MODELING AND ANALYSIS OF ANNULAR THERMOELECTRIC GENERATOR USING BISMUTH TELLURIDE AND HALF HEUSLER ALLOYS

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Abstract

The contribution of this project is to apply the principle of thermoelectric power generation which can be used for small appliances. Thermoelectric power generation is one of the cleanest source of energy which involves the direct conversion of waste thermal energy into electrical energy. Thus it can be utilized to extract waste heat from various sources. For good understanding of thermoelectric principle annular TEG have been modelled using software CATIA V5R18 & PTC CREO 2.0 and steady state thermoelectric analysis has been carried out using software ANSYS 15.0. Bismuth telluride (Bi_2Te_3) with ZT~1 and half-heusler alloys with ZT~ 0.78 have been selected for TEG. Annular TEG (ATEG) is analysed and compared for the two different types of material selected i.e. bismuth telluride and half heusler alloys. Results so obtained are presented in this study.

Keywords: Waste heat recovery, thermoelectric generator (TEG), Annular TEG (ATEG), CATIA V5R18, PTC CREO 2.0, ANSYS15.0.

I. INTRODUCTION

As the energy demand is increasing continuously it becomes very essential to utilize the waste heat rejected to the surroundings with exhaust gases of a power plant, automobile vehicles etc. In a typical automobile vehicle the temperature of the exhaust gases ranges from 250°C to 700°C. A thermoelectric device creates electric voltage when temperature difference is applied across its two sides (hot side and cold side). At the atomic scale, an applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side. This effect can be used to generate electricity, measure temperature or change the temperature of objects. The direction of heating and cooling is determined by the polarity of the applied voltage. The term thermoelectric effect encompasses three separately identified effects: the Seebeck effect, Peltier effect, and Thomson effect. Sometimes it is also referred as the Peltier–Seebeck effect. When the high temperature is applied to one side of the TEG, the other side is kept at the lower temperature. As a result of the difference in the temperature between the two sides, the end of the TEG generates an electrical voltage V. When the end of the TEG is connected to an external load, a current flows through the load as shown in figure 1.

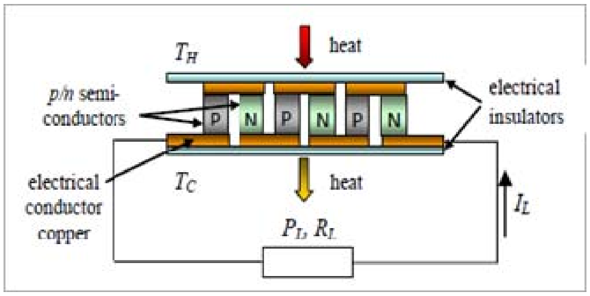

Fig. 1. Structure of the TEG. [5]

The electrical power P and the current obtained from the TEG depend on the temperature difference ΔT, the properties of the semiconductor materials. TEGs have limitations such as relatively low efficiency and maximum surface temperatures. Thermoelectric material which greatly affects the efficiency is of huge importance for thermoelectric power generation. The material should have large Seebeck coefficient, good electrical conductivity, and small thermal conductivity.

A thermoelectric generator where a number of n series units are cascaded to generate useful output voltages, hot and cold junctions are connected by p and n doped semiconductor legs. ρ_p & ρ_n are electrical resistivity and k_p and k_n are thermal conductivity of p-type and n-type semiconductor respectively. A block of length *L* and cross-sectional area *A* owns a thermal conductance K given by

$$K_i = k_i \frac{A_i}{L_i} \qquad (1)$$

Where i refers to either p or n. From the thermal point of view the two conductor are in parallel, so that the total thermal conductance *K* for *n* elements is given by

$$K = K_N + K_P = n\left(k_P \cdot \frac{A_P}{L} + k_N \cdot \frac{A_n}{L} \right). \qquad (2)$$

The electrical resistance is calculated in a similar way except that the n elements are in series. The resistance *R* of the power-generating portion (without the connecting metal stripes) of the circuit, is given by

$$R = R_P + R_N = n\left(\rho_P \cdot \frac{L}{A_P} + \rho_N \cdot \frac{L}{A_N}\right) \qquad (3)$$

Seebeck coefficient which is function of temperature is given by

$$S = S_P - S_N \qquad (4)$$

For Bismuth Telluride, the seebeck coefficient is given by:

$$S = S_P - S_N = 2(22224.0 - 930.6T_m - 0.9905T_m^2) \times 10^9 \qquad (5)$$

The conversion efficiency, η_{TE}, is related to a quantity called the figure of merit, Z that is determined by three main material parameters: the Seebeck coefficient S, the electrical resistivity R, and the thermal conductivity κ.

$$Z = \frac{n^2 . S}{K . R} \qquad (6)$$

The three factors Seebeck coefficient, electrical conductivity, and thermal conductivity are interrelated and make it quite challenging to optimize Z.

II. LITERATURE REVIEW

[1] Experimentally presented an enhancement in thermoelectric figure of merit by a reduction of thermal conductivity in PbTe and Bi_2Te_3-superlattices parallel to the layer planes despite a drop of the total power factor results also shows the suitability of Bi_2Te_3 and PbTe-based superlattice structures for highly efficient thin film thermoelectric applications.

[2] Measured the thermoelectric properties of the compounds like half-Heusler alloys with nominal compositions of $Ti_{0.37}Zr_{0.37}Hf_{0.26}NiSn$at 2 K < *T* < 900 K and showed a high figure of merit, reaching a value of *ZT* = 1 at 725 K.

[3] Reviewed that Bi_2Te_3 module TEG is high efficient in room temperature by using multiple stages of TEGs both the high temperature with standing TEG and low temperature with standing TEGs and also concludes that combination of both material, which means multistage Hot side area use PbTe and CMO modules after that less temperature area use Bi_2Te_3 module TEG.

[4] Suggested that over the past few decades, more promising thermoelectric materials have been developed with Z values that are a factor of 2 larger than those of previous materials. Another 50% increase in Z (to Z~3) with the appropriate material characteristics and costs will position thermoelectric to be a significant contributor to our energy needs, especially in waste heat or solar energy conversion.

[5] Presented the role of thermoelectric generators (TEGs) in conversion of geothermal energy into electrical energy and shown that the conversion efficiency of the thermoelectric modules (TEMs) used commercially is less than about 10%.

[6] Investigated the exoreversible thermodynamic model of an annular

thermoelectric generator (ATEG) considering Thomson effect in conjunction with Peltier, Joule and Fourier heat conduction using exergy analysis and found that the power output, energy and exergy efficiency of the ATEG is lower than the flat plate thermoelectric generator.

[7] Reported that $CuAlTe_2$ is found to be more promising, in comparison with $CuGaTe_2$, which is reported to be an efficient thermoelectric material with appreciable figure of merit. Another interesting fact about $CuAlTe_2$ is the comparable thermoelectric properties possessed by both *n*- type and *p*-type carriers, which might attract good device applications.

III. MODELLING AND ANALYSIS

In the first step a realistic theoretical model of a large scale thermoelectric power generator is developed. Here the thermoelectric devices are large number of thermoelectric couples characterized by its dimensions and average material properties. Linearity and one-dimensionality of temperature and electrical potential distributions are also assumed for above mentioned examinations. To evaluate if these simplifications are acceptable a physical 3D model of small scale thermoelectric devices, including all nonlinearities and irreversibility is developed and simulated with the method of finite elements. In this study modelling and steady state analysis of annular thermoelectric generator is carried out on two different materials namely Bismuth Telluride (Bi2Te3) and half heusler alloys with 24 legs. The Modelling is done using a cad model of large scale thermoelectric generator using software CATIA V5R18 & PTC CREO 2.0. and analysis is carried out in Finite Element analysis of cad model using ANSYS 15.0 then finally the result is validated with experimental data from module performance calculator of Hi-Z Technology.

IV. RESULTS AND DISCUSSION

Results shows that for a temperature range for a temperature range of 323K – 500K the maximum output voltage obtained for Half Heusler alloy is 0.81062 V as shown in fig. 3 and that of Bismuth Telluride is 1.0105 V shown in fig. 4. The efficiency is obtained 2.947% for half heusler alloy and that of Bismuth Telluride is 4.933%. Efficiency is calculated using the following software based equations:

Efficiency $\eta_{sw} = \frac{P_{out}}{Q_{in}}$ (7)

Power output $P_{out} = \frac{V_o^2}{4R}$ (8)

For bismuth telluride:

$$R = 1.7468 \times 10^{-1}\ \Omega$$

$$Q_{in} = 2.9688 \times 10^{1}\ W$$

For half heusler alloy:

$$Qin = 31.3456\ W$$

$$R = 1.085628 \times 10^{-3}\ m$$

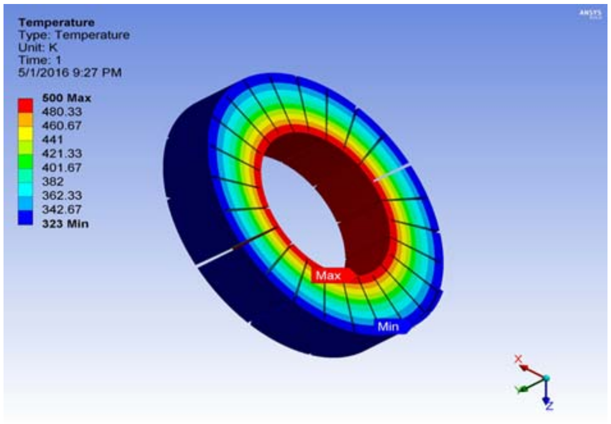

Fig. 2. Variation of temperature in a TEM

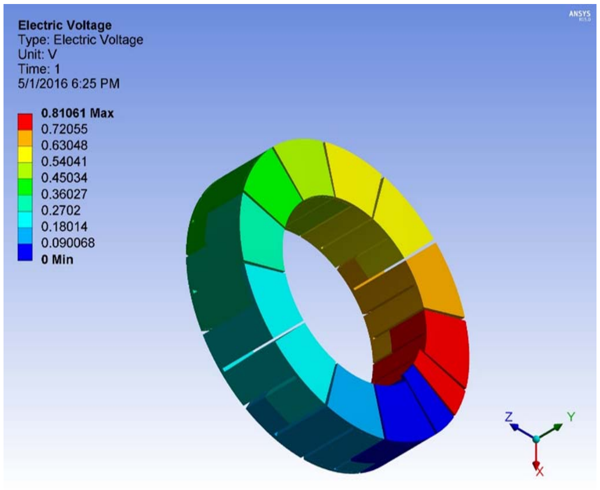

Fig. 3 Electric voltage output in a TEM for Half Heusler alloy.

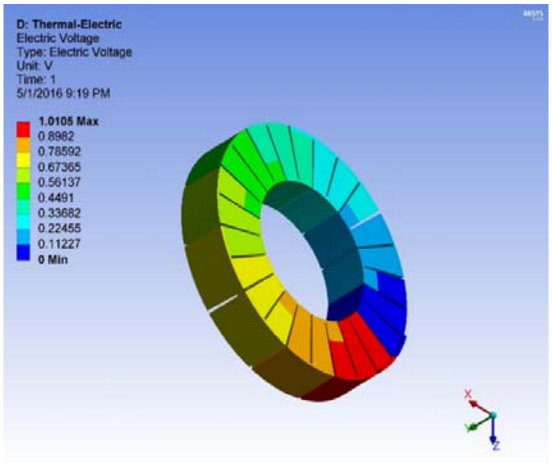

Fig. 4 Electric voltage output in a TEM for Bismuth Telluride.

IV. CONCLUSION

To know the accuracy of result obtained from simulation a TEG with 98 legs is modelled with given specification in module calculator of Hi-Z technology, its output power & efficiency is compared with thermoelectric module of Hi-Z technology. The result obtained is in good approximation with the experimental result. It is therefore suggested that for ATEG Bismuth Telluride will have more efficiency as well as it will produce high voltage output for medium temperature range. Hence number of TEGs can be connected in series to produce more power output. The annular TEG is selected as it can be easily manufactured in the required dimensions and assembled with the pipes carrying hot flue gases. With the discovery of new higher efficiency materials, the means of extracting waste energy through thermoelectric devices will become more prevalent.

V. APPLICATIONS

Thermoelectric Generators are basically used in where the power production is less. In automobile vehicle produce heat that can be used for generating electricity by using TEG. Recharge the battery where ever waste heat is obtained .Self charging battery by fixing the TEG a radiator or two wheeler silencers pipe.

VI. REFERENCES

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