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Thermoelectric Generator Based On Vehicle Exhaust Waste Heat Recovery Using Matlab

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***Abstract*—**This paper studies an ATEG system which works on the temperature difference between the exhaust gases (hot side) and circulating engine coolant liquid (cold side) of an Internal Combustion (IC) engine. The approach taken in this paper is theoretical analysis by understanding the basic physics (mathematical equations) of the ATEG system. These mathematical equations are modeled in MATLAB/GUI environment for computer simulation. The inputs to this model, for simulation, are given from the IC engine test bench data. The results indicate that the ATEG system is suitable to drive all the small electrical loads of a car and thus increasing the efficiency of the car. Therefore, ATEG system forms a great candidate to replace the alternator for small and midsized Automobiles. Replacing the alternator by the ATEG eliminates the load of the alternator on the IC engine and increases the overall fuel efficiency of the automobile greatly (about 4-7% depending on the IC engine and electrical demand of the car).

***Keywords*—** ATEG; MATLAB/Simulink; exhaust gas; engine coolant liquid.

I. Introduction

With the ever increasing environmental effects of fossil fuels, it has become the utmost priority of engineers and scientists around the world to improve the efficiency of IC engines. One such way is to recover waste heat from the exhaust gases in an automobile [1]. In a typical IC engine driven automobile, only about 25% of the energy supplied by the fuel is used vehicle mobility and accessories. About 40% of the energy is reflected in the form of heat in exhaust gases and about 30% is reflected in the form of the heat carried away by the engine coolant liquid [2]. This is pictorially represented in figure 1.

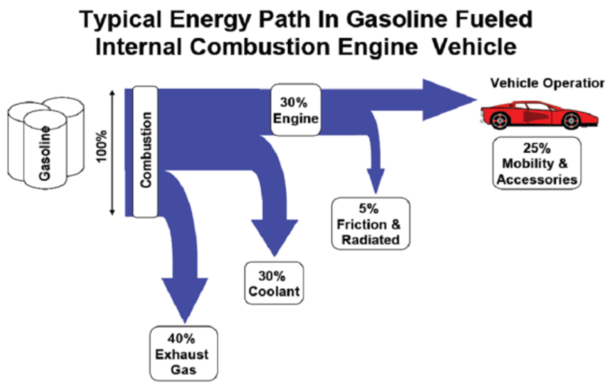

Fig. 1. Typical energy flow in an IC engine driven automobiles.

One heat recovery technique is the ThermoElectric Generator (TEG), which recovers heat from the IC engine exhaust and converts a part of it to electricity. TEG has no moving parts and is not bulky and hence is very suitable for automotive applications. With the improvements in the material technology, TEGs power output and efficiency of conversion (thermal to electrical) has improved to a significant level so that the applications of TEGs in an automobile have become viable (technically and financially). This electricity generated by the TEG can substitute/eliminate fossil fuel based electricity generated in the automobile by the alternator (existing automobiles). When we adapt TEG technology to an automobile, we generally call the system an Automotive ThermoElectric Generator (ATEG). The approach taken in this paper is to model the ATEG system for computer simulation. The initial design is optimized by the modeling approach, and by doing this we significantly save cost involved in testing a physical prototype in the laboratory. The obvious succeeding step to this model based design approach is to validate the design in simulation environment with a physical prototype giving the same inputs to both the model (simulation environment) and physical prototype. The entire modeling and simulation activities were carried out in MATLAB/Simulink environment. The inputs to this model are given from the test bench data of the target IC engine. The detailed ATEG conceptual design, modeling approach, simulation results are explained in detail in the following sections. Thermoelectric or the Seebeck effect The Seebeck effect is the conversion of temperature differences directly into electricity and is named after the Baltic German physicist Thomas Johann Seebeck.

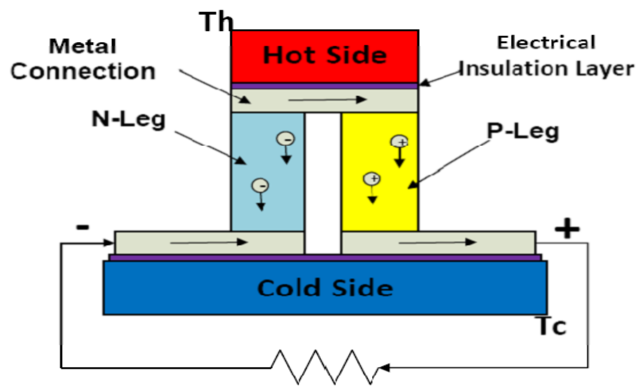

Fig. 2. Conversion from heat energy to electrical energy by the TEG.

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ThermoElectric Generators (TEG) are devices which convert heat (temperature differences) directly into electrical energy, using a phenomenon called the "Seebeck effect" (or "thermoelectric effect"). Older TEG devices used bimetallic junctions and were bulky. More recent devices use semiconductor p-n junctions. These are solid state devices and unlike dynamos have no moving parts, with the occasional exception of a fan or pump.

When we realize TEG concept to the automobile, the hot side is the exhaust gases and the cold side is generally the IC engine coolant liquid, though the cold side can be the ambient air or a circulating fluid dedicated to the ATEG system [3].

II. Basic Physics Governing the ATEG System

A. *Seebeck Coefficient -S*

The Seebeck coefficient (also known as thermoelectric sensitivity) of a material is a measure of the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material, as induced by the Seebeck effect. The SI unit of the Seebeck coefficient is volts per kelvin (V/K)

$$Eemf=-S\nabla T$$

Where, S=seebeck coefficient, ∇T=temperature difference between two side of the material.

B. *Figure of Merit – ZT*

For thermoelectric materials, the ability to produce high energy conversion efficiency is the most important standard in determining the performance of materials. The figure of merit (FOM) is a very convenient measure for comparing the potential efficiencies of devices built with different materials. The FOM for thermoelectric devices is defined as

$$ZT= (\sigma(S^2)T)/\lambda$$

where, S=seebeck coefficient, λ=thermal conductivity , σ =electrical conductivity

The conventional unit for Seebeck coefficient in calculating FOM is μV/K. More commonly used measure is the dimensionless FOM, ZT, where T is the average temperature (T2+T1)/2 in the device. Several TE materials have reached figures of merit (ZT) that are around or above unity [4-8], 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. It is obvious from Equation that to improve the value of FOM, we can either increase Seebeck efficient, or decrease thermal conductivity. These are also the focus of current TE material research. With the advancements of nanotechnology, these targets can be achieved by manipulating the nanostructure of the materials.

C. *Efficiency of Conversion*

Exhaust waste heat is given by:

$$Qe = me*Cp*(TH-TL)$$

where, Qe=Exhaust Waste Heat, Cp=specific heat capacity at constant pressure of exhaust gas, TH=Temperature of hot side, TL=Temperature of cold side.

Number of modules required for selected application is given by:

$$ne=Qe/[2*[[alpha*amp*(TH+273)]-[(((amp^2)*rho)/(2*G))]+[k*(TH-TL)*G]]]$$

where, ne=number of modules, alpha=electrical conductivity, amp=Current rating of selected application, TH=Temperature of hot side, TL=Temperature of cold side, k=constant, G=selected dimension of TEG material.

Efficiency of conversion is given by:

$$TE\_eff=100*(p/Qe)$$

where, p = Outpower power required for driving selected application, Qe = Exhaust heat available.

III. Modeling of ATEG Introduction

The above said basic physics is used to model a single thermoelectric material. Many such thermoelectric materials are connected together keeping in mind the cost constraint, space constraint (volume constraint) and the target electrical demand of the automobile [9]. ATEG system is modeled and simulated in MATLAB/Simulink environment. The model requires the exhaust gas and engine coolant liquid's temperature and mass flow rate as inputs and the geometrical dimensions of the thermoelectric material(s) and their properties as model parameters, as shown in figure 3. The inputs to this model are given from the target engine test bench data.

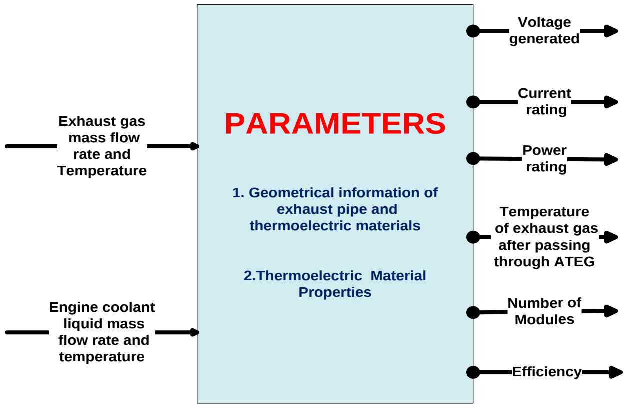

Fig. 3. Inputs and outputs and parameters for ATEG model developed in MATLAB simulink.

IV. Simulation Results

We have taken the parameters Kirloskar Oil engine for our simuation. Following results are for Bi2Te3. From figure 4 and figure 5 we have concluded that figure of merit (Z) and average conversion efficiency increases with temperature. From figure 6 it is concluded that Conversion efficiency increases with temperature of hot side. Various results for application headlamp and all accessories is shown in figure 7, 8,9 and figure 10. For these results we have considered material Bi2Te3.

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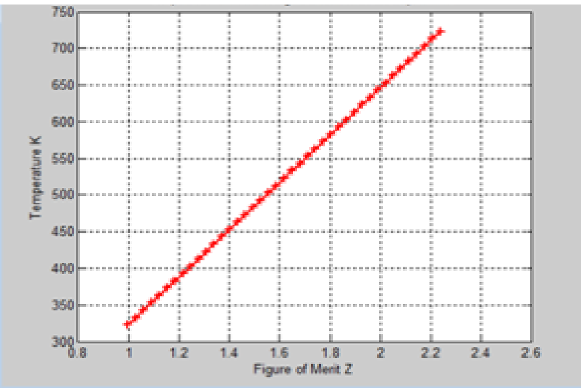

Fig. 4. Figure of merit Z vstemperature T.

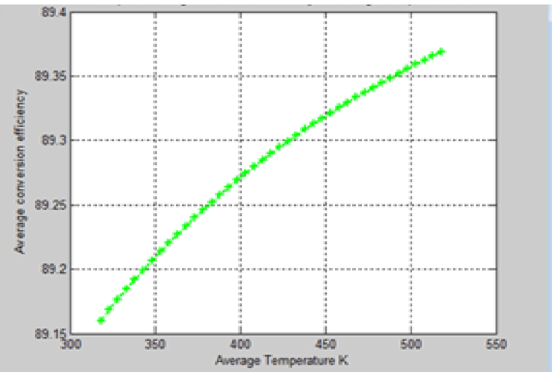

Fig. 5. Average conversion efficiency vs average temperature .

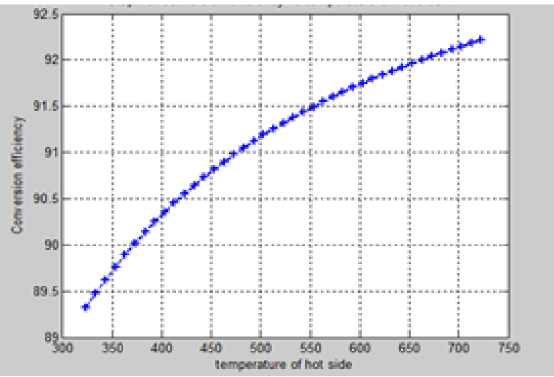

Fig. 6. Conversion efficiency vs temperature of hot side.

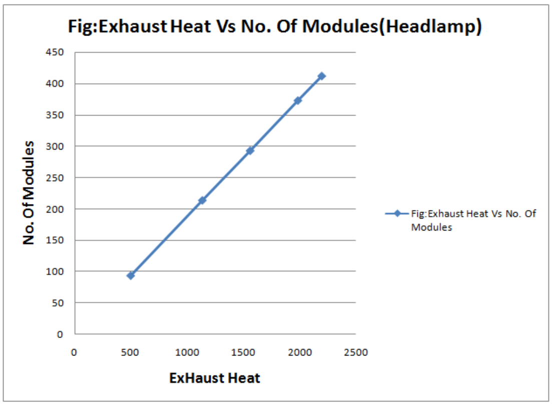

Fig. 7. Exhaust heat vs number of modules (size considered is 10mmx10mm).

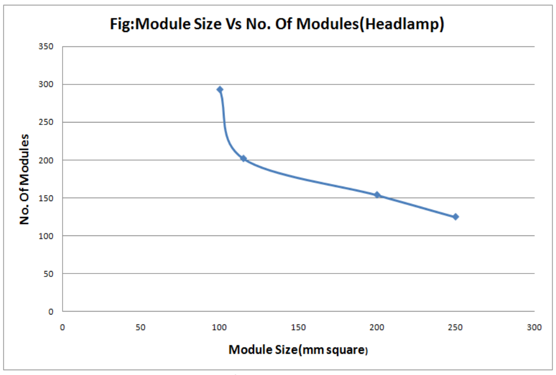

Fig. 8. Module size and number of modules.

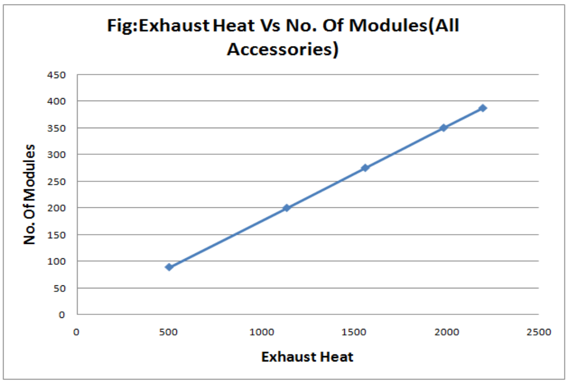

Fig. 9. Number of modules (size considered is 10mmx10mm) vs exhaust heat.

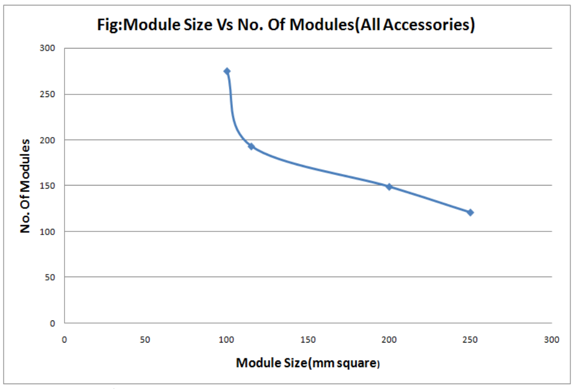

Fig. 10. Number of modules vs module size.

V. Conclusion

The inputs were given from a Kirloskar Oil engine and results show that ATEG can give a comparable power to drive the accessories of a car like tail lamp,head lamp etc.Thus ATEG increases the overall fuel efficiency of car.It is also concluded that efficiency of TEG material increases by increasing the temperature of hot side.

References

[1] India Bureau of Energy Efficiency, Thermal Energy Equipment: Waste Heat Recovery, obtained the 4th of February 2011.

[2] P. Aranguren, D. Astrain, A. Rodríguez, and A. Martínez, "Experimental investigation of the applicability of a thermoelectric generator to recover waste heat from a combustion chamber," *Applied Energy*, vol. 152, pp. 121-130, 2015.

[3] G. P. Meisner, "Advanced thermoelectric materials and generator technology for automotive waste heat at GM," General Motors Global

Baldev Raj, Shivani Choudhary, Simran Gupta and Arjun Singh, "Thermoelectric generator based on vehicle exhaust waste heat recovery using matlab", *Journal of Scientific and Technical Advancements*, Volume 1, Issue 3, pp. 127-130, 2015.

Research & Development, Warren, MI, Thermoelectrics Applications Workshop, January 3-6 2011, Hotel DelCoronado, San Diego, CA.

[4] D. Y. Chung, T. Hogan, J. Schindler, L. Iordarridis, P. Brazis, C. R. Kannewurf, C. Baoxing, C. Uher, and M. G. Kanatzidis, "Complex bismuth chalcogenides as thermoelectrics," *Proceedings IEEE 16th International Conference on Thermoelectrics*, pp. 459 – 462, 1997.

[5] T. Caillat, A. Borshchevsky, and J.-P. Fleurial, *In Proceedings of 7th International Conference TEs*, K. Rao, ed., University of Texas, Arlington, pp. 98 – 101, 1993.

[6] T. C. Harman, P. J. Taylor, M. P. Walsh, B. E. LaForge, " Quantum dot superlattice thermoelectric materials and devices," *Science*, vol. 297, no. 5590, 2002.

[7] A. I. Hochbaum, R. Chen, R. D. Delgado, W. Liang, Erik C. Garnett, M. Najarian, A. Majumdar, and P. Yang, "Enhanced thermoelectric performance of rough silicon nanowires," *Nature* 451, pp. 163-167, 2007.

[8] A. I. Boukai, Y. Bunimovich, J. T.-Kheli, J.-K. Yu, W. A. Goddard, and J. R. Heath, "Silicon nanowires as efficient thermoelectric materials," *Nature* 451, pp. 168-171, 2007.

[9] F. Stabler, Automotive Thermoelectric Generator Design Issues, Future Tech LLC, DOE Thermoelectric Applications Workshop, San Diego, CA.

Baldev Raj, Shivani Choudhary, Simran Gupta and Arjun Singh, "Thermoelectric generator based on vehicle exhaust waste heat recovery using matlab", *Journal of Scientific and Technical Advancements*, Volume 1, Issue 3, pp. 127-130, 2015.