Mechanical Design of the DAMPE BGO Calorimeter

YIMING HU[1,2], JIN CHANG[1,2], JIANHUA GUO[1,2], DENGYI CHEN[1,2],

[1] *Purple Mountain Observatory , Chinese Academy of Sciences , NanJing P.R.China 210008*
[2] *Key Laboratory of Dark Matter and Space Astronomy , Chinese Academy of Sciences 2010DP173032*

huyiming@pmo.ac.cn

Abstract: The Dark Matter Particle Explorer, DAMPE, is a newly designed satellite developed for the CAS's new Innovation 2020 program. As the main component of DAMPE, the newly designed BGO calorimeter consists of 308 BGO crystals coupled with photomultiplier tubes. In this article, we describe the BGO calorimeter structure design, and then prove that it will work in the environments of rocket launch and flight.

Keywords: DAMPE, mechanical, BGO calorimeter, dark matter.

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. Satellite DAMPE, the Dark Matter Particle Explorer, will be launched in the year 2015 to prove the existence of 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 matter.[**?**]

The predecessor of DAMPE is Chinese high-energy cosmic ray detector Supported by a grant from the Major State Basic Research Development Program of China (973 Program) and Chinese Academy of Sciences (CAS). In 2009, 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.

Under CAS's new Innovation 2020 program, the prototype of DAMPE has already been done, and the qualification model will be done by the end of year 2013.A schematic drawing of DAMPE payload is shown in Figure **??**. The payload is composed of four major subsystems from top to bottom:

- The plastic scintillator detector,
- The silicon tracker,
- The BGO calorimeter,
- The neutron detector.

The plastic scintillator detector is composed of two orthogonal layers, with each layer contains 78 plastic bars. The dimensions of plastic bar is about 884mm by 28mm by 10mm. The main purpose of the plastic scintillator detector is to distinguish high-energy electrons (charged particles) and photons (non-charged particles), and to identify the species of incident high energy heavy ion (Z = 1 20). The Silicon Tracker (STK) consists of multiple layers of silicon micro-strip detectors interleaved with Tungsten converter plates. The principal purpose of the STK is

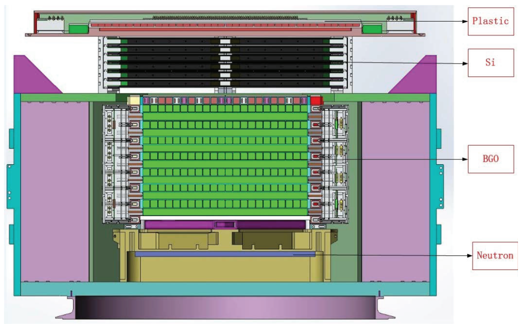

Figure 1: Section view of satellite DAMPE.

to measure the incidence direction of high energy cosmic rays, in particular gamma rays, as well as the charge of charged cosmic rays. The neutron detector is used to measure the secondary neutrons produced by interaction between hadrons from cosmic ray and upper detectors.

2 The BGO Calorimeter

As the most important payload of China's first scientific satellite for detecting dark matter, the main purpose of BGO calorimeter is to measure the energy of incident high energy electrons and gamma rays (5GeV-10TeV) and to identify hadron and electrons.

The BGO crystal, shown in Figure **??**, 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.

2.1 BGO Package Structure

According to the physical design requirements, the calorimeter consists of 308 BGO crystals arranged in 14 orthogonal layers, with each layer having an area of $600\times600\text{mm}^2$. Each layer of the BGO calorimeter is composed of 22 BGO crystals coupled with photomultiplier tube. Each of the crystal has a dimension of 25mm by 25mm by 600mm. The spacing between adjacent ones of

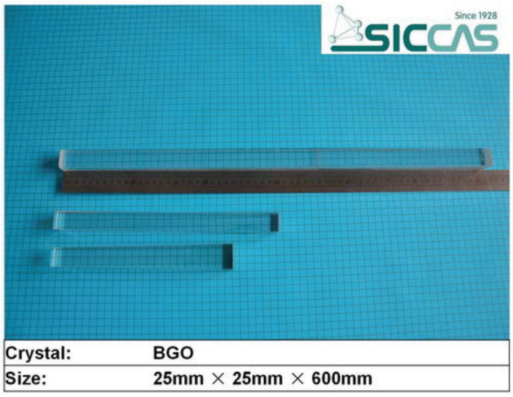

Figure 2: The BGO crystals.

the crystal array is 2.5mm in the horizontal and 4mm in the Vertical direction. The total weight of the crystals is about 830kg. The most important thing is how to package so heavy crystals into a detector as required arrangement and to guarantee reliability and safety.

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. For the structural design of BGO calorimeter, additional requirement is not to use material with large density such as aluminum, magnesium alloy and stainless steel, etc.

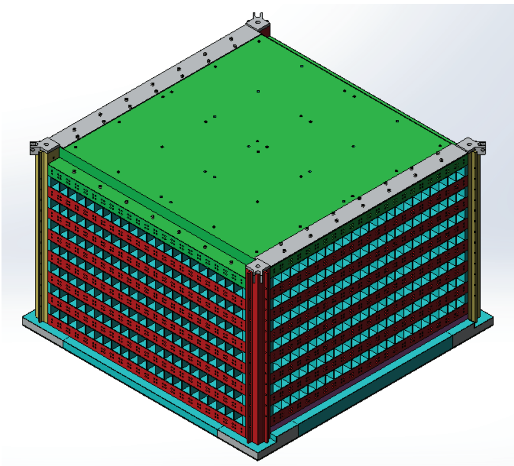

Figure 3: The CFRP honeycomb case.

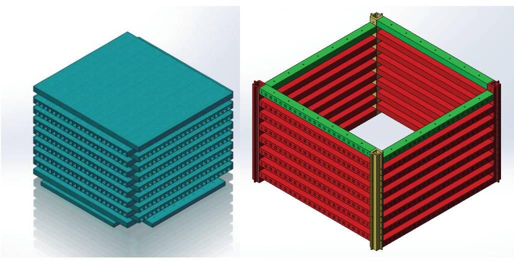

Figure 4: Two components of CFRP case.

We design the CFRP honeycomb case to place the crystals, shown in Figure**??**, of which the envelope size is 742mm by 742mm by 494.5mm. The CFRP honeycomb case has two components shown as Figure**??**. The main component composes of 14 orthogonal layers of CFRP square pipes, each of which has inner cavity size of 26mm by 26mm by 700mm. The other part around the main component, which composes of 4 CFRP upright columns and several crossbars, is the support structure and load transfer path of the calorimeter.

2.2 PMT Protective Structure

We place the crystals into the square pipes of CFRP honeycomb case, filling the 0.5mm gap around crystals with Dow Corning Sylgard 170 silicone elastomer.

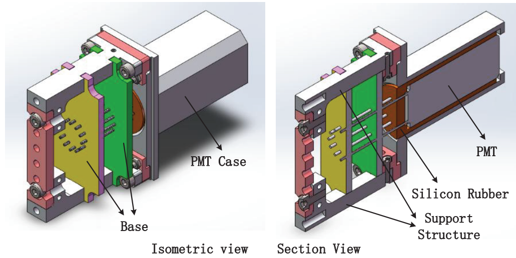

Figure 5: The PMT unit.

Each crystals signal is read out by two Hamamatsu R5611 photomultiplier tubes (PMT) glued onto two ends of crystal with PMT protective structure. Figure**??** shows a cross section of the PMT protective structure unit with PMT sealed inside. Each PMT is put into the aluminium alloy protective case, filling with DC 170. The two base electronics boards are fixed by the support structure on top of the PMT protective case. There are 50mm space to place the PMT unit on both sides of the crystals in the CFRP square pipes, since the crystals are 100mm shorter than the pipes. In this way, all crystals and PMTs are placed inside of the CFRP honeycomb case entirely to make sure all important units are rigid enough to resist the high accelerations and the vibrational loads induced into the experiment during the launching.

3 Modal Analysis

In order to prove the design reliability, some mechanical structural analyses have been done. Preprocessing and post processing are completed using HyperWorks, and solution is done through Nastran. We use the FEA model contains 185172 nodes, shown as figure **??**, and mesh number of which is 210774.

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 avoid frequnce from 45Hz to 55Hz. To ensure safety, the value for the frequency of natural vibrations of satellites is usually recommended to be higher than 70 Hz.

According to the result of modal analysis, shown as following figures, we find that the natural frequency is much more than 70Hz and the first modal frequency approximately is around 95.0Hz.

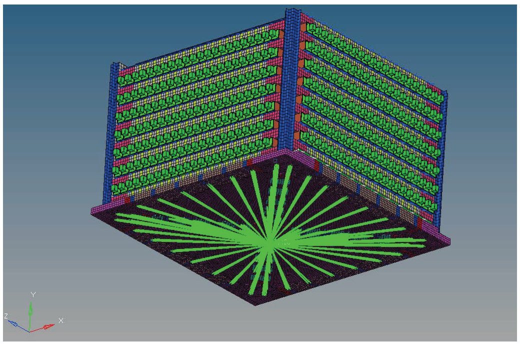

Figure 6: The FEA model of BGO calorimeter.

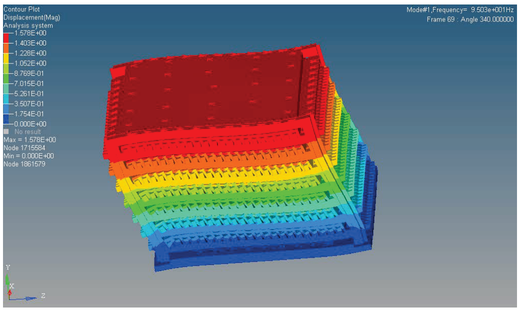

Figure 7: First frequency around 95.0Hz.

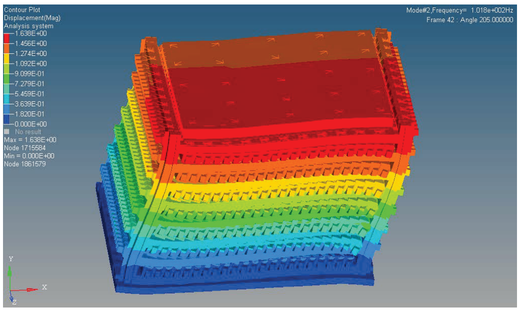

Figure 8: Second frequency around 101.8.0Hz.

4 Conclusion

According to the requirements of the detector performance, we designed the mechanical structure of our BGO calorimeter onboard satellite DAMPE. We design BGO package and PMT protective structures to ensure reliability of calorimeter. And the result of preliminary FEA such as model analysis shows the structure meets the mechanical requirements. However, more mechanical analyses should be done in the next period.

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