Journal of Engineering and Applied Sciences 13 (Special Issue 5): 4823-4826, 2018
ISSN: 1816-949X

Cooling System Analysis of Thermoelectric Generator Used for Marine Waste Heat Recovery

S.P. Venugopal
Department of Marine Engineering, AMET University, Chennai, India

Abstract: There has been awesome enthusiasm on investigating the capability of waste heat extraction utilizing Thermoelectric Generator (TEG) system on marine application because of extraordinary measure of gas volume, numerous potential areas with predictable high temperature and accessibility of unbounded cooling ocean water. To enhance the general yield execution of TEG framework regarding proficiency, legitimate framework level of designing and coordination have been viewed as vital other than improvement of thermoelectric materials with bigger ZT (figure of legitimacy) and ideal control methodology of electrical interface system. In this research, preparatory exploratory examination and numerical displaying enhancement on the cooling system for a thermoelectric module level gadget are discussed. The anticipated open-circuit voltages by thermoelectric reproduction for gadget with customary water cooling plate are in great concurrence with the deliberate test information for different hot gas temperatures. The model is then amended for further reproduction to upgrade the cooling plate configuration by analyzing point by point warm execution and electrical current-voltage attributes for the thermoelectric module gadget with shifting electrical load. These examinations show that a good cooling system is essential for high effectiveness TEG usage. This module level perception serves to see how TEG framework incorporates and demonstrate potential change for TEG control transformation system. With great exactness, the utilized apparatus is prepared to do quickly describing TEG system level execution in future work.

Key words: Thermoelectric generator, thermoelectric module, figure of merit, TEG, open-circuit, describing

INTRODUCTION

Applying waste warmth recuperation advancements in marine application have drawn extraordinary consideration for their capability to address developing petroleum derivative expenses and in addition stringent emanation directions.

Thermoelectric Generator (TEG) is a strong state innovation that produces power when there is a temperature distinction over the intersections of thermoelectric materials. TEG framework comprises of thermoelectric modules (exhibit of thermoelectric material combines), a hot-side warmth extraction framework, an icy side warmth dissemination system or cooling system and a power control gadget to convey the coveted electrical yield (Nielsen *et al*., 2014). Aside from the advancements of thermoelectric materials with bigger ZT esteem:

$$ZT = \frac{S^2\sigma}{k}T$$

Where:

S = See beck coefficient
σ = Electrical conductivity
κ = Warm conductivity
T = The Temperature of material

It was recognized that appropriate framework level coordination of these four segments is significant for high-productivity. TEG usage demonstrated that TEG framework ought to be created vitally to match warm flux through each segment for the advanced framework level execution (Zhang *et al*., 2015). This process is apparently direr than enhancing ZT estimation of materials had thought about between TEG system proficiency and thermoelectric material effectiveness for three potential waste warmth recuperation uses of water radiator, car fumes and modern heater (Singh and Pedersen, 2016). It is demonstrated that the TEG system effectiveness is 32, 33 and 59% lower than the transformation productivity of thermoelectric materials for these three applications individually (Kim and Lai, 2008).

The electrical power used in automobiles is generated using part of the energy converted into a driving force with an alternator. The main problem of this energy transformation is that only part of the energy flow supplied by the fuel in an automobile is converted into brake power output and although, the efficiency of the alternator is high, the ratio between the electric energy produced and the fuel consumed is very low (Laird and Lu, 2013; Montecucco and Knox, 2015).

The efficiency of a modern internal combustion engine oscillates from 37% in a normal passenger car spark ignition engine to more than 50% in a low speed marine diesel engine. The energy dissipated is lost by transmission to the environment through exhaust gas, cooling water, lubrication oil and radiation (Tian and Chen, 2013). For instance, in a gasoline engine about 30% of the primary gasoline energy is discharged as waste heat in the exhaust gases. Furthermore the electric load of a vehicle is increasing due to improvements of comfort, driving performance and power transmission. In line with this tendency, the alternator size, load of engine power and engine weight are becoming larger (LeBlanc, 2014; Freunek *et al*., 2009). However, the engine room is becoming smaller in order to improve the aerodynamic characteristic and expand the passenger room. For this reason, the space for the alternator cannot be freely increased. If approximately 6% of the exhaust heat could be converted into electrical power, more or less the same quantity of driving energy that demands the production of electrical power would be released and then, it would be possible to reduce the fuel consumption around 10%. This is the reason why Thermoelectric Generators (TEGs) can be profitable in the automobile industry (Rosado and Stevens, 2009; Leavitt *et al*., 1996).

Elements of a TEG: A thermoelectric generator basically consists of the support structure where the thermoelectric modules are located. The internal part of this structure normally is modified in order to absorb the most part of the heat accumulated in the exhaust gases. The thermoelectric modules, depending on the range of temperatures, silicon germanium, lead telluride or bismuth telluride modules are used. The heat dissipation system which favours the heat transmission through thermoelectric modules. The following sections of this paper describe the ideas and designs proposed by the research community (Bass *et al*., 1990).

Support structure of the TEMs: This structure is extremely important in any thermoelectric generator oriented to be used due to the following reasons and limitations: The heat transmission from the exhaust gases to the structure must be done normally in a short length. Usually it is necessary to introduce internal fin heat sinks or other structures which increase the contact area between the gases and the support structure and raise the turbulence augmenting the average heat convection coefficient. However, the fin heat sinks or bundles are real obstacles in the way of the exhaust gases, generating a pressure drop. This can affect the engine efficiency, even causing a new design of the camshaft.

The available space to mount a thermoelectric generator: In an automobile is normally reduced because of the tendency to put more equipment in less space. There are mainly three possible locations for the TEG:

- Just behind the exhaust manifold
- Between the manifold and the catalyst converter
- After the catalyst converter

The weight of the structure: Approximately it represents at least 50% of the total weight of the TEG. If the system is too heavy, the loss in the engine efficiency can surpass the electrical energy produced by the TEG making it completely inefficient.

Variability of the exhaust gas temperature: The different working points of the engine can cause 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.

MATERIALS AND METHODS

Thermoelectric modules, materials, shape and size: The TE modules used in a typical TEG can be classified according to the semiconductor material used and the shape, size and configuration of their thermoelectric pairs. The semiconductor material used in the fabrication of the pellets has been selected according to the position of the TEG in the exhaust pipe:

- Just behind the exhaust manifold: where the temperature range of the exhaust gases is between 1000 and 750°C
- Between the exhaust manifold and the catalyst converter where the temperature range of the exhaust gases is between 750 and 400 °C
- Just behind the catalyst converter where the temperature range of the exhaust gases is between 400 and 200°C

Another interesting classification of the TEGs is taking into account the shape, size and configuration of their thermoelectric pairs. The TEGs analyzed and can be classified into two groups:

TEGs with traditional square TE modules: Each of these modules is composed of several thermoelectric pairs in series. This type of configuration requires flat surfaces in order to mount the modules and has been used in many applications.

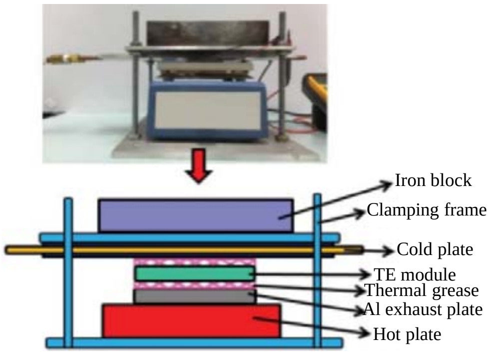

Fig. 1: Thermoelectric module device test rig and its schematic diagram

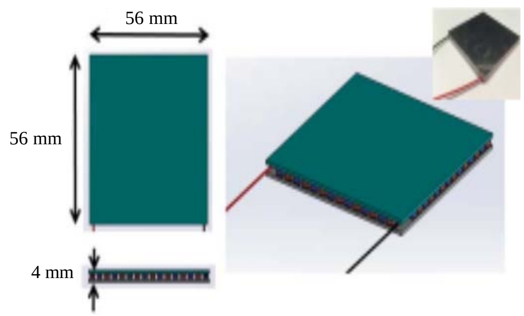

Fig. 2: Schematic of Thermoelectric module: TEG1-12611-6.0

TEGs with linear shape TEMs: In this case, the thermoelectric pairs form lines which can adjust better to the circular shape of the exhaust pipe.

Experimental setup and numerical modelling: The above figure demonstrates the exploratory test apparatus and its schematic outline for portraying a thermoelectric module gadget. A business Bismuth Telluride (Bi2T e3) thermoelectric module TEG1-12611-6.0 (56×56×4 mm with 126 thermoelectric sets) from TECTEG is tried in this work (Fig. 1 and 2). An aluminum plate (60×60×7 mm) is utilized as the external surface of the fumes warm exchanger that is warmed up by a hot plate (Stuart UC150).

A traditional tube water cooling plate (aluminum base and double pass copper tubes) is utilized to scatter warm at the icy side of thermoelectric module. To keep up great surface contact, the entire gadget is held together with a brace and warm oil is connected between the interfaces of aluminum fumes plate, thermoelectric module and chilly plate. A substantial iron square is put on top of gadget to ensure that the deliberate information is free of clasping power. Thermocouple is utilized to measure the temperature and an advanced multi meter is utilized to gauge the open-circuit voltage of the thermoelectric module. Cooling water is coursed through the icy plate by a chiller.

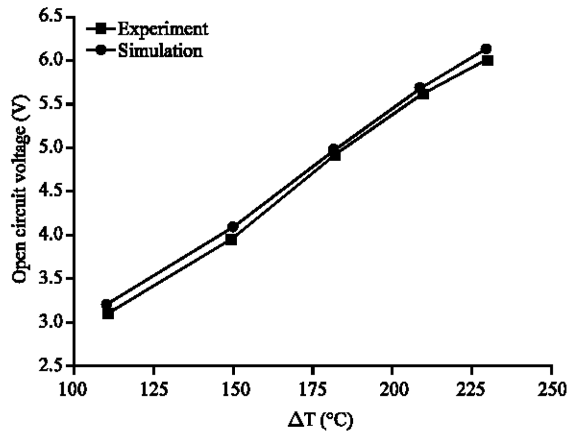

Fig. 3: Comparison of open-circuit voltage output of thermoelectric module device at various temperature and simulation analysis

RESULTS AND DISCUSSION

Keeping up the cooling water at 25°C by a chiller, the execution of thermoelectric module gadget is tentatively tried for different hot-side temperatures of aluminum fumes plate. To abstain from harming the thermoelectric module, the most extreme temperature of fumes plate is set as 250°C which is lower than its greatest working temperature of 320°C. Under a similar temperature conditions, the thermoelectric examination has been performed to inspect the warm and electrical conduct of the gadget.

At different temperature contrasts between aluminum deplete plate and cooling water, Fig. 3 introduces the open-circuit voltage yield of the module gadget through trial estimation and numerical count. Since, the voltage produced is corresponding to the connected temperature inclination, a direct connection between open-circuit voltage and temperature distinction can be watched and the recreation results are in a decent concurrence with trial estimation. Along these lines, the utilized numerical displaying can be utilized to anticipate the execution of thermoelectric module gadget with great precision.

CONCLUSION

Numerical and test examination on thermoelectric module level gadget have been performed to look at the effects of chilly side warmth dispersal framework on the general execution of TEG framework utilized for marine waste warmth recuperation. The warm and electrical execution of the thermoelectric module gadget with customary tubed icy plate and enhanced installed level depression icy plate have been contemplated and analyzed in detail. From those outcomes and discourse, it can be presumed that:

The deliberate yield open-circuit voltage increments directly with connected temperature angle crosswise over thermoelectric module gadget. For different temperature contrast, the electrical current is contrarily corresponding to voltage with a negative direct relationship; the greatest power yields when the heap voltage is half of the open-circuit voltage.

REFERENCES

Bass, J.C., N.B. Elsner and R. Slone, 1990. Design study and experience with thermoelectric generators for diesel engines. Proceedings of the Annual SAE Conference on Automotive Technology Development Contractors Coordination Meeting, October 22-25, 1990, SAE, Dearborn, Michigan, ISBN:1560911379, pp: 451-455.

Freunek, M., M. Muller, T. Ungan, W. Walker and L.M. Reindl, 2009. New physical model for thermoelectric generators. J. Electron. Mater., 38: 1214-1220.

Kim, R.Y. and J.S. Lai, 2008. A seamless mode transfer maximum power point tracking controller for thermoelectric generator applications. IEEE. Trans. Power Electron., 23: 2310-2318.

Laird, I. and D.D.C. Lu, 2013. High step-up DC/DC topology and MPPT algorithm for use with a thermoelectric generator. IEEE. Trans. Power Electron., 28: 3147-3157.

LeBlanc, S., 2014. Thermoelectric generators: Linking material properties and systems engineering for waste heat recovery applications. Sustainable Mater. Technol., 1: 26-35.

Leavitt, F.A., N.B. Elsner and J.C. Bass, 1996. Use, application and testing of the HZ-14 thermoelectric module. Proceedings of the 15th IEEE International Conference on Thermoelectrics, March 26-29, 1996, IEEE, Pasadena, California, ISBN:0-7803-3221-0, pp: 378-386.

Montecucco, A. and A.R. Knox, 2015. Maximum power point tracking converter based on the open-circuit voltage method for thermoelectric generators. IEEE. Trans. Power Electron., 30: 828-839.

Nielsen, R.F., F. Haglind and U. Larsen, 2014. Design and modeling of an advanced marine machinery system including waste heat recovery and removal of Sulphur Oxides. Energy Conversion Manage., 85: 687-693.

Rosado, E.S. and R.J. Stevens, 2009. Experimental characterization of thermoelectric modules and comparison with theoretical models for power generation. J. Electron. Mater., 38: 1239-1244.

Singh, D.V. and E. Pedersen, 2016. A review of waste heat recovery technologies for maritime applications. Energy Conversion Manage., 111: 315-328.

Tian, Z. and G. Chen, 2013. Heat transfer in thermoelectric materials and devices. J. Heat Trans., 135: 061605-061620.

Zhang, C., G. Shu, H. Tian, H. Wei and X. Liang, 2015. Comparative study of alternative ORC-based combined power systems to exploit high temperature waste heat. Energy Conversion Manage., 89: 541-554.