The JEM-EUSO Focal Surface Mechanical Structure

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Abstract: JEM-EUSO is a space mission devoted to study extremely high-energy cosmic rays on board of the Japanese Experiment Module on the International Space Station (ISS). The JEM-EUSO instrument is a wide-angle refractive telescope in near-ultraviolet wavelength region to observe time-resolved atmospheric fluorescence images of the extensive air showers. The Focal Surface (FS) is a spherical curved surface, area about 4.5 m², composed by a grid of ~5,000 Multi Anode Photo Multipliers Tubes arranged in modular support structures, Elementary Cells and Photo Detector Modules (PDM) that cover all the surface to collect the light of the optical system. The design of the FS mechanical structure is presented together with the PDM support structure. FEM analysis, to study the optimization of the overall configuration, is described as well as the acoustic and random loads evaluation, stress analysis and mass optimization. Prototypes of the first PDM modules are shown and discussed.

Keywords: Ultra High Energy Cosmic rays, Instrumentation

1 The JEM-EUSO Mission

The Extreme Universe Space Observatory on Japanese Experiment Module (JEM-EUSO) [1, 2, 3, 4] is a science mission planned to be launched by a H2B rocket about JFY 2016 and transferred to the International Space Station (ISS) by a H2 Transfer Vehicle (HTV). It will be attached to the Exposed Facility of the Japan Experiment Module, “KIBO”.

The main objective of the mission is to investigate the nature and origin of Extreme Energy Cosmic Rays (EECR) beyond energies of the order of \( E_0 > 5 \times 10^{19} \text{eV} \), to perform charged-particle astronomy in this energy region by collecting a large sample of events (~ 500-1000 above \( E_0 \)) in 3-5 years of operation and to measure their energy and arrival direction with sufficient accuracy in order to infer the energy spectrum of the sources.

JEM-EUSO is a wide-angle telescope (60 degrees full field of view) and consists of high-transmittance Fresnel lenses 2.5 m in diameter, an advanced photo-sensitive detector at the focal surface and a suitable electronics. An infrared camera and a LIDAR system will also be used to monitor the Earth's atmosphere and provide significant information on cloud coverage.

2 The Focal Surface Mechanical Structure

The Focal Surface (FS) of JEM-EUSO (Figure 1) is composed by a grid of ~5,000 Multi Anode Photo Multipliers Tubes (MAPMT, Hamamatsu M64) arranged in modular support structures, Elementary Cells (EC) and Photo Detector Modules (PDM) (Figure 2), that cover all the surface to collect the light of the optical system. The design of FS and PDM mechanics has been studied and developed at INFN-Frascati National Laboratories.

Figure 1. Focal Surface Mechanical Structure Assembly.

2.1 FS Geometry

The focal surface is a portion of sphere of radius 2505 mm, inserted within an in-plane section 2650 mm x 1900 mm (allowed by the HTV Exposed Pallet dimensions) (Figure 3). An extensive use of CAD (Computer Aided Design, CATIA v.5) has been done to study the Focal Surface geometry and to analyze different PDM distributions in order to maximize their number within the allocated space. The adopted configuration consists of a total of 137 PDMs lying in 11 rows along the parallels of the men-
tioned sphere, with one PDM located at the center of FS geometry as shown in Figure 4.

2.2 PDM Mechanical Structure

Each PDM is composed by 3x3 Elementary Cells and each EC is composed by 2x2 Multi Anode Photomultiplier Tubes.

The mechanical structure, shown in Figure 5, is designed in order to place the 9 ECs on a spherical surface (radius 2505 mm) in the same way as for the overall geometry (Figure 6).

Figure 2. MAPMT Modular Arrangement, the Elementary Cell and the Photo Detector Module.

Figure 5. PDM Mechanical Structure.

Figure 3. Focal Surface front view and overall dimensions.

Figure 6. PDM Spherical Shape.

The frame on which the ECs are positioned presents quite a complex shape (Figure 7) and is built by machining a single aluminum alloy piece, with a mass reduction, at the end of machining, larger than 87% (from 2,7 kg to 0,330 kg).

Figure 4. PDM Arrangement on the Focal Surface.

Figure 7. PDM Frame (front and rear view).
This frame, besides allocating the ECs, is rigidly connected to the main FS structure (Top Frame), contributing to the overall rigidity and strength. Each EC base can accommodate two electronic boards (MAPMT, ASIC) (Figure 8), while the PDM layout is completed by 5 aluminum alloy frames supporting 6 electronic boards: 1 board for PDM electronics, 1 board for High Voltage, 3 boards for Power Distribution and 1 optional board. The total mass of each PDM mechanics is 0.624 kg.

2.3 FS Structure (Top Frame)

The FS main structure, Top Frame (Figure 9), is an assembled structure, composed by 2 head Master Frames, connected by 2 Side Frames and 10 supporting “Ribs” lying along the parallels of the Focal Surface sphere, as shown in Figure 10.

Locking bars housings are positioned in Master and Side Frames for a total of 6 holes: 2 in each Master Frame (Ø 50 mm) 1 in each Side Frame (Ø 20 mm). Threaded holes have been considered for Tilting Mechanism connection as well for Electronics Boxes, FRGF, GPS, etc.; reinforced zones are provided for the connection to the 4 telescopic masts foreseen for the telescope deployment to the operational configuration.

2.4 Structural Analysis and Mass Optimization

FEM (Finite Element Method) analyses have been worked out in order to evaluate the consistency of the Top Frame and optimize its mass (minimize) and first natural frequency (maximize). As already mentioned, PDMs mechanical structures, once connected with fasteners to the main structure, become part of it giving their contribution in terms of rigidity and strength (Figure 11). The material considered is aluminum alloy 7075-T7351, both for main structure and PDM structure, for its good properties in terms of strength, elongation, crack toughness and machining.

The Modal Analysis reports the first natural frequency of 45.7 Hz while Stress Analysis led to a maximum Von Mises stress at launch of 105 MPa localized at few points, with an average stress less than 10 MPa over most of the structure.

3 Prototypes

Besides design, simulations and FEM studies, real prototypes of the PDM modular structure have been recently produced in the INFN-Frascati National Laboratories mechanical workshop: the mechanics of few complete PDM was realized in aluminum alloy (6000 Series, Alcoa Mic-6). In particular, a sector of 3 PDMs has been worked out in order to test the assembly procedure on the main structure and to check any possible issue due to curvature (Figures 12 and 13).
4 Space Qualification Studies

Based on the above described design, space qualification studies have started with National Aerospace Companies in order to delivery the Focal Surface Assembly consisting of:

- Structure
- Thermal Control
- On Board Data Handling
- Harness
- Integration
- Qualification
- Pertinent GSE (Ground Support Equipment)

The activities under study will comply to a System Engineering Approach and be organized in Program Phases typical of the design of a space mission.

A combined Structural/Thermal Model of JEM EUSO is being proposed for the following purposes:

- verify the FEM model by modal survey included in sine test;
- derive, respectively confirm the structural loads for subsystems and equipment;
- achieve qualification for the spacecraft structure;
- verify the structural strength of primary/secondary structure versus qualification loads;
- verify the spacecraft thermal design;
- verify the interface to launcher adapter;
- verify the mechanical interface between PLM (Payload Module) and SVM (Service Module);
- exercise the alignment methodology and demonstrate the alignment stability.

References


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