Design and simulation of a thermoelectric device to harvest energy from a vortex tube

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Problem Statement

The increasing demand for high power density and weight ratio presents opportunities for alternative power sources like small scale thermo-mechanical systems and thermal energy harvesters. A vortex tube with no moving components, long life, and low maintenance is ideal for energy harvesting and powering wireless autonomous devices like wearable electronics and sensor networks.

Abstract

The Ranque-Hilsch vortex tube, a device that splits compressed gas into hot and cold vortices, has potential for small-scale power generation. Its temperature gradient could be used for energy harvesting, powering wireless autonomous devices like wearable electronics and sensor networks. This technology is particularly useful in low-access locations like downhole wells. This project modeled and simulated an arc-shaped thermoelectric generator geometry using COMSOL Multiphysics software, resulting in approximately 4.25 watts of power at 300°C and 2 ohms load resistance.

Model

Since the module has to go deep down into a well and will receive its input from a curved vortex tube, the TEG module is also designed to be curved-shaped as shown in Figure 2. The multi-couple model comprises 45 thermocouples with an outer arc length of length 74.13mm, with a radius of 84.44 mm. 84.44 The module has a height of 19.05 mm, which is approximately the same as the diameter of the vortex tube. The complete TEG module consists of 90 legs connected electrically in series and thermally in parallel as shown in Figure 3. Each leg has a cross-sectional area of 1.5mm x 2mm and a height of 4mm. The bottom planar surface is defined as the TEG cold side at 20°C and the top is defined as the hot side at 100°C, 200°C and 300°C. The TEG module dimensions with applied boundary conditions are illustrated in Figure 1.

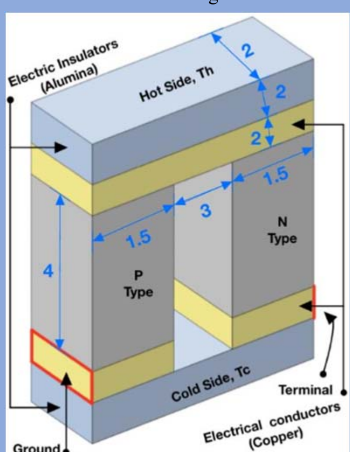

Figure 1: Single-couple TEG device boundary definitions

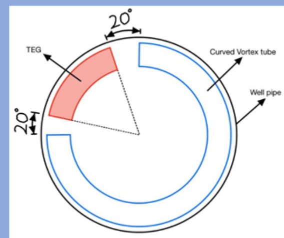

Figure 2: The TEG layout inside the well

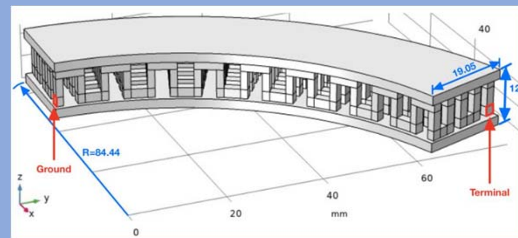

Figure 3: Multi-couple TEG device boundary definitions

Simulation Results

The power produced by the multi-couple model at the three hot surface temperatures as a function of load resistance is presented in Table 1.

Table 1: Power predicted due to changes in hot surface temperature and load resistance.

Power	Hot surface temperatures		
Load resistances	100°C	200°C	300°C
0	1	2	3
1	0.358154	1.622057	3.80055
2	0.374389	1.787354	4.249341
3	0.344356	1.69319	4.060499
4	0.309915	1.554261	3.749045
5	0.278952	1.417781	3.43376

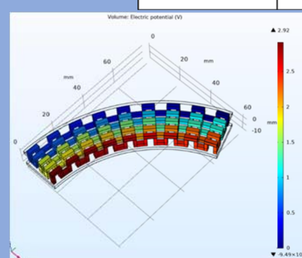

Figure 4: Electric Potential for 300°C

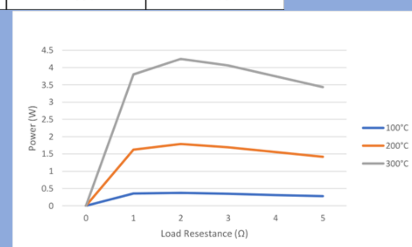

Figure 5: Power vs Load Resistance

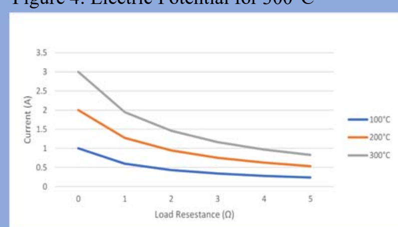

Figure 6: Current vs Load Resistance

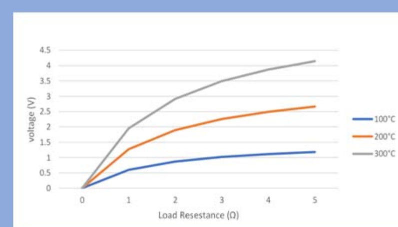

Figure 7: Voltage vs Load Resistance

Discussion of multi-couple model

The simulated results for the multi-couple TEG module shows that a maximum power of approximately 4.25 W is produced at a temperature of 300°C and a load resistance of 2 ohms. The corresponding voltage and current at this condition are 2.915 V and 1.458 A respectively.

Conclusion

- In this project, a thermoelectric generator is designed and simulated using COMSOL Multiphysics software.
- the multi-couple model having 45 thermocouples and an arc length of 74.13mm, a radius of 84.44 and a height of 19.05mm is developed that uses the same materials as the single couple.
- When TEG internal resistance (R) equals load resistance (RL) at 2Ω and a maximum temperature of 300°C, the power output is equal to 4.249W. The corresponding voltage and current at this condition are 2.9153 volts and 1.4576 amperes respectively.

Acknowledgments

We express our deep sense of gratitude and reverence to our supervisor Dr. Syed Hasani, for the invaluable encouragement, helpful suggestions, and supervision throughout this work. We are thankful to the members of our examination committee Prof. Dr. Maaz Akhtar and Dr. Murugesan Palaniappan Papathi for their valuable time spent in going through the manuscript and providing useful suggestions. Thanks are due to Dr. Bechir ben Hamida for teaching us COMSOL Multiphysics software and providing useful simulation tips. Finally, we are grateful to Dr.Abdulaziz Alasiri, Chairman, Mechanical Engineering Department and Dr. Nashmi Alrasheedi, Dean College of Engineering, for providing the necessary departmental support to pursue this work.

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