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Generation of Electricity by Utilizing Waste Heat from Internal Combustion Engines

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ABSTRACT

In the working of internal combustion engines, lot of heat energy is dissipated in the form of exhaust gases. This paper involves the conversion of waste heat in to useful electric power by using thermo electric power generator. Thermo electric generators (TEGS) are currently a topic of interest in the field of energy harvesting for automobiles. In applying TEGS to the outside of the exhaust tailpipe of a vehicle, the difference in temperature between the hot exhaust gases and the automobile coolant can be used to generate a small amount of electrical power to be used in the vehicle. The amount of power is anticipated to be a few hundred watts based on the temperatures expected and the properties of the materials for the TEG.

Keywords : Thermoelectric Generator, Internal Combustion Engine, Engine Exhaust, Waste Heat Recovery.

I. INTRODUCTION

Heat engines are predominantly designed to produce useful work only. Waste energy in the form of heat is normally a byproduct resulting from the irreversibility of the processes involved in the conversion of primary energy to mechanical or electrical energy. The efficiency of a modern internal combustion engine is about 37% in a normal passenger car spark ignition Engine whereas 50% in low speed marine diesel engine. The energy dissipated is lost by transmission to the environment through exhaust gas, cooling water, lubrication oil and radiation.

The electric power used in automobile is generated by taking part of useful mechanical energy. Due to improvements of comfort, driving performance and power transmission the electric load of a vehicle is increasing day by day. Due to this tendency, the alternator sizes, load of engine power and engine weights are becoming larger. However, the engine room is becoming smaller in order to expand the passenger room. For this reason, the space for the alternator cannot be freely increased. With the help of TEG, fuel consumption can be reduced by 10% by converting only 6% of waste heat into electrical power. In this way the overall efficiency of the internal combustion engine can be increased.

In thermoelectric based power generation, the primary research focus has typically involved improving the properties of the material used in the thermoelectric material. While improving the material properties could increase the efficiency up to 50% of the stated Carnot efficiency, the efficient transfer of heat to/from the TEG is also critical in the overall efficiency of the thermoelectric (TE) device. The temperature drop across the TE element can be increased by improving the heat transfer to the hot side of the TEG module and from the cold side using the coolant flow.

Thermoelectric generation is currently being explored for its power recovery potential in automobiles. Out of the energy that comes from a combustion process in an engine, 40% is lost through exhaust gases.

II. PURPOSE OF TEG

The Project Has Started Since the discovery of the thermoelectric effect, the development of TE materials and devices has long been the pursuit of researchers. But only until recent years, the introduction of new material structures has improved the TE material properties significantly. Several TE materials have reached figures of merit (ZT) that are around or above unity which leads to the possibilities of building high efficiency thermoelectric devices that are suitable for industrial applications. Targeting applications include waste heat harvesting, cooling systems, radioisotope thermoelectric generators, and etc.

Automotive industry is one of the main application fields of TE technologies. Among all the possible applications of TE 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. The high quality of the waste heat is demonstrated by the high temperature characteristic of vehicle internal environment, 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.

Up until now, investigation has been extended to the development of the whole TEG system for vehicles. However, such investigation is mainly under feasibility study, while some detail research on optimal solutions is conducted that mainly concerns functioning of TEGs at single vehicle section. The further development of TEG for vehicles is walking towards an application-oriented integrated TEG system.

III. EXPERIMENTAL SETUP

1. Elements of Thermoelectric Generator:

Thermoelectric generator basically consists of three elements these are thermoelectric module, support structure and sink.

a. **Thermoelectric module**: Depending upon the range of temperature different thermoelectric modules are selected like Silicon Germanium, Bismuth Telluride, Lead Telluride also many new material like Zinc Anti-monides, Thermoelectric oxide material NaxCo2O4, Thin Films Materials etc.

b. **Support structure**: It is the very important part of the TEG, where the thermoelectric modules are mounted. The internal part of this structure normally is modified in order to absorb the most part of the heat accumulated in the exhaust gases.

c. **Sink_**: It is nothing but the heat dissipation system which favors the heat transmission through thermoelectric module.

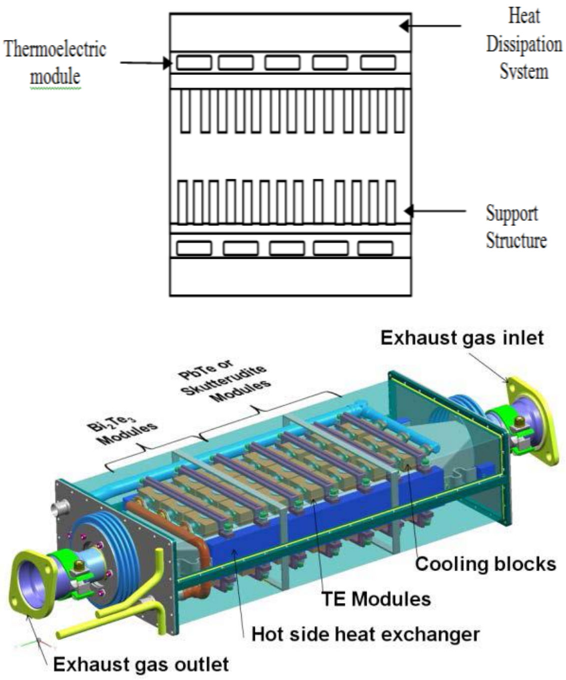

Figure 1: Thermoelectric Generator

2. Thermoelectric module

The Thermoelectric module used in a typical TEG can be classified on the basis of material used, shape and size and configuration of their thermoelectric pair.
The semiconductor material used in fabrication of TEG is dependent on maximum temperature obtained and hence location of TEG mounting on the exhaust pipe. There are three positions for TEG mounting
1) Just behind the exhaust manifold- The temperature range of the exhaust gases obtained is in between 10000 c and 7500 c. The thermo elements were fabricated on the basis of β-FeSi2, with co-doping for N type and Aluminium doping for P type. Si-
Ge alloys are also used.
2) Between the exhaust manifold and the catalytic convertor- In this region the temperature range of exhaust gases is in between 7500 c and 4000c.The lead telluride material is generally used for this temperature range.

3) Just behind the catalyst convertor- The
temperature range obtained in this region is in between 4000 c and 2000c.All the TEGs designed to this temperature range are based on Bismuth Telluride alloys. Another interesting classification of the TEGS is based on the shape and size thermoelectric module.

The TEG analyzed can be classified into two groups Traditional square

Thermoelectric module:

Each of these modules is composed of several thermoelectric pairs in series. This type of module require flat surface for mounting. Linear shape thermoelectric module: -In this case, the thermoelectric pairs form lines and therefore they can adjust better to the circular shape of the exhaust pipe

3. Support structure

This structure is extremely important in any thermoelectric generator oriented to be used in an automobile due to the following reasons:

The heat transmission from the exhaust gases to the structure must be done normally in a short length. Therefore it is necessary to use fins or other structure to maximize the surface area and to raise the turbulence so that convective heat transfer coefficient should increase. However fins and other structure may cause the problem of backpressure and hence decrease the efficiency of the engine.

Variation in the exhaust gas temperature. The varying speed causes the temperature of the exhaust gases at the same point of the exhaust pipe to vary. This affects the coefficient of performance of the TEG, and hence the electrical power generated. The structure must be designed in such a way that all the thermoelectric modules mounted are working near their optimum performance for the most common working point of the engine.

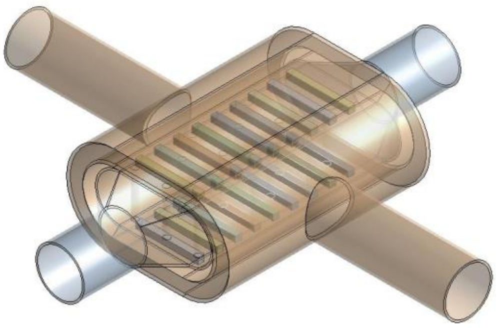

Figure 2 : Layout of the baseline heat exchanger. The brown piping is the cold side of the test section, the gray is the hot side, and the rectangular pieces are sample TEGs.

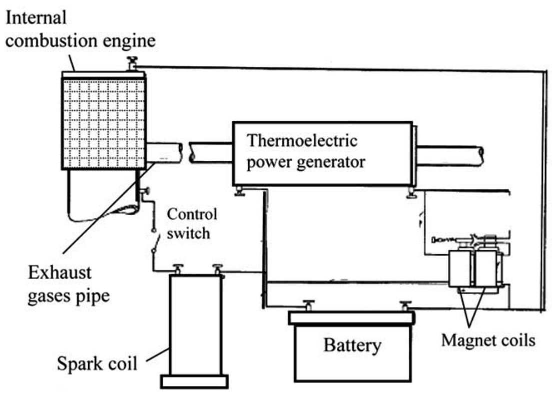

Figure 3 : Schematic diagram showing early invention of converting waste heat into electrical power applied to an internal combustion engine using a thermoelectric power generator

4. Seebeck effect:

The Seebeck effect is also used for the thermocouple operation (but at a much higher scale), in which a temperature difference between the junctions of two different materials produces an electric voltage and an electric current flows when the electric circuit is closed. This effect is quantified by the Seebeck coefficient, α, as represented in eq. 1:

$$\alpha = \frac{\Delta V}{\Delta T} \qquad (1)$$

A good thermoelectric generator device should have a high Seebeck coefficient, and at the same time a low electrical resistance – Ri (thus allowing higher currents) and a low thermal conductance KP (thus reducing heat loss through the generator). The figure-of-merit (ZT) is used to quantify the performance of a thermoelectric module,or a single thermoelectric material, at a specific temperature T

$$ZT = \frac{\alpha^2}{R_i K} t = \frac{\alpha^2}{\rho K} T \qquad (2)$$

where α is the Seebeck coefficient, ρ is the mean electric resistivity, k is the mean thermal conductivity and T the temperature (K). These coefficients are temperature dependent. Figure 3 shows the See-beck co-eficient (S), the electrical resistance (R) and the thermal conductance (K) as function of the hot face temperature from a commercial thermoelectric module (40 mm x 40 mm x 3.6 mm, 127 junctions, 7A, 15V) when the cold face is keep at constant temperature (27 ºC). Despite the reduction of figure-of-merit (ZT) with temperature, higher efficiency of the TEG is obtained when a high temperature difference is present between both faces of the module.

IV. TEG Materials

Metals have been the main materials used in building TEGs, until the middle of 20th century, when Ioffe noticed semiconductor materials due to their high Seebeck coefficient and their phonon-transport-dominated heat conduction. Despite metals' merit of high ratio of electrical to thermal conductivity, modern TE materials are 26 mainly semiconductors. The performances of TEGs are largely affected by the features of materials used. Hence, the selection and combination of TE materials is vital for the design of a good TEG. It is necessary to examine and compare the existing families of TE materials. Chalcogenides material family is main contributor to TEGs, among them bismuth telluride (Bi2Te3) and its alloys are very good TE materials below room temperature. Bi2Te3 can be alloyed with Sb2Te3 or Bi2Se3 so as to considerably reduce thermal conductivity. However, since tellurium is scarce, toxic and volatile at high temperatures, its usage is limited. Lead telluride (PbTe) was found to have good thermoelectric properties at temperatures in the range of 300-700 K. Similar thermoelectric materials such as PbS and PbSe, also belong to chalcogenides system.

The alloy of silver antimony telluride $AgSbTe_2$ with germanium telluride GeTe ($(AgSbTe_2)_{1-x}(GeTe)_x$, commonly referred to as TAGS) was initially sought as a replacement for p-type PbTe in applications at higher temperatures such as radioisotope TEGs for space power supplies. TAGS has been successfully used in long-life thermoelectric generators . SiGe alloys are superior materials for thermoelectric generation and is typically used for both n- and p-legs in high temperature (>900 K) TEGs. However, the ZT of these materials is fairly low, particularly for the p-type materials . Skutterudites ($ReTm_4M_{12}$) are complex materials containing rare earth elements (Re), transition metals (Tm) and metalloids (M). Skutterudites have reduced thermal conductivity due to rattling of the heavy rare earth element within the loosely bound lattice. The ZT of skutterudite has been found to be higher than unity at 700 K.

Metal oxide was introduced by Ohta in 2007 as a new class of TE materials. The introduced metal oxide was a two-dimensional electron gas (2DEG) in $SrTiO_3$. The 2DEG demonstrate a Seebeck coefficient that is enhanced by a factor of about 5 compared with the bulk and an optimized ZT that reaches 2.4, which is twice that of conventional thermoelectric materials. The oxide TE materials appear to be promising, since they are chemically stable at high temperatures and are nontoxic. However, they have general problems of weak mechanical strength, as well as high contact resistance at interfaces of oxides and electrodes.

For several materials, the figures of merits over the temperature range of 0-1000°C.

V. AUTOMOTIVE APPLICATION OF TEGS

TEG technology was first tested in automotive waste heat recovery by Neild, followed by tests on modified cars/engines such as a Porsche 944 , a 14 litre Cummins Turbo-diesel engine truck a GM Sierra Pickup Truck and other, more recent works, but in most cases the potential for power recovery is just enough to meet the electric demands of the various electrical accessories. However, reputable studies indicate that, if the system is properly designed, it should be possible to recover a significantly higher amount of energy, when adding the combined potential of the cooling system, lubrication system and exhaust system. A major OEM (BMW) is testing this technology and is making plans to commercialize in the near future a car with TEGs generating up to 1kW (currently 200W), with the aim of 5% fuel savings. In fact, work such as Matsubara refer an efficiency of heat recovery (to electricity) using advanced thermoelectric generators of 5%, which would translate into an extra 6% (1% from coolant, 5% from exhaust) of available (electric) energy in a hybrid car. Consequently, an engine with 33% efficiency could earn 3% extra mechanical power, translated into 5% in fuel savings.

One of the reasons for the small thermal efficiency of TEG modules has to do with the limitations in the maximum temperature that current modules are able to withstand (normally, up to 230ºC). Rather than the core materials of the module, it is normally the solderings between parts that are currently limiting their ability to work at higher temperatures. This is one of the main obstacles when trying to regenerate exhaust heat by using TEGs.

One rather crude way of protecting TEGs against the extreme temperatures found in exhaust systems would be to partially insulate them. This solution would be highly ineffective as only a small portion of the heat would be available for recovery, mainly at light loads. Some tried to minimize this problem with the help of several heat exchangers. The ideal solution, however, would be to effectively control the maximum temperature at the modules without sacrificing the heat available for recovery, or, in other words, it would be to regulate the temperature reaching the modules to nearly their working limit.

This would be made, not by insulating them or deflecting the heat flux away from them but, by supplying the heat to a sufficiently low temperature while still maintaining a high heat transfer rate. As it will be shown in the present work (and also previous work by the group), this can be achieved with the combined use of heat pipes (HP) and TEGs.

VI. CURRENT & FUTURE DEVELOPMENTS

Recently, an increasing concern of environmental issues of emissions, in particular global warming and the constraints on energy sources has resulted in extensive research into innovative technologies of generating electrical power and thermoelectric power generation has emerged as a promising alternative green technology. In addition, vast quantities of waste heat are discharged into the earth's environment much of it at temperatures which are too low (i.e. low-grade thermal energy) to recover using conventional electrical power generators. Thermoelectric power generation offers a promising technology in the direct conversion of waste-heat energy, into electrical power. In this paper, a background on the basic concepts of thermoelectric power generation is presented and recent patents of thermoelectric power generation with their important and relevant applications to waste-heat energy are reviewed and discussed. Currently, waste heat powered thermoelectric generators are utilized in a number of useful applications due to their distinct advantages. These applications can be categorized as micro- and macro-scale applications depending on the potential amount of heat waste energy available for direct conversion into electrical power using thermoelectric generators. Micro-scale applications included those involved in powering electronic devices, such as microchips. Since the scale at which these devices can be fabricated from thermoelectric materials and applied depends on the scale of the miniature technology available. Therefore, it is expected that future developments of these applications tend to move towards nano technology. The macro-scale waste heat applications included: domestic, automobiles, industrial and solid waste. Currently, enormous amounts of waste heat are discharged from industry, such as manufacturing plants and power utilities. Therefore, most of the recent research activities on applications of thermoelectric power generation have been directed towards utilisation of industrial waste heat. Future developments in this area might focus onto finding more suitable thermoelectric materials that could handle higher temperatures from various industrial heat sources at a feasible cost with acceptable performance. Another future direction is to develop more novel thermoelectric module geometries and configurations. The developments of more thermoelectric module configurations by developing novel flexible thermoelectric materials will make them more effective and attractive in applications where sources of waste heat have
arbitrary shapes.

VII. RESULT

The new concept of TEG-based DC-DC conversion networks is the basis of this project. The general goal of this project is to develop a systematic design approach which serves as a guideline for future design work to achieve high conversion efficiency in vehicle WHR systems.

VIII. CONCLUSION

The performance of TEG is mainly depend upon heat transfer from the exhaust gas to TE module, material of TE module, location of TEG. In order to achieve that the TE modules work close to their best conditions of power, it is necessary to reduce the thermal resistance from the exhaust gas flow to the hot surface of the modules. Several improvements can be done to reduce Thermal resistance.TE module is basically a heat conduction problem.The materials used in all the paper for support structure are Hastelloy and aluminium. The use of Copper for support structure can give better result as the thermal properties of copper are better than this two.

Locations of TEG behind exhaust manifold is the best condition as it gives more exhaust temperature provided that TEG design should be such that it should not diversely affect the engine performance. In this way we can increase the efficiency of TEG. Once TEGs achieve an optimum efficiency, despite the high cost of thermoelectric modules, their use in the automobile industry will become a reality because the world's largest and most efficient cost reduction systems would be in operation, and this would certainly lower the overall cost.

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