Energetic radiation observations near meter-scale sparks in the laboratory

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The discovery that ordinary laboratory sparks produce x-rays implies the existence of a population of energetic electrons. These electrons may be produced by streamers or interaction of streamer systems, but their exact production mechanism and properties are not well-known. We report on experiments designed to measure x-rays and energetic electrons at a variety of positions near meter-long sparks. The detectors used are coupled by fiber optics to a well-shielded data acquisition system and can be placed quite near to the spark or electrodes. The results suggest variability in observations is due to a combination of variability from one spark to the next and strong spatial variability from one location to another within a single spark. Specific examples and statistical analysis will be presented.

1. X-ray production by sparks

Spark discharges in the laboratory are typically considered to consist only of hot (10000 K) plasma with very minor non-thermal contributions. The discovery that such sparks produce x-rays with energies up to several hundred keV (10^9 K) is surprising[1]. Such x-rays have been observed[2] and electron production has been modeled[e.g. 3] in the context of streamers, but the connection between streamers and laboratory-scale sparks is uncertain. Similar x-rays can be observed in natural[4] and triggered lightning[5], and may play a role in phenomena like sprites and terrestrial gamma-ray flashes[6].

We report on experiments to directly detect such energetic x-rays and electrons in the environment near meter-scale sparks. The detectors consist of small volumes of plastic scintillator, coupled via fiber optics to photomultiplier tubes. Observations have been carried out with multiple detectors during nearly 1000 sparks, allowing for statistical analysis of various properties of the observations.

2. Experiment description

2.1. Setup

The experiments were conducted at the high-voltage laboratory at the Technical University of Eindhoven in the Netherlands. The lab is equipped with a 2 MV Haefly Marx generator, which for our experiments was configured to generate a pulse of approximately 1 MV on a 1 m point-point spark gap. Spark voltage, high-voltage electrode current, and ground electrode current are measured by well-shielded storage oscilloscopes.

In addition to the electrodynamic properties of the spark, we also measure energetic radiation produced with up to four detectors. Two of these detectors are standard LaBr scintillation detectors coupled to photomultiplier tubes within a shielded cabinet 2 meters from the spark gap. The two other detectors were short lengths of scintillating plastic optical fibers suspended at a variety of locations near the spark. These scintillating fibers were coupled to non-scintillating optical fibers of the same diameter to carry the light to associated photomultipliers within the shielded cabinet. Voltage signals from the photomultipliers were directly digitized by storage oscilloscopes.

2.2. Results

Data for a sample spark is shown in Figure 1. The spark in question shows signals in 3 detectors during the initial voltage rise and during a burst of activity of Ihv, the high-voltage electrode current, possibly also coincident with the first rise in ground electrode current. Detector 1 also shows a second burst of energetic radiation during the main discharge when the voltage is falling.

Such data is typical. Roughly half of the time, no energetic radiation is detected, but this depends on the location of the detectors. Statistical analysis is ongoing, but suggests strong variation from one position to another within a single spark, but weak overall variation with distance of the average behavior.

The total energy detected often exceeds the maximum possible energy in a single particle, requiring pileup of many particles to account for the observations. The statistical properties of this pileup suggest an average energy around 100 keV, but further analysis is required to strengthen this statement and will be presented at the workshop.

Initial crude statistical analysis suggests that the variability observed previously from one spark to the next may of the same magnitude as the spatial variability of radiation intensity within a single spark. Once again, further analysis is required to strengthen this conclusion and will be presented at the workshop.

3. Conclusion

These studies indicate that the variable behavior of energetic radiation produced by sparks is more rich than previously suspected. Statistical analysis is very fruitful, and more data will be very beneficial. Future experiments will help shed light on this important and fascinating topic.

3. References

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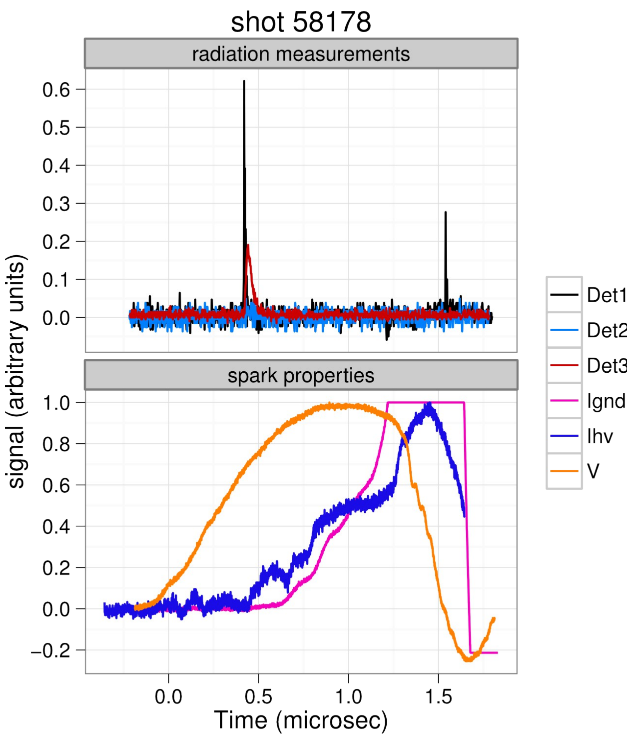

Figure 1: Typical data. Det1 refers to our scintillating fiber detector, Det2 and Det3 are LaBr detectors. Ignd and Ihv are current at ground and high voltage electrodes, respectively. V is the high voltage. Signals have been rescaled.