Mechanical Design of BGO Calorimeter for Chinese High Energy Cosmic Ray Detector in Space

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Abstract: The BGO calorimeter is the main component of the Chinese high energy cosmic ray detector. The BGO calorimeter consists of 576 BGO Crystals coupled with photomultiplier tube. The reliability and safety of the BGO Calorimeter structure play a very important role in the operation of whole detector. During the rocket launch, the calorimeter structure should be stable against vibration and environmental factors to ensure the detector works in good conditions. In this article, we make the BGO calorimeter structure design, and then prove that it will work in the environments of rocket launch and flight.

Keywords: structure, reliability, safety, calorimeter

1 Introduction

At present, the research of dark matter is a hot point. There has been strong evidence for the existence of the dark matter. The updated theoretical model suggests that dark matter may exist in the form of some special particles, and that the dark-matter particles can be searched for by observing the fundamental particles, such as electrons and gamma-rays, produced by the decay and interaction of dark matters.[1]

Supported by “a grant from the Major State Basic Research Development Program of China (973 Program)” and CAS, Purple Mountain Observatory established cooperative relationship with several institutes and universities under CAS as a development team of scientific satellite whose major scientific purpose is to detect dark matter during its space flight.

Space flight is of most importance to scientific research. Since the atmosphere of the Earth blocks out most kinds of radiation, research into space planets, stars, the universe as a whole) is more feasible from space than it is from Earth.

As the most important payload of China’s first scientific satellite for detecting dark matter, the Chinese high energy cosmic ray detector in space will be launched into space during the year of 2015. The structure design of the detector has already been done, and the prototype has been completed by the end of June this year.

Chinese high-energy cosmic ray detector consists of two parts, shown in Figure 1, top part is the scintillation detector composed of plastic scintillator used to record the track of incident particle; the lower part is the BGO calorimeter composed of BGO crystals (Bi4GeO4 scintillator crystal) to record the incident particle energy.

Figure 1. Chinese high energy cosmic ray detector.
2 BGO Calorimeter Structure

The BGO calorimeter consists of 576 BGO Crystals coupled with photomultiplier tube. The BGO Crystal, shown in Figure 2, is intrinsic scintillation material with high absorption power. Due to its high effective atomic number and high density, BGO is a very efficient gamma absorber with high photo effect fraction which results in a very good photo peak to Compton ratio. BGO detectors are preferred for medium and high-energy gamma counting and high-energy physics applications. The size of BGO crystal, provided by SICCAS (Shanghai Institute of Ceramics, CAS), is $2.5\text{cm} \times 2.5\text{cm} \times 300\text{mm}$.

![Figure 2. BGO crystals.](image)

The BGO calorimeter is the main component of the Chinese high energy cosmic ray detector. The BGO calorimeter weighs about 1050 kg. And the envelope size of the BGO calorimeter is $827\text{mm} \times 827\text{mm} \times 564\text{mm}$, inside of which the whole crystal size is $624\text{mm} \times 624\text{mm} \times 417\text{mm}$. The calorimeter has a field of view about $112^\circ$ and 27 radiation length.

![Figure 3. BGO calorimeter.](image)

Six BGO sub-calorimeters of the same structure constitute the main body of BGO calorimeter. Exploded view of each sub-calorimeter is shown in Figure 4, where we can find that each sub-calorimeter contains two orthogonal layers of 48 BGO crystals covered by CFRP (carbon fiber-reinforced plastics) material. Figure 5 shows one half of the BGO crystal layers with CFRP case. The thickness of the CFRP case on each side is 2.5 mm. Around the two layers, we design aluminum bracing structures to ensure the BGO crystal arranged in a relatively fixed position and no damage to the crystals. We fasten the PMT (photo-multiplier tube) in the holes in aluminum bracing structures with epoxy resin in an effort to protect the PMT. The photomultiplier provides extremely high sensitivity and ultra-fast response. Photomultiplier tubes have high bandwidth and noise-free gain on the order of a million. This makes them ideal for the detection of extremely low light or short pulses of light.

![Figure 4. Exploded view of BGO sub-calorimeter.](image)

![Figure 5. BGO crystal layer with CFRP case.](image)

3 Mechanical Structural Analysis

The reliability and safety of the BGO Calorimeter structure play a very important role in the operation of whole detector. During the rocket launch, the calorimeter structure should be stable against vibration and environmental factors to ensure detector works in good conditions. In order to prove the design reliability, some mechanical structural analyses have been done.

3.1 Static analysis

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects. Static analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time.

Here we set the loading conditions as follows:
1. Standard Earth Gravity
2. Acceleration
3. Base Surface Fixed Support

where the vertical acceleration we choose is 6.1g and the horizontal acceleration is 2.25g.

Figure 6 and 7 depict the distribution of stress and deformation computed with the finite element analysis soft-
ware. According to the calculations by the finite element analysis software, the maximum stress is 5.40 Mpa and the maximum deformation value is 0.00536 mm. As the weight of the BGO calorimeter is concentrated around on the centre of the vertical axis, it is subjected to a greater vertical acceleration. The greatest deformation of the calorimeter occurs on the upside bracing structure, and the maximum stress occurs on the bottom bracing structure.

Figure 6. The total deformation result

Figure 7. The equivalent stress result

3.2 Modal analysis

We use modal analysis to determine the natural frequencies and mode shapes of our BGO calorimeter. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. They are also required if we want to perform a spectrum analysis or a mode-superposition harmonic or transient analysis.

The frequency of natural vibrations should be higher than that of rocket carriers in order to avoid resonance of the launch and carrier and the resulting damages to the satellite. Generally, the frequency of natural vibrations for payload satellites should be no less than 35 Hz. To ensure safety, the value for the frequency of natural vibrations of satellites is usually recommended to 50 Hz.[2]

Our design should determine that the natural frequency should be more than 50 Hz. According to the result of modal analysis, we find that the natural frequency is much more than 50 Hz and the first modal frequency approximately is 447.35 Hz. The real natural frequency of the BGO calorimeter should be less than 447.35, because the analysis model used does not consider the impact of electronics devices.

4 Conclusion

According to the requirements of the detector performance, we designed the mechanical structure of our BGO calorimeter and did some mechanical analyses which showed that the design meets the mechanical requirements. However, more mechanical analyses should be done as next step, such as harmonic response analysis, transient dynamic analysis, spectrum analysis etc.

5 References