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X-rays from negative laboratory sparks in air: Influence of the anode geometry

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ABSTRACT

In this experimental work, the influence of the grounded anode geometry is studied on the X-ray production from the laboratory sparks in air at atmospheric pressure when a negative impulse voltage is applied to a high voltage rod which served as a cathode. The result shows that the smaller the diameter of the anode, the higher the energy of X-ray bursts. This observation can be explained by the mechanism that the encounter of negative and positive streamer fronts just before the final breakdown is the event that accelerates electrons to X-ray generating energies, but may not be the only mechanism that generates X-rays.

1. Introduction

Emissions of high energy particles and radiation in air at atmospheric pressure are of high current interest. X-rays have been recorded both from discharges in the atmosphere and from discharges in the laboratory. In the latter case, many experiments have been conducted to understand this phenomenon (Dwyer et al., 2005, 2008; Rahman et al., 2008; Nguyen et al., 2008; March and Montanyà, 2010, 2011; Kochkin et al., 2012, 2015).

In these experiments, the detection of X-ray radiation, the region of the radiation in the gap, the energy and the spatial distribution of the radiation, the stage of the discharge process from where the radiation is generating have been studied. Further, the influence of the applied voltage, the derivative of the applied voltage, the polarity and the rise time of the applied voltage, the electrode shapes and the gap lengths etc. were also studied.

Regarding the issue of the electrode geometry, the observations in these studies are as follows. Dwyer et al. (2008) performed experiments with several different electrode configurations where the high voltage and the ground electrodes were either both spheres (2–12 cm in diameter), a rod and sphere, or a rod and plane. They observed the most intense bursts of X-rays when two 12-cm-diameter spherical electrodes separated by an 85-cm gap were used even if some amount of X-ray emission was observed for each electrode configuration for the negative polarity sparks. Their observation further suggests that it was not only the electric field configuration at the high voltage electrode that was influencing the runaway electrons because it was the larger electrode (12-cm-diameter sphere as compared to 1-cm-diameter rod) that produced the brightest X-rays at least for the negative sparks. As one possible reason for this observation, the higher voltage, achieved in the gap before the breakdown occurs in the case of larger electrodes, was mentioned.

March and Montanyà (2011) studied the influence of the positive and negative electrodes in the production of runaway electrons and they had found that emissions were affected by the distribution of the equipotential lines around the cathode. This conclusion was based on the observation that the X-ray detection rate was increased when the grounded electrode (cathode) was changed from the plane to the longer cylindrical electrodes in the case of positive polarity sparks. For negative polarity sparks, no such influence was observed when the grounded electrode (anode) was changed in a similar way.

In this study, we are interested in studying the influence of the grounded anode geometry on the production of X-rays in laboratory sparks when a negative impulse voltage is applied to a high voltage rod which serves as a cathode. The reason for this interest is partly because we see some effects of the anode geometry in the data presented in March and Montanyà (2011) and partly due to the fact that it is the negative spark that produces more energetic X-rays (Nguyen et al., 2008; Cooray et al., 2009). It should be noted here that several experimental studies found the X-ray emission to be polarity dependent (Dwyer et al., 2005, 2008; Rahman et al.,

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2008; Nguyen et al., 2008; March and Montanyà, 2010, 2011). Recently, it has been discussed and shown in time resolved images of discharge evolution of negative (Kochkin et al., 2014) and positive (Kochkin et al., 2012) discharges together with X-ray records that the discharge evolution and X-ray emission conditions depend on polarity.

2. Experiment

The experimental study reported here was conducted at the high voltage laboratory of Uppsala University, Sweden. Fig. 1 shows the approximate arrangement of the experiment schematically. A rod-sphere air gap was used at atmospheric pressure where the rod was made of brass and had a diameter of 10 mm. Three different spheres were used with the diameters 2.1, 6.3 and 12 cm respectively. A negative so-called standard lightning impulse voltage (the impulse front time is 1.2 μs and time to half value is 50 μs) was applied to the rod, defining the rod as cathode. The spheres were grounded and effectively served as anode. The gap length was 95 cm. The voltage impulse was generated by using a Marx impulse voltage generator (Haefely Test AG, SGSA 1000-50, maximum charging voltage: 1 MV, maximum energy: 50 kJ). In this experiment the charging voltage was 950 kV. This charging voltage which was applied to the rod-sphere air gap was enough to create a spark breakdown between the electrodes.

There were a total of 45 sparks. As mentioned before, spheres with three different diameters were used as the anode which made three different electrode configurations and for each rod-sphere combination 15 sparks were applied. The voltage across the gap, the current through the gap and the emission of X-rays produced by the laboratory spark were measured. A capacitive impulse voltage divider (Haefely CS 1000-670) was used to measure the voltage. A current transformer (Pearson model 411, maximum peak current 5 kA, rise time 20 ns, upper frequency response 20 MHz) measured the current at the grounded end. Both the voltage divider and the current transformer were connected to a PC via a data acquisition card (Dias 733 from Haefely). The X-rays were measured using a NaI(TI) scintillator assembled with a photomultiplier tube (PMT). The direct anode output of the NaI (TI)/PMT was then connected to a fibre-optic transmitter (Terraheartz LTX-5515). The detector system was manufactured by Saint-Gobain (model 3M3/3). The whole detector system consisting of scintillator, PMT and PMT base together with 12-V battery that supplied power to the detector system and a fibre optic transmitter were placed inside a 0.32 cm thick aluminum box. The box was then placed 105 cm away from the anode electrode on the grounded metal floor of the high voltage hall. The measured X-ray signal was then sent to a transient recorder (Yokogawa SL1000) through an optical link where at the transient recorder end a receiver converted the signal back to an electrical signal. The X-ray detector system together with the complete fibre-optic transmission link was calibrated daily both before and after the measurements using a ^{137}Cs source. It is important to mention that the rising edge and the falling edge of the detected X-ray signals in this measurement system is solely determined by the bandwidth of the fibre-optic link (20 Mhz) and the slow decay time of the NaI (Ti) scintillator (250 ns) respectively. The time synchronization of voltage, current and X-ray signals were achieved by splitting the current signal and sending the current signal to both the Dias 733 and the Yokogawa SL1000.

The X-ray detection system is the same as that used before in Dwyer et al. (2005, 2008). In order to avoid optically and electrically induced noise in the X-ray detector system, the box was made light tight and RF gasket was used between the lid and the bottom of the box. In addition to the shielding around the detector using μ metal and lead, the whole system was wrapped inside aluminum foils and black electrical tape.

3. Results and discussions

As stated before, three different electrode geometries were used where the cathode was always the same but the anode diameter was changed. X-rays were observed from 42 out of the total 45 negative sparks. For the 6.3 cm anode there was one spark and for the 12 cm anode there were two sparks where no X-rays were observed. The measured breakdown voltages and peak currents for these sparks where no X-rays were detected were comparable to other 42 sparks where X-rays were detected. The detection rate is very close to 100% here. Fig. 2 shows the measured X-ray signal together with the voltage and the current as an example. For all sparks where X-rays were detected, X-rays occurred around 200 ns – 300 ns before the current peak. There is already a small

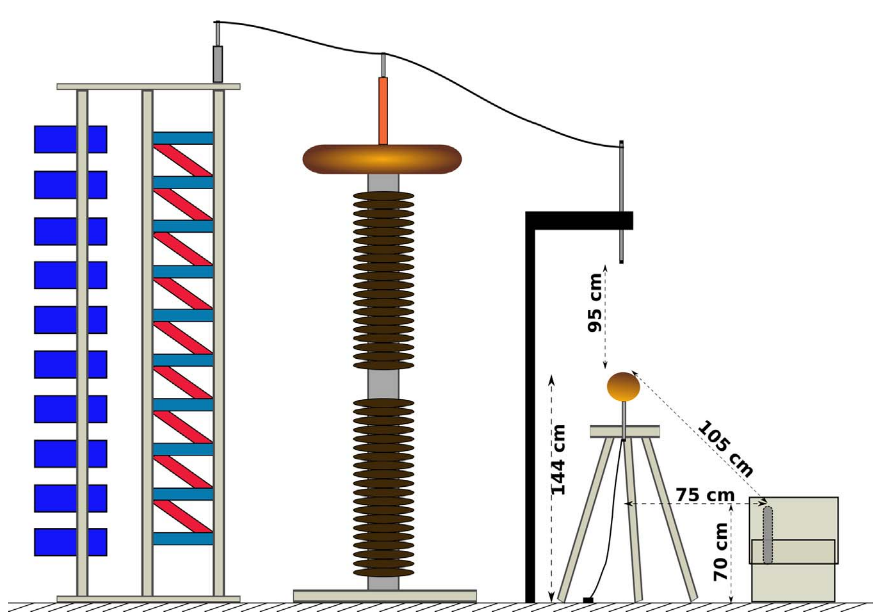

Fig. 1. Experimental setup showing (from left to right) the Marx generator, voltage divider, spark gap and the X-ray detector (not in real proportions).