Tc_1)$$

Where, m_{water} is the mass flow rate of the water to the sink side of the thermoelectric generator (TEG),
T_{ei} is inlet temperature of exhaust gas to the TEG,
T_{eo} is outlet temperature of exhaust gas from the TEG,
T_{wo} is outlet temperature of coolant i.e. water from TEG,
T_{wi} is inlet temperature of coolant i.e. water to TEG
The efficiency of a TEG will increase linearly with temperature difference. For maximum Power/Area for a given TEG, the following major two conditions should be maximized for the power output from TEG:

- nput Heat/ Area, Q/A
- emperature difference, ΔT

To summarize the theory in short, the temperature difference (ΔT) between the Heatsource (T_H)and Heatsink (T_L) leads to a difference in the Fermi energy (ΔE_F) across the thermoelectric material yielding a potential difference, which drives a current. The basic of a thermoelectric module is shown in the figure-3

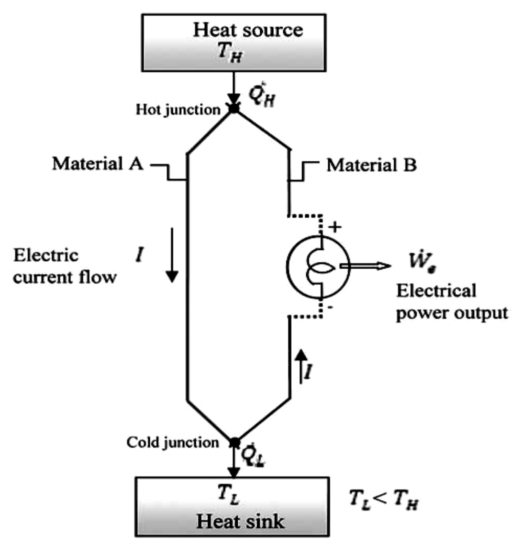

Figure - 3 Basic setup of a Thermoelectric Module

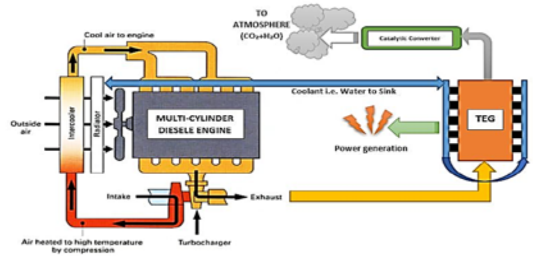

Figure - 4 Turbocharged Diesel Engine with TEG Unit

The cause of exhaust gas generation is Diesel engine.as the exhaust gases output having nearly 40% of energy of the fuel and sufficient temperature and pressure so as to recover the energy from the exhaust in various stages. The proposed layout as shown in the figure - 4 is to recover that thermal energy present in the exhaust can be used to enhance the engine power by using a turbocharger and additional amount of electricity can be generated.

5. TEG in the automotive industry:

Figure 4 is showing the arrangement of components in TEG. For an automobile engine, there are two main exhaust heat gas sources which are readily available. The radiator and exhaust gas systems are the main heat output of an IC engine. The radiator system is used to pump the coolant through the cham-bers in the heat engine block to avoid overheating and seizure .Conversely, the exhaust gas system of an IC engine is used to discharge the expanded exhaust gas through the exhaust mani-fold. Zhang and Chau reported that presently TEG is mostly installed in the exhaust gas system (exhaust manifold) due to its simplicity and low influence on the operation of the engine. Figure 5 is showing the power conversion layout of the engine with TEG & turbocharger.

Figure 5 Energy Conservation Layout

From the Figure-6, it is observed that the electrical power output in terms of mW is increasing exponentially with the difference between the exhaust gas temperature and cooling fluid

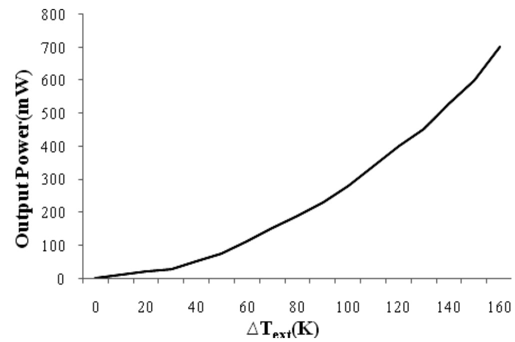

Figure 6. Output power as a function of external temperature difference (ΔT) across the device

6. Conclusion:

Automobiles are an example of high energy usage with lower efficiency. Roughly 75% of the energy produced during combustionis lost in the exhaust or engine coolant in the form of heat. By utilizing a portion of the lost thermal energy to charge the battery instead of using an alternator the overall fuel economy can be increased by about 10%.The prototype of a thermoelectric energy recovery module (TERM) was generated on the basis of energy generation from temperature difference. The TERM is aimed at converting the waste heat from processor into electrical energy. Results demonstrated an obvious fact that the greater heat energy into the TERM, the better generation performance. Generated power profiles with respect to source heat flows appeared to be parabolic. This result is mainly due to the fact that the generated power varies quadratically with the temperature difference across TEG's hot and cold sides. The junction temperature was seen to almost linearly vary with the source heat flow. With this project it is possible to eliminate the need of Coolers for Servers and also additional energy required to run the coolers. The waste heat is converted into useful power and also from the generated power it is possible to any one of the module in the computer. The same concept when applied to large database servers will bring enormous amount of energy saving to the world. Also, the companies looking for the Cooler Server can also be satisfied with considerable cost.

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