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Heating-island test bench for thermal energy harvesting characterization

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Annotation:
The paper presents characterization test bench for thermal electric generators (TEG). It is basically a heating island, that is supplied by a constant power and the thermoelectric generators are used to harvest the energy back to the useful load. This test simulates practical application of the TEGs to harvest a waste energy of some device and using it for powering e.g. sensor node. The cold side is considered to be at the room temperature and different heatsinks can be used for testing.

Anotace:
Článek představuje testovací lavici pro charakterizaci termoelektrických generátorů (TEG). Jde v podstatě o topný ostrůvek, který je napájen konstantním výkonem a termoelektrické generátory slouží ke sběru energie zpět do užitečné zátěže. Tento test simuluje praktickou aplikaci TEGů ke sběru odpadní energie ze zařízení a její použití pro napájení např. IoT nodů. Studená strana termoelektrického generátoru je udržována na pokojové teplotě pomocí chladičů, které mohou být voleny podle zamýšlené aplikace.

INTRODUCTION

Energy harvesting allows operate electronic devices without battery or support the battery to increase its lifetime. It is suitable mainly for places where the standard powering cannot be applied or where it is inconvenient to replace the battery. Typical application can be IoT nodes. Unfortunately, the alternative energy sources are usually weak and cannot provide enough energy for direct powering of the device. The energy thus should be collected to the capacitor or battery first and afterwards it can be released to the load [1]. Beside this, the voltage levels from the energy harvesting transducer is usually low and some kind of DC/DC conversion must be performed [2, 3]. This paper deals with thermoelectric generators [4, 5], where the DC/DC conversion is crucial. It is necessary to know properties of the equivalent circuit to predict potentiality of this kind of powering at given environment.

TEST BENCH

Test bench is presented in figure 2. It consists of a heating island that is isolated from the surroundings using the mineral wool. The temperature of the island is controlled using the build-in thermocouple K. Testing is performed by feeding the island by a constant heat and TEG is harvesting back the energy at different conditions. Thermal resistance of the bench was measured to be 10 $K \cdot W^{-1}$ for uncovered island. The heat from the island is dissipated by the upper surface and via the mineral wool around it. When the island is covered by the thermal isolation, the thermal resistivity of the bench increases to 13 $K \cdot W^{-1}$.

The TEG under test is clamped between the bench and the heatsink. The thermally conductive paste is used to minimize the thermal resistance and additional cotton wool is used to thermally isolate the TEG from sides (fig. 1).

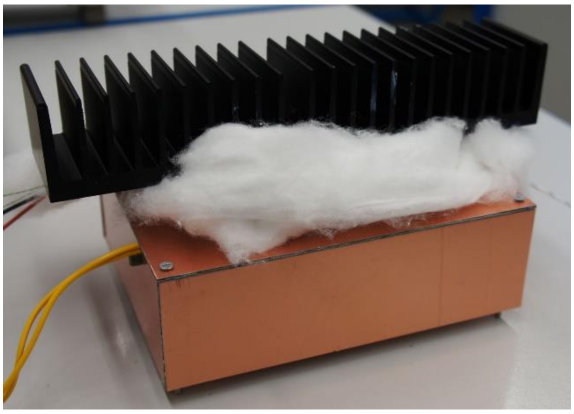

Fig. 1: Big heatsinks on the TEG and cotton wool for additional thermal isolation

Harvested energy from the TEG is fed to the loading resistor that is optimal to each TEG (the resistance is equal to the internal resistance of the TEG).

MEASUREMENT SETUP

Figure 3 presents TEC devices that were tested as the thermal generators. Two identical devices were connected in series to increase the generated voltage and to cover maximum surface of the heating island. Total footprint was $40 \times 80\ mm^2$, thickness was 3 mm and total number of PN junctions was 254 [5].

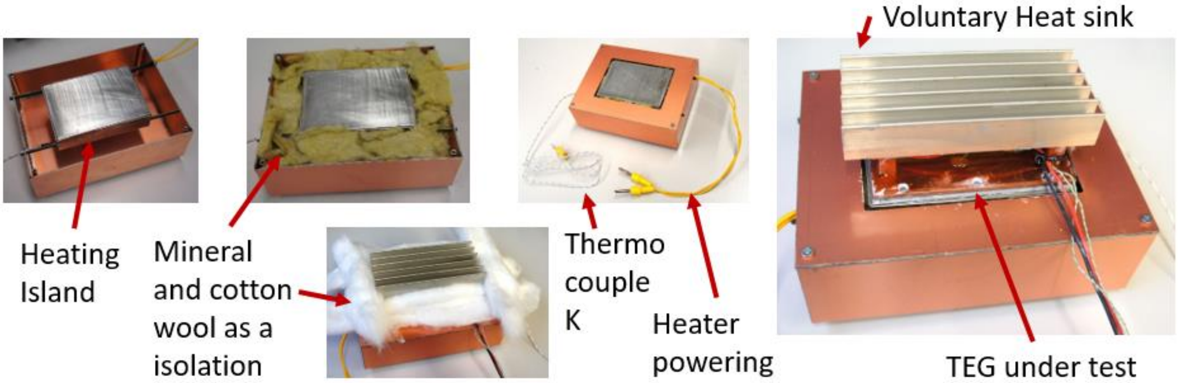

Fig. 2: Test bench for TEG characterization

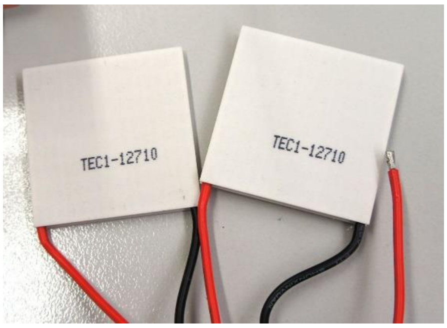

Fig. 3: Thermoelectric coolers TEC1-12710 used as the thermoelectric generators connected in series [5]. Total footprint is 40 × 80 mm^2, thickness is 3 mm and total number of PN junctions is 254.

There were tested two different heatsinks with the TEGs. The input power to the heating island was changed from 0.5 W to 10 W. Only the steady values were registered – each measurement was stabilized at room temperature for more than 2 hours. The TEGs were loaded by a resistor during the stabilization process and its value was close to the optimal load.
Efficiency of the harvesting process is given by the ratio between the input power to the heating island and the energy harvested to the optimal load. The efficiency is affected namely by the properties of the heatsink, heating island's thermal resistance, isolation properties of the wool and thermal conductivity of the TEGs. This measurement thus allows only to compare the TEGs' performance at given specific environment and conditions.
Table 1 shows an example of the registered data and calculated parameters. The open-circuit voltage of the TEG V_{OC} and voltage measured on the loading resistor V_L were used to calculate the equivalent circuit of the TEG according to the Thévenin's theorem (1). The parameters V_i and R_i are valid at the optimum operation point. Maximum possible power P_{max} is then given by the (2).

$$V_i = V_{oc};\ R_i = R_L \cdot \frac{V_{oc} - V_L}{V_L} \quad (1)$$

$$P_{max} = \frac{V_i^2}{4 \cdot R_i} \quad (2)$$

MEASUREMENT RESULTS

The TEGs were tested with two different heatsinks. Figure 4 presents the measurement results of the power harvested to the optimal load for different input power to the heating island. Figure 5 presents the efficiency of the harvesting as a function of the input power.
Considering the thermal resistance of the heating island itself (13 K·W^{-1}), significant portion of the power is dissipated just by the test bench. Rest of the power goes to the heatsink via the TEG and some portion of it is harvested to the load.

Table 1: Example of measured data – thermoelectric generators with big heatsink (see fig. 1)

Heater's power (W)	Bench temperature (°C)	Room temperature (°C)	TEG's open circuit voltage V_{OC} (mV)	loaded TEG voltage V_L (mV)	Loading resistor R_L (Ω)	TEG's Vi (mV)	TEG's Ri (Ω)	TEG Pmax (mW)	harvesting efficiency mW·W^{-1}
0,54	24.8	23.0	19.8	10.1	3.3	19.8	3.18	0.031	0.057
2.01	30.3	23.2	80.0	40.2	3.3	80.0	3.27	0.490	0.24
3.58	34.8	24.5	147	74.5	3.3	147	3.21	1.682	0.47
4.94	37.5	23.6	205	103	3.3	205	3.27	3.209	0.65
7.95	44.2	23.2	330	164	3.3	330	3.35	8.131	1.02
10.0	51.2	23.9	430	204	3.3	430	3.66	12.644	1.26

Table 2: TEGs' efficiency with big heatsink and for input powers 2 W and 10 W

Input power (W)	Temperature difference between heated island and the room temperature (K)	Power dissipated by the heating bench @ R_T = 13 $K \cdot W^{-1}$ (W)	Power to TEG + heatsink (W)	Power harvested to the load (mW)	TEG's efficiency ($mW \cdot W^{-1}$)
2	7.1	0.5462	1.4648	0.4897	**0.33**
10	27.3	2.1	7.915	12.61	**1.59**

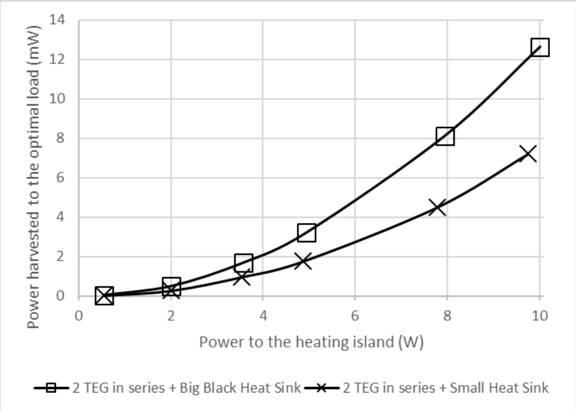

Fig. 4: Power harvested to the optimal load for different input power to the heating island

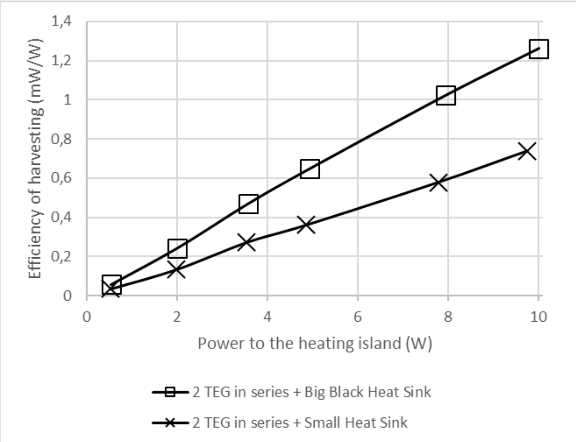

Fig. 5: Efficiency of the harvesting process for different input power to the heating island

The table 2 summarizes the power ratios for input power 2 W and 10 W and with the big black heatsink. The efficiency of the TEG is calculated as a ratio between the power harvested to the load and the power dissipated on the TEG + heatsink (the power dissipated by the mineral wool is excluded from the calculation).

CONCLUSIONS

The paper has presented a test bench that can be used for characterization of the thermoelectric generators as the energy harvesters for powering some sensor nodes. It simulates real applications where the waste heat is harvested. The cold side of the TEG is kept at the room temperature using the heat sink and only the free convection is cooling it.

Efficiency of this conversion can be calculated for all the system (testbench + TEG + heatsink) or it can be expressed just for the TEG with heatsink. In this case the heat dissipated by the testbench is eliminated from the calculation.

Efficiency of the conversion depends on the thermal difference between the hot and the cold sides of the TEG. For temperature difference around 30 K the efficiency is approximately 1.6 mW/W and maximum useful power from the TEG is about 13 mW, which is enough for low power IoT applications

ACKNOWLEDGMENTS

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