Mechanical simulation optimization of RTG prototype

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Abstract. The thermocouple energy converter in the radioisotope thermoelectric generator (RTG) requires a long time work under high temperature and large temperature difference, and needs to withstand the harsh service conditions of heat, force, electricity and other external fields during the launch process. In order to understand the dynamic purchase response and dynamic strain of various parts of the structure when the thermoelectric module is under dynamic load under different conditions, this paper uses software to simulate the vibration and shock scenarios of the thermoelectric module in the RTG prototype. According to the existing conditions, a three-direction impact spectrum analysis was carried out. It was found that in the three-direction random vibration, from the root mean square stress result, the risk of damage is small; while during the impact, the shell and the thermoelectric The displacement in the in-plane direction between the module furnishing surfaces will cause the thermoelectric material in the thermoelectric module to produce a large shear stress, which will cause the risk of shear damage to the structure. The imitation result provides a reference for the further optimization design of RTG prototype.

1. Introduction
The radioisotope temperature difference power supply is currently the most developed and advanced radioisotope power supply [1]. It is usually composed of a central heat source, a collector coil, a thermocouple energy converter, a cooling module and structural components. The center is divided into an isotope heat source, and the thermocouple energy is in close contact with its converter [2]. The thermal energy of the converter is split and converted into electric energy, and the other part is discharged into the surrounding environment through the shell and the radiator. In order to reduce heat leakage, a thermal insulation material is filled between the heat source and the shell [3]. In order to verify the practicability of the RTG structure on the ground, a simulated heat source is generally used instead of a radioisotope heat source to verify the reliability of the thermocouple energy converter.

The thermocouple energy converter is a device composed of two types of P-type and N-type thermoelectric conversion materials in series and parallel. Generally, the thermoelectric conversion material is a brittle semiconductor, which has low shear strength and is easily broken by the stress generated by thermal expansion [4, 5]. And the thermocouple energy converter in the RTG requires long-term operation under high temperature and large temperature difference or even changing temperature field environment. It needs to withstand the harsh service conditions of the interaction and coupling of various external fields such as heat, force, and electricity, and the long-term reliability of
the device performance and service performance have become another barrier restricting the industrial application of devices [6]. Therefore, it is necessary to carry out simulation analysis and optimization of its force in the RTG to ensure that it will not be damaged due to impact and vibration during the launch process [7].

This article refers to the thermoelectric power supply simulation prototype of the RTG structural design released by the United States. It adopts a simple and peripheral component junction design. According to its three-dimensional model and design report, the thermoelectric power supply is mechanically analyzed, and shock loads are applied in three directions, and random vibration load, judge the risk of damage through force analysis, and determine whether the designed thermoelectric power supply simulation prototype needs further optimization.

2. Experiment

2.1. Modelling
According to the three-dimensional model and related documentation, the risk of the entire thermoelectric power supply lies in the thermoelectric module. The other structural risks such as aluminum alloy bases, fiber limit plates, high temperature alloys, and graphite collector plates are low, so the main consideration is the modeling of thermoelectric modules. In the finite element model, first establish the finite element model of the base, the fiber limit plate, the super alloy, and the hot plate in the stone. Because of the use of the use of conical fit or threaded connection, these components are connected by tie connection, and the installation of the office around the foot is encrypted, and the rest of the structure is applied to the model in the form of quality points, as shown in the figure 1.

![Figure 1. Schematic diagram of thermoelectric module installation.](image)

In order to investigate the shear stress of the thermoelectric module, solid element modeling is used for the thermoelectric module, and the components in the thermoelectric module are connected by node fusion and tie connection. The finite element model is shown in the following figure 2. In the model, the thermoelectric module and graphite the space between the plates is compressed in the radial direction by the elastic force of the elastic, and in the axial direction, it is limited by the boss on the graphite plate.

![Figure 2. (a)Finite element model of prototype; (b) Finite element model of thermoelectric module.](image)
For the convenience of explanation, the thermoelectric module on the positive x side of the entire model is taken for analysis and explanation, and the axial direction is the positive z direction. The tangential direction is the positive y direction, and the radial direction is the positive x direction, as shown in the following figure 3.

![Figure 3. Location of the single thermoelectric module in the prototype.](image)

### 2.2. Simulation
In order to understand the overall load of the RTG during impact and vibration, the RTG is modeled as a whole. The thermoelectric module and the graphite heat collector are connected by contact, and frictional contact is established between the upper and lower end covers. The type of the translator and connector unit between the shell and the thermoelectric module is connected. The direction of the unconstrained degrees of freedom is the normal direction of the thermoelectric module, and the other directions are in the constrained state. The overall center of mass is adjusted through the mass point, and the spring preload is simulated by applying uniform pressure. The impact and vibration load is applied at the bolt connection point at the bottom of the prototype.

### 3. Result and discussion
The stress distribution diagram of thermoelectric module after the X, Y, and Z three-direction impact is shown in Figure 4. It can be seen that the aluminum alloy mounting support connection point in the structure may show a large local stress. It is recommended to use gaskets or bushings in the design to strengthen. The rest of the stress level is low. Near the thermoelectric module, due to the point connection of the spring bud element in the finite element, stress concentration may occur at the substrate. In the actual design, the method of increasing the contact surface should be used to reduce the risk of stress concentration. Considering the tensile and compression failure, the axial stress at the PN section of the thermoelectric module is greater than the strength limit when impacted in the X direction (i.e., the thermoelectric module), and the other working conditions are within its strength limit; considering the shear failure, the three sides During the impact, the in-plane shear stress is greater than the shear limit of the welded material, so measures to prevent shear damage should be considered in the design. In addition, according to the analysis, the maximum shear stress of the three-direction impact load is above 170Mpa, and there is a risk of material shear failure.
Figure 4. The stress distribution diagram of thermoelectric module. (a) X direction; (b) Y direction; (c) Z direction.
Under the conditions of random vibration input in the X direction, the maximum root mean square stress of the thermoelectric module in the X direction is 2MPa, the Y direction is 871 MPa, the Z direction is 311 MPa, and the equivalent mises stress is 39.7 MPa. After calculation, under the condition of random vibration input in the Y direction, the maximum root mean square stress of the thermoelectric module is 23.3 MPa in the X direction, 288 MPa in the Y direction, 13.17 MPa in the Z direction, and the equivalent mises stress is 34.3 MPa. Under the 2-direction input random vibration conditions, the maximum root-mean-square stress of the thermoelectric module in the x direction is 13 MPa, the Y direction is 6.49 MPa, the Z direction is 21.3 MPa, and the equivalent mises stress is 2673 MPa.

4. Conclusions
According to the analysis, for impact loads in three directions, the biggest risk point in the structure as a whole is located at the installation foot, which needs to be strengthened locally by bushings or reinforcing pieces. For thermoelectric modules, it should be noted that the maximum shear stress is relatively large, which may cause damage at the junction of thermoelectric module, followed by out-of-plane impact, which may appear under tension and compression. For random vibration in three directions, from the root mean square stress result, the risk of damage is small, and the equivalent mises stress of the structure is about 30 Mpa. The thermoelectric module is connected with the cooling block by the ball head of the piston in the in-plane direction, and the cooling block is press-fitted with the shell and cover plate. The displacement of the shell in this direction will cause greater stress at the thermoelectric module. During an impact, the displacement between the housing and the installation surface of the thermoelectric module in the in-plane direction will cause the thermoelectric material in the thermoelectric module to generate a large shear stress, which will cause the risk of shear damage to the structure. Therefore, it is necessary to optimize the cooling block and the cooling block during further design.

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