Evaluation power generation efficiency of space ETG for in vacuum

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1. Introduction

June 2022, the Korea Space Launch Vehicle (KSLV-2) Nuri was launched into space carrying a satellite. This satellite accommodated a small ETG (Electrically-heated Thermoelectric Generator) and its performance was verified in space. Instead of conducting the experiment using radioisotope, an electric heater was used to comply with UN international norms prohibiting the use of radioactive materials in low Earth orbit. The Korea Atomic Energy Research Institute (KAERI) has been developing an RTG for Lunar lander [1].

In 1954, the United States manufactured the first RTG using Pu-238 as a heat source and a thermoelectric element to generate electricity of 1.8 mW [2]. The principle is that RTG generates electricity by converting the heat produced by the decay of a radioisotope (Seebeck effect). This conversion occurs with the use of a thermoelectric element [3-4].

The main advantages of RTG include long lifespan, generating electrical current for several decades, depending on the type of isotope used; and environmental independence, which generates current regardless of external environments, such as extreme temperatures and the presence of the sun [4].

In general, during the development phase, a heater is used instead of radioisotopes to test the performance of the RTG system. The voltage, current, power, and conversion efficiency are measured by supplying 120 W of power into the heater of the ETG.

2. Methods and Results

2.1 Methods

The prototype was placed in a specially manufactured vacuum chamber, and a total of 90 cycles were performed at about 10^{-3} Torr of vacuum state for 8 hours. To provide a temperature gradient, the chiller was set to a value of -10 °C.

There are a total of 4 sections for measuring the changing temperature during the experiment. The hot shoe is on the thermoelectric element, the radiating part where heat is dissipated and electricity is generated, the ETG surface and the water chamber.

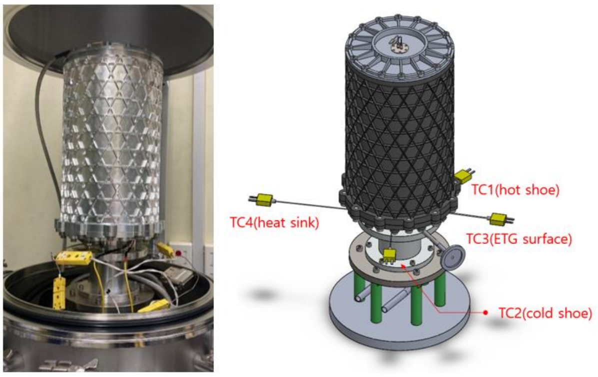

Fig. 1. Position of thermocouples in the RTG prototype

2.2 Results

The input supply should be fixed at 101 V for 90 cycles, but experiment by setting it to 100 V by mistake on the 9th cycle. The graph in Figure 2 shows the temperature inside and outside the thermoelectric element. During the 90 cycles, the average temperature of the hot shoe was about 209.1 °C and the average temperature of the cold shoe was 27.6 °C, showing a temperature difference of about 181.5 °C.

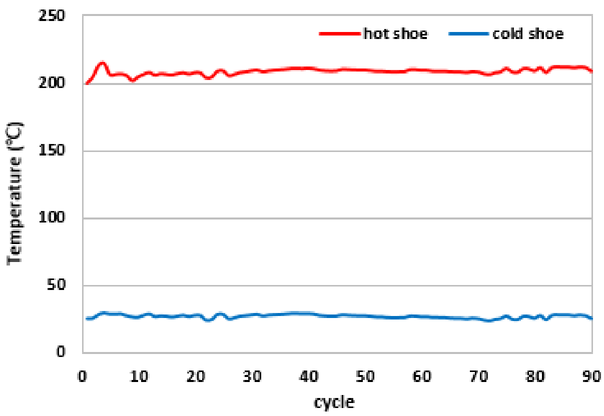

Fig. 2. Temperature distribution diagram of hot shoe part and cold shoe part during the 90 days cycle.

In Figure 3, the input voltage is constant except for 9 cycles. However, in the first 1 to 4 cycles, the coil of the thermoelectric element inside the ETG was short-circuited and the resistance was lower than the input value. The resistance can be found using Ohm's law, and it was confirmed that the resistance for 1 to 4 cycles was gradually lower than the 85 ohms set at 83, 82, 80, and 80, respectively. As can be seen in Figure 4, the voltage was constant, but the resistance was lowered, thus the current was higher. It can be seen from Figures 3, 4, and 5 that the output voltage, current, and power also increased as the input current increased.

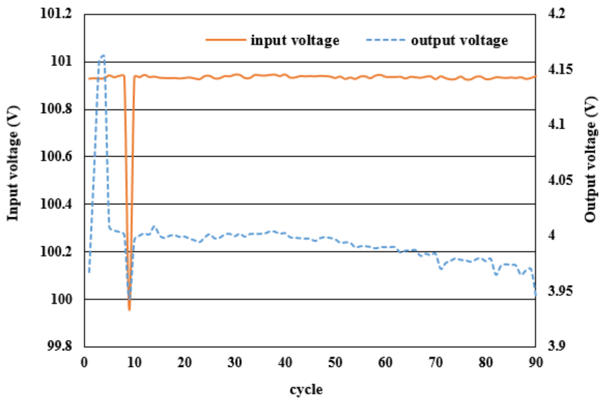

Fig. 3. Injection and emission voltages during the 90 days cycle.

In Figures 4 and 5, the output current and power gradually decrease after half the cycle. The output current was initially about 1.34 A, but eventually dropped to 1.32 A. The output power went down from 5.32 W to 5.2 W. This was affected by the deterioration of the thermoelectric element and the environment in which the experiment was carried out. According to the existing literature, as the cycle progresses, the thermoelectric element sublimes and the surface area of legs decreases, which leads to deterioration of the thermoelectric element with reduced output. In addition, the experiment did not last for 90 days consecutively, but was carried out for 6-5 days and rested for 1-2 days. In the first half of the cycle, there was no noticeable drop in power even after taking a break and then proceeding with the experiment, but in the second half, the power drop increased.

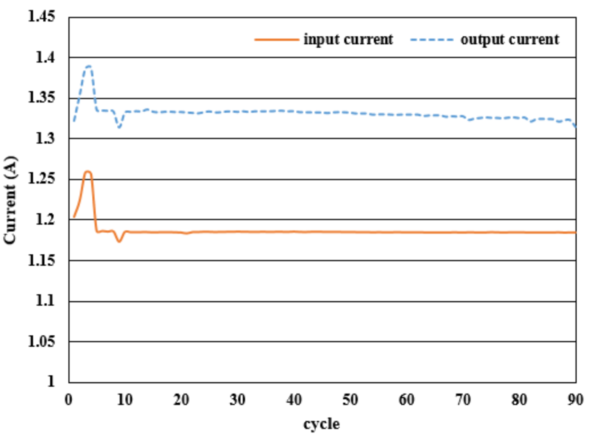

Fig. 4. Injection and emission currents during the 90 days cycle.

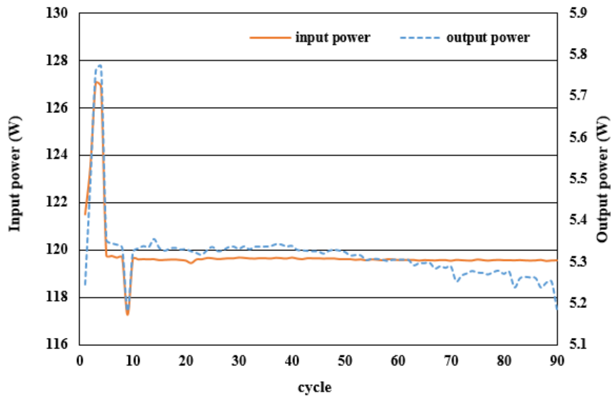

Fig. 5. Injection power and emission power during the 90 days cycle

Figure 6 is a graph showing the efficiency of output power versus input power. It was confirmed that when ETG uses a pressure of 10^{-3} torr and a temperature difference of about 181°C, an efficiency of about 4.5% is obtained. The efficiency is calculated (output power) / (input power) x 100.

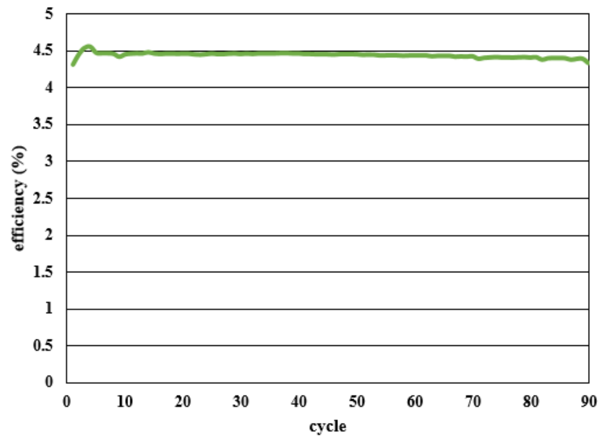

Fig. 6. Changed thermoelectric conversion efficiency during 90 cycles.

3. Conclusions

The RTG, which is being developed by KAERI for lunar exploration. When 90 cycles were performed at 10^{-3} torr, the ETG efficiency dropped by about 0.1% from about 4.45% to 4.35%, and the output power dropped from 5.3 W to 5.2 W. The lunar atmosphere is 10^{-9} to 10^{-12} torr. Although there is a big difference from the lunar environment, in terms of efficiency, it has a similar result after 10^{-4} torr. If a high vacuum pump is used, it can be up to 10^{-6} torr, so it is thought that the results similar to the experimental value in the lunar environment will be obtained.

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