Mechanical test of thermoelectric device in RTG prototype

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Abstract. Since the United States launched the first space radioisotope thermoelectric generator (RTG), the United States has launched a total of 28 spacecraft with 43 RTGs. There are still more than 30 RTGs in orbit, and the longest working life has exceeded 30 years. During the launching process of RTG, the thermoelectric energy converter needs to withstand the impact at start up and high-frequency vibration during flight, and it faces the harsh service conditions that heat, force, electricity and other external fields are used and coupled together. For this reason, this paper has carried out environmental test verification on the designed RTG prototype through vibration and shock tests. By applying shocks of the same magnitude as the launch and vibrations of the same magnitude during flight, it is found that the thermoelectric devices loaded inside are in the experiment. There is no obvious change in the internal resistance before and after, indicating that the installation method can withstand the complex mechanical environment test during launch, which provides a reference for RTG’s thermoelectric device loading method.

1. Introduction

The isotope thermoelectric power supply is the most widely used nuclear power supply in space [1]. It is a power supply that uses a thermoelectric conversion module to convert the thermal energy generated by isotope decay into electrical energy. The uniformity and stability of its thermal performance directly determines the quality of the transmitted electrical energy, and its transmission the thermal performance is largely related to its structural characteristics [2, 3]. In order to meet the effectiveness of heat transfer and ensure the stability of its structure, a regular polyhedral heat transfer support structure is generally used, with isotope heat sources placed in the middle, both ends are used for prototype mechanical interface and thermoelectric interface design, and the sides are used for heat transfer. And thermoelectric conversion, in order to ensure that the heat only flows through the two ends of the thermoelectric module on the side as much as possible, a good insulation treatment is required. At the same time, the cold end of the thermoelectric module must be assisted by heat measures to make the thermoelectric module work within the optimal temperature range [4].

In addition, in order to meet the requirements of the thermocouple energy converter in RTG to work for a long time under high temperature and large temperature difference or even changing temperature, it needs to withstand the harsh service conditions of heat, force, electricity and other external fields [5]. Many structures are designed in the RTG launched by the United States to avoid damage to thermoelectric materials during launch. In GPHS-RTG, the elastic force of the spring is in close contact
with the hot end, and the thermal stress generated by high temperature can be released [6]; and on the PiTe-based Mars detection vehicle, the mechanical structure is used to process the electrode of the thermoelectric material instead of welding, which can reduce the risk of stress fracture of the thermoelectric material [7].

This article refers to the thermoelectric power supply simulation prototype of the RTG structure design released in the United States. The current design uses a thermoelectric module where one end is attached to the graphite collector (hot end), and the other end is attached to the cooling module (cold end). In order to prevent the thermal expansion of the hot end from squeezing the thermoelectric module, a spring is used to connect the cooling module with the thermoelectric module in the radial direction, so that the thermoelectric module can always be pressed on the cooling module while having a certain radial movement space. Through vibration and shock tests on the RTG prototype assembled according to the current design, it is verified that the current design can be used to guide the installation of thermoelectric devices in the RTG.

2. Experiment

The mechanical test of the RTG simulation prototype includes random vibration and impact. The random vibration was test in X, Y, and Z three-direction of the thermoelectric module in the RTG prototype. The impact was test in the two directions of X and Y. The direction perpendicular to the mounting surface of the thermoelectric device is defined as X, and the direction parallel to the mounting surface of the thermoelectric device is defined as Y. In order to prevent the test pieces from being damaged, the structural parts are used for the bottom test first, and different working conditions are set for the test according to several structural optimization strategies. On the basis of the test results of various working conditions, the installation method with the least load on the thermoelectric module is selected, and then the mechanical test of the product specimen is carried out. The test pieces are tested in order. The initial resistance value is measured before the test, and then the acceptance level test is performed. After the test, the resistance value changes little, and then the qualification level test is performed.

The vibration test is carried out on a vibrating platform, as shown in the figure 1. This experiment adopts the random vibration mode. The load time of a single vibration test is 120 seconds. A total of six vibration tests are carried out. First, the acceptance level and the identification level random vibration test in the XY direction in the plane are carried out, and then the acceptance level and the identification level in the Z direction are carried out. Through the change of the internal resistance of the thermoelectric device to determine whether the structure has passed the vibration test assessment.

Figure 1. The vibration test. (a)X and Y direction; (b) Z direction.

The impact test is carried out on the impact table. As shown in the figure 2, the magnitude of the single impact test is 30g, and the impact is performed twice in each direction. By measuring whether the
internal resistance of the thermoelectric device changes before and after the impact test, the thermoelectric device can be judged whether the installation method can pass the impact test.

![Figure 2. The impact test.](image)

### 3. Result and discussion

#### 3.1. Vibration test

The acceleration responses of random qualification-level vibration are shown in figure 3, and the internal resistance changes before and after the vibration is shown in Table 1. It can be found that the internal resistance of the thermoelectric device is almost unchanged before and after the vibration in each direction, and the resistance in the Z direction increases compared to the Y direction. This is because of the process of tuning the vibration table. The heat generated by the vibration caused the RTG prototype to increase, which increased the internal resistance of the thermoelectric device. After testing, after the random vibration test, the electrical resistance of the thermoelectric module did not change significantly, indicating that the thermoelectric module was not damaged. Therefore, the module can withstand the appraisal-level random vibration test. Therefore, it can be considered that the use of springs and metal rubber damping has little effect on the thermoelectric module, and the measure to reduce the random vibration and deformation of the structure should be to ensure the connection rigidity of one end of the thermoelectric module. It is expected that if the test piece adopts a fixed connection at one end and a flexible compression at the other end, it can withstand the test under random vibration conditions.

|                      | Before acceptance-level vibration(mΩ) | After acceptance-level vibration(mΩ) | Before qualification-level vibration(mΩ) | After qualification-level vibration(mΩ) |
|----------------------|----------------------------------------|--------------------------------------|------------------------------------------|----------------------------------------|
| X                    | 122.46                                 | 122.52                               | 123.26                                   | 123.32                                 |
| Y                    | 126.19                                 | 126.43                               | 126.51                                   | 126.43                                 |
| Z                    | 128.32                                 | 128.20                               | 128.85                                   | 128.76                                 |
Figure 3. The acceleration responses of random qualification-level vibration. (a) X direction; (b) Y direction; (c) Z direction.
3.2. **Impact test**

The internal resistance changes before and after the impact test are shown in Table 2. It can be found that the resistance of the thermoelectric device does not change before and after the impact in each direction, indicating that the installation method can protect the thermoelectric device from being launched before the fire or when the detector is looking at the land. The test results show that the installation method designed in this paper has passed the impact test assessment.

|       | Before impact (mΩ) | After impact (mΩ) |
|-------|-------------------|-------------------|
| X     | 121.48            | 121.53            |
| Y     | 121.80            | 121.82            |

### 4. Conclusions

According to the random vibration test of the test part and the structural simulation part, it is shown that when the thermoelectric module is fixed at one end and the buffer medium is used at the other end, there is no obvious change in the product state before and after the test, and it can withstand the appraisal level random vibration test. Damage or damage will occur. According to the test results of the impact test, it can be seen that when the thermoelectric module is fixed at one end and the buffer medium is used at the other end, there is no significant change in the state of the product before and after the test, and it can withstand the impact test assessment of this magnitude without damage or damage. After structural optimization design, thermoelectric modules are installed in the whole machine-level structural parts, which can withstand the appraisal-level random vibration and shock test assessment. After the test, there is no obvious damage or failure of the components.

### References

[1] PRELASA M A, WEAVER C L, WATER—MANN M L. A review of nuclear batteries[J]. Progress in Nuclear Energy, 2014,75:117-148.

[2] Lange R G, Carroll W P. Review of recent advances of radioisotope power systems[J]. Energy Conversion & Management, 2008, 49(3):393-401.

[3] Ambrosi, R, M, et al. Sintering-trials of analogues of americium oxides for radioisotope power systems[J]. Journal of Nuclear Materials: Materials Aspects of Fission and Fusion, 2017, 491:18-30.

[4] Karin E B, Harald H, Jorn H. Estimation of lunar surface temperatures and thermophysical properties: test of a thermal model in preparation of the MERTIS experiment on board BepoColombo[J]. Planetary and Apace Science, 2014(101): 27-36.

[5] Hunt, M.E. High efficiency dynamic radioisotope power systems for space exploration-a status report[J]. IEEE Aerospace & Electronic Systems Magazine, 1993, 8(12):18-23.

[6] Chan K L, Tang K T, Kong B, et al. Lunar regolith thermal behavior revealed by Chang’e-1 microwave brightness temperature data[J]. Earth and Planet Science Letters, 2010(295):287-291.

[7] MASON, Lee S. Realistic Specific Power Expectations for Advanced Radioisotope Power Systems[J]. Journal of Propulsion & Power, 2007, 23(5):1075-1079.