Report on TEA-IS Short Visit 4570 – Direct search for runaway electrons near spark channels in the laboratory

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Introduction

Though long-believed to be a process only involving high-temperature gas and thermal free electrons, spark discharges have recently been discovered to produce an astonishing amount of high-energy x-rays. These x-rays indicate the presense of a significant non-thermal population of energetic electrons. How these electrons are produced remains a mystery, and their properties have never been directly measured. The physics involved may have broad implications for energetic radiation production in lightning and thunderstorms, and may play a role in other poorly-understood branches of physics including lightning initiation, upper atmospheric lightning (sprites), and terrestrial gamma-ray flashes.

Purpose of the visit

The proposed short visit is to carry out experiments designed to directly detect these energetic electrons near sparks generated with the 2 MV Marx generator at the high voltage lab at the Technical University of Eindhoven (TU/e). The TU/e group led by prof. van Deursen has extensive experience with the electromagnetic compatibility techniques necessary to shield electronics and radiation detectors in the extreme environments near the spark, while the University of Bergen (UiB) group represented by Dr. Carlson has experience with energetic particle detector design and data analysis. In particular, the TU/e group has the necessary shielded detector electronics and data acquisition, while Dr. Carlson has the necessary sensitive detector materials and methods. The UiB group that participated in the visit also included Ragnhild Hansen and Øystein Grondahl, Ph.D and Masters students at UiB, both of whom traveled under other funds. The experiments were assisted by Pavlo Kochkin, a Ph.D student at TU/e.

Description of work and results

The visit consisted of a series of nearly 900 discharges, where each discharge included simultaneous measurements of spark properties and energetic particle detector signal. TU/e's unique measurement setup allows for repeated high-quality measurements of the spark properties (current and voltage) associated with energetic particle measurements conducted with the UiB group's detectors. Repeating the experiments many times allows statistical analysis of spark and energetic radiation properties.

The TU/e group's experiment setup included two Pearson current probes, one located on the voltage electrode and one on the ground electrode. The current probe on the high-voltage electrode was necessarily battery operated, with signal reported by fiber optic cable. The current probe on the ground electrode and the Marx generator voltage were directly measured. These signal measurements were recorded with a LeCroy WaveRunner oscilloscope inside a well-shielded and grounded electromagnetic compatibility cabinet. Another oscilloscope in the cabinet measured the signals from up to four photomultiplier tubes.

Two of these photomultipliers measured optical signals from Lanthanum Bromide scintillators placed inside the shielded EMC cabinet at a fixed location about 2 meters from the spark gap and provide an overall measurement of spark luminosity in x-rays. The other two photomultipliers monitored the UiB detectors, segments of scintillating optical fiber coupled to non-scintillating fibers to carry the scintillation light to the photomultipliers inside the EMC cabinet. The flexibility and length of these fibers allows the scintillator to be placed at a variety of locations to give a measurement of the spatial distribution of energetic particle production. The fact that the fibers are non-conducting allows the fibers to be placed very near the electrodes, within the region where energetic electrons are expected to be produced. A photo of the experiment setup is shown in Figure 1.

Over the many sparks produced during the visit, measurements were made with the UiB detectors at a variety of locations from 15 cm to 2 meters from the electrodes. Signals were detected in coincidence with the time of x-ray production, and over a gigabyte of signal data was collected. Preliminary analysis gives clear measurement of the statistical variation from spark to spark, as well as a measure of the non-uniformity of energetic particle production. Analysis is ongoing.

Future collaboration

The short visit provides a sound basis for future collaboration. The data collected was surprising in many ways, and suggests further experiments to better explore the spatial and inter-spark variability. Changes in detector design are also suggested (less sensitive detectors with smaller sensitive area but thinner shielding, for example). We plan to continue the collaboration with further experiments, more refined detectors, and more refined statistical analysis. The results of this visit will be presented at the European Geophysical Union conference in Vienna in April 2012, and a draft of a

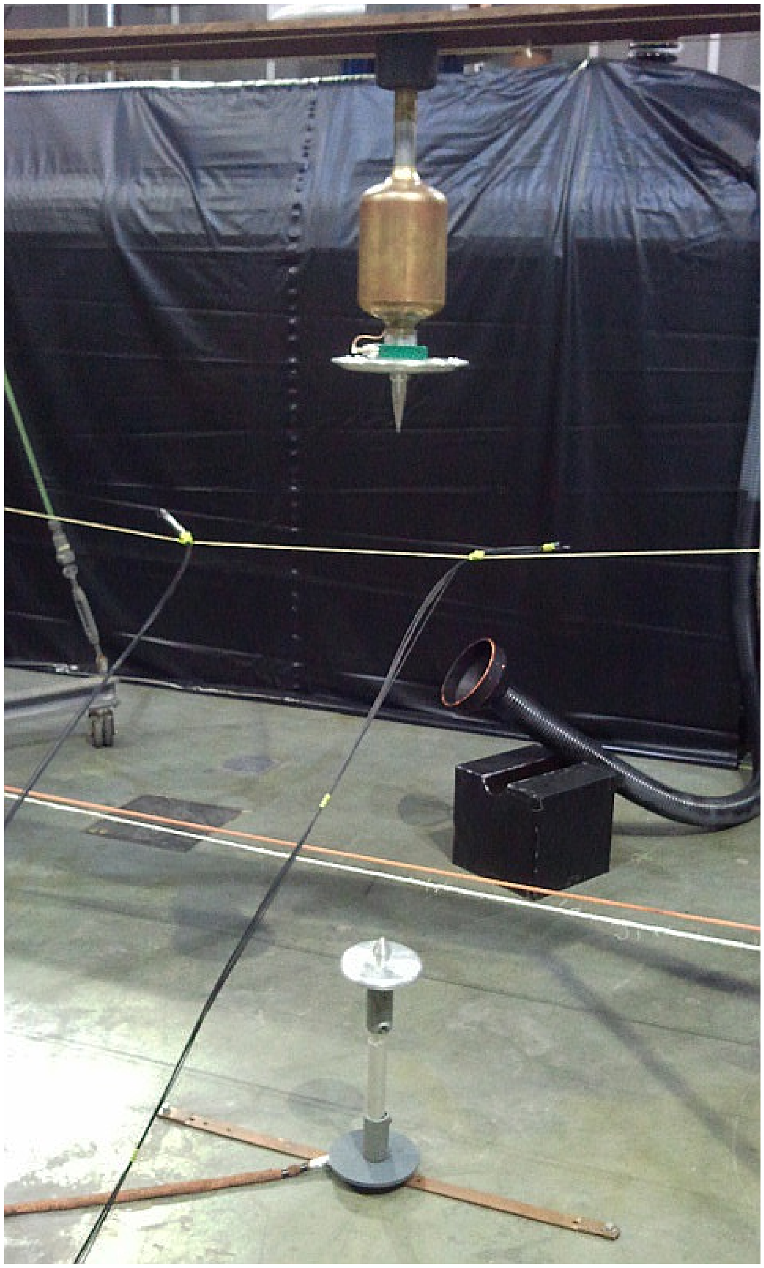

Figure 1: The experiment setup. The high-voltage electrode and current probe (green) are visible at the top, while the ground electrode is at the bottom. Two of the UiB detectors (black fiber bundles) are supported near the high-voltage electrode by the horizontal rope. The funnel and tube in the background is a ventilation system to dissipate ozone produced by the spark.

paper describing the experiment is in preparation.

Comments

The Marx generator facility at TU/e is one of the best in the world, and these measurements are the first of their kind. This was a very interesting and productive visit with many possibilities for fruitful future collaboration, and we gratefully thank the TEA-IS program for funding such activities.