

Study on the Design of Radioisotope Thermoelectric Generator for Earth Low Orbit Test

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1. Introduction

Radioisotope batteries have been developed as a unique solution that supplies stable power to a spacecraft or a lander in deep sea space far from the sun. In 1960s, USA and Russia developed radioisotope thermoelectric generator (RTG) using ⁹⁰Sr and ²³⁸Pu. Recently, the European Space Agency is developing a space RTG using ²⁴¹Am.

Korea plans to launch a Korean launch vehicle in 2020 with the goal of launching a low-Earth orbiting satellite. At this time, various equipment will be installed in the satellite for scientific observations and experiments. In particular, a Korean-type radioisotope battery which aims at utilization as a deep space power source is also planned to be installed in the satellite to verify operation performance and reliability in a space environment. Korea Atomic Energy Research Institute (KAERI) has been studied on radioisotope batteries for space mission since 2014, and will develop a radioisotope battery for the satellite on the basis of previous research know-how.

In this study, a small - sized radioisotope battery will be designed according to the on - board specification, and the conceptual design will be developed with reference to the result of heat transfer analysis, and vibration analysis.

2. Design RTG for Low Orbit Test

2.1 Design Requirement

The payload of the Korean launch vehicle to be launched in 2020 is 42kg, and the weight allocated to the isotope battery is 800g. Calculating RTG specifications based on Russian case studies, it is expected that the power output of 200 mW will be obtained by using a ²³⁸Pu 8 Wth heat source.

The Korean-type launch vehicle to be launched in 2020 will be used for testing purposes. Instead of using ²³⁸Pu as a heat source for RTG, 10W of electric heater will be inserted as a heat source and it is called electrically-heated thermoelectric generator (ETG).

Basically, RTGs contain radioisotopes and must be designed to withstand external shocks in launch and accident situations. In advance, it should be designed to withstand the launch vibration and shock delivered to the RTG during initial launch, and the specification was received from the Satellite Technology Research Center as approximately 14Grms, 1200G respectively. It shall

also be designed to safely protect radioisotopes against re-entry accidents and debris from explosion of the spacecraft.

2.2 Initial Design and Material Assignment

Referring to the shape of the 'Angel' RTG in Russia, an ETG for 10Wth was designed as shown in Fig. 1. The heat source consists of an alumina rod and induction coil. And its volume is the same as the capsule of ²³⁸Pu. The heat source is protected by an impact shell that can withstand impact in the event of a spacecraft explosion or re-entry accident, a sleeve and an aeroshell that can withstand aerodynamic heating.

The material of impact shell and aeroshell is high density carbon composite, and that of aeroshell is low density carbon composite. In particular, the thickness of the aeroshell material was determined to be 5 mm by the abrasion test, which simulate the reentry accident. The thermoelectric module uses a BiTe type material. The structural components that support and fix the heat source module are designed with Al6061. To minimize the heat loss of the heat source, the RHU fixture which supports the heat source module is fixed to the three supporting rods by three wires, respectively. If the wires are fastened, the contact surface between the RHU fixture and the thermoelectric module will be increased, and a high thermoelectric conversion efficiency can be obtained.

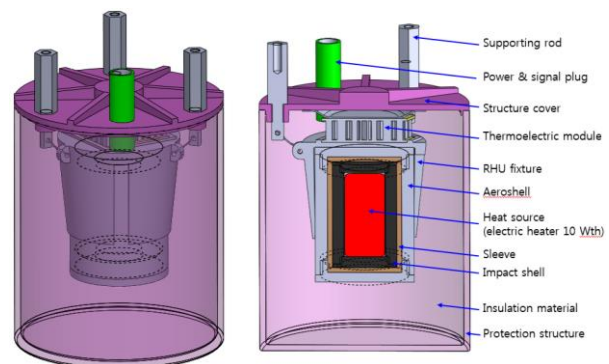


Fig. 1. Initial design of 10 Wth ETG.

Based on the above design of ETG, design variables need to be optimized using finite element analyses.

2.3 FE analysis

Heat transfer analysis and natural vibration analysis have been carried for the initial design of 10 Wth RTG.

According to the result of natural vibration analysis, the heat source module is easy to be disassembled from the RHU fixture. Otherwise, the heat source module can damage the protection structure. Therefore, additional fixture is necessary to fix the heat source module.

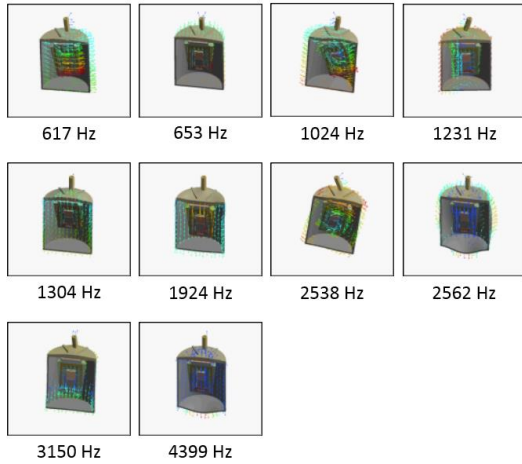


Fig. 2. FE analysis of natural vibration for the initial design of 10 Wth ETG

According to the result of heat transfer analysis, the amount of heat loss is 39%, and the exposed part of the heat source module needs to be insulated. In addition, design of the sleeve needs to be improved in order to prevent the temperature of heat source from rapidly changing due to aerodynamic heating.

2.4 Design improvement

Fig. 3 shows the improved design of ETG by considering the above result of FE analyses. An additional fixture, 'RHU fixture_bottom', is designed to prevent the heat source from disassembling with RHU fixture. In addition, a fixture spring is added between the heat source module and the RHU fixture_bottom to push the heat source module upward. To enhance the heat insulation, design of the sleeve is improved to have two layers, which have a vacuum layer between the sleeve layers.

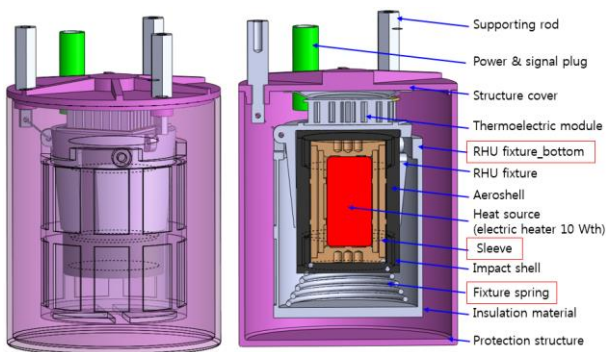


Fig. 3. Improved design of 10Wth ETG.

3. Conclusions

Conceptual design of ETG has been carried out to meet the design requirement for earth low orbit test. Initial design of ETG was designed by imitating Russian 'angel' RTG, and it has been improved through the natural vibration analysis and the heat transfer analysis.

201mW of electric output is estimated from thermoelectric analysis, and it satisfies the design requirement.

However, the design still need to be improved to endure the external shock owing to the reentry accident and the vibration delivered from the flight.

Because mass of the ETG with the improved design is 570 g, there is margin to add components to enhance shock endurance and the endurance for the forced vibration.

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