Generation of Electron Runaway from Air Discharges at Atmospheric Pressure with Potential Anode

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Abstract – The experimental results confirming the presence of an electron beam behind a potential anode surface, generated by a nanosecond pulsed discharge in air atmosphere have been obtained. The experimental setup represented by itself a coaxial electrodes discharge system with an internal high-voltage anode of cylindrical form. A cathode in the form of a thin ring or knife was positioned on the internal surface of the outer cylinder. It is established that the discharge glowing consists from two areas. The first brightly glowing area has the form of an isosceles triangle, bearing on the anode surface. The ratio of the discharge height to its base is about 2:1, being not essentially dependent on the gap value. The second area is rather large with a weak glowing. The presence of ionizing radiation behind the potential anode was defined by using a photometric method. At that the width of film light-striking area was essentially larger than the near-anode area of the bright glowing discharge plasma. It has been experimentally established that the high-voltage anode hollow filled in with air under atmospheric pressure is also a source of X-ray radiation.

1. Introduction

To date many publications are devoted to the studies of pulsed discharges under high pressures of various gases, including atmospheric pressure air, which are the sources of X-ray radiation and beams of runaway electrons [1-11].

The principal concern of investigators was such a phenomenon as a diffuse (volume) discharge, formed without additional preionization source at subnanosecond duration of the leading edge of a high-voltage nanosecond pulse [4-10]. The studies of a gas discharge in high and ultra-high pulsed electric field allowed to reveal a number of regularities associated with accelerated motion of electrons in a gas and occurrence of X-ray radiation at electrons braking, taking place either in electrodes material or in gas itself, providing the more clear ideas concerning the nature of a diffuse discharge [5–10].

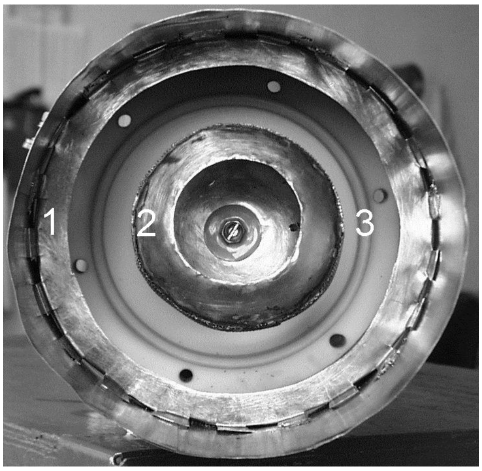
The X-ray radiation observed at nanosecond pulsed discharges in gases has been found and investigated in many publications, and the first ones were [1-4]. For that aims a two-electrode gap with a configuration “point – to – plane electrode” was used. Usually a high-voltage electrode of such a system was a point. Various constructions of high-voltage electrode were used (needle, sphere, cone, tube), and recording X-ray radiation was made behind thin-wall metal plane. In a majority of publications devoted to this phenomenon the high-voltage electrode had the negative potential. And only a few papers [2,4] report on X-ray radiation recording using a high-voltage electrode of positive polarity.

In our experiments the identical configuration point – to – plane electrode was used. It is seen from the experiment [6] that irrespective of high-voltage electrode polarity there is in a discharge gap a stable formation of a volume discharge. Moreover, while using two electrodes as needle-like there is either a stable formation of a volume discharge observed. Nevertheless, recording X-ray radiation to a film is available only at a negative polarity voltage pulse applied to a potential electrode.

This work was aimed to study possibilities of generation of runaway electrons in air under atmospheric pressure at a volume discharge formed in a discharge gap with a high-voltage electrode of positive polarity.

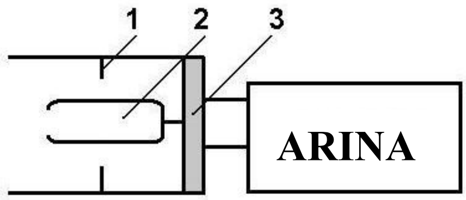
2. Experimental setup and techniques

A generator of nanosecond pulses, belonging to the X-ray equipment ARINA-02 was used in our experiments [12]. The high-voltage generator formed the voltage pulses with amplitude of up to 150 kV (no-load voltage). Pulse duration at a half-height was several nanoseconds, varying with respect to the load resistance. Duration of a voltage pulse leading edge was no more than 1 ns. At the generator output there was installed a specially developed isolator (3), as shown in Fig. 1, with the external diameter of 160 mm, owing to which even at an anode-cathode spacing above 70 mm there was no total breakdown over the isolator surface in an air atmosphere observed. A chamber shown in Fig. 1 was fixed to the generator. A cylindrical surface of the chamber was made of a copper plate of 250 μm in thickness. The internal diameter of the chamber was equal to 160 mm.



a)

b)



c)

Fig. 1. The general view of the chamber (*a*) and (*b*). Setup schematic in configuration 1 (*c*): 1 – grounded ring electrode, 2 – potential electrode, 3 – isolator

There was a two-electrode air gap in the chamber, formed by a ring electrode (1), made of a copper plate of 250 μm in thickness, and a potential electrode, being cylinder-like with round edges (2). The central part of the potential electrode was made of a metal grid with transparency of 50%. The electrode edges were made of a copper foil and rounded. From one end the electrode had an output window of 47 mm in diameter. Figure 2 shows a photograph image of the potential electrode.

The schematic of the configuration 2 of the setup with a blade electrode linearly set to the chamber presented in Fig. 3.

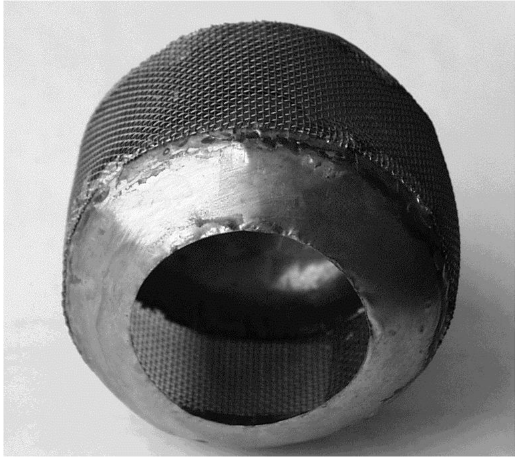


Fig. 2. General view of a potential electrode

In our experiments we used a photographic technique of ionizing radiation detection. A perforated photofluorographic film RF-3 of 35 mm in width was used as a photodetector. Experimentally the photographic film was put in one-layer envelope made of black paper of 90 μm thickness, being positioned by its emulsion layer to ionizing radiation flow supposed. The discharge glowing was photographed by ZENIT-TTL camera.

3. Experimental results

The volume pulsed discharges were ignited in the chamber with two different configurations, which are shown in Fig.1(c) and Fig.3, respectively, with a ring electrode and a blade electrode. Both electrodes were made of a copper plate on 250 μm in thickness.

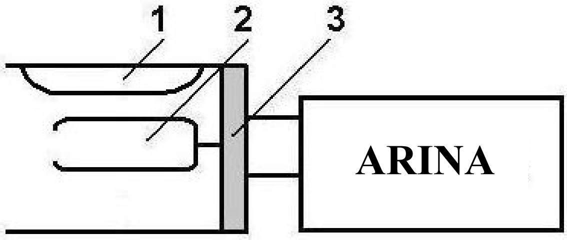


Fig. 3. Setup schematic in configuration 2: 1 - grounded blade electrode; 2 – potential electrode; 3 – isolator

The first run of experiments in the electrode configuration 1 has revealed that the X-Ray radiation is recorded on application of a positive voltage pulse to the potential electrode (2) with a photographic film inside. With the volume discharge diameter of 83 mm the value of interelectrode gap was about 25 mm. A plenty of minor diffuse discharges formed united annular discharge, which patch is shown in Fig. 4.

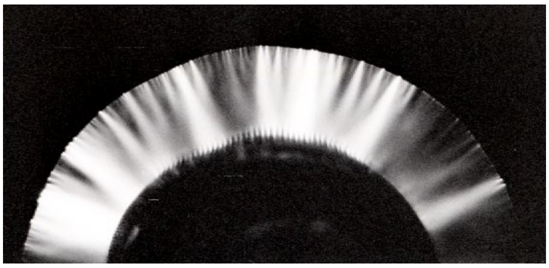


Fig. 4. Integral pattern of the discharge glowing obtained with a ring electrode (the dark circle below is the potential anode)

The X-ray radiation obtained during five pulses inside the anode has blackened a photographic film, and the imprint of the electrode - grid surface was rather clearly. The light striking has occupied the total sensitive area of the photographic film. Despite so major exposure as 150 pulses, the X-ray radiation was not recorded in the near-cathode area. At the same time, the secondary X-ray radiation was recorded from the anode output window. An exposure of 50 pulses was enough to lighten a photographic film, placed distant from the anode window by 15 mm, and to obtain an image of the output window. We were not succeeded in X-ray radiation recording when the output window was covered with a copper plate of 250 μm in thickness, though exposure was increased up to 150 pulses.

Change of high-voltage electrode polarity had no effect on quality of the diffuse discharge. When a negative polarity pulse was applied to the gap 1, there was formed a diffuse discharge similar to that shown in Fig. 4. After changing voltage pulse polarity, we managed to record X-ray radiation near the circular blade (anode) only.

Fig. 5. Integral pattern of the discharge glowing in configuration 2. At the discharge basis there is a potential anode. The discharge tip onset is from the grounded blade electrode

With the electrode configuration 2, the ring electrode was changed for a blade one, placed along the cylinder generator of the setup chamber. After application of a voltage pulse of positive polarity, a brightly glowing diffuse discharge in the form of a cone formed in the interelectrode gap, as it is shown in Fig. 5. The ratio of the basis length to the height is about 1:2. Despite the fact that the value of interelectrode spacing was varied as 11, 20, and 29 mm, such mentioned above ratio remained.

The experiments carried out with three different discharge gaps have shown the presence of X-ray radiation occurred in the anode region. The width of film light striking exceeds the size of the basis of a diffuse discharge, the source of runaway electrons and associated X-ray radiation, by several times. During exposure of 20 pulses the distinct image of the grid anode surface was imprinted on the film. We could not manage to record X-ray radiation at the anode output window. Maybe that is explained by local sizing of a diffuse discharge in this geometry, that determine quantitative characteristic of a runaway electron beam. In order to have such data it is necessary to carry out additional experiments, which were not scheduled on this task solving.

No X-ray radiation was detected in the area near the grounded blade cathode at application of a positive polarity voltage pulse to the discharge gap with 200-pulse exposure.

With alternation of positive polarity of a voltage pulse to negative one the pattern of diffuse discharge glowing in the chamber was the same. At the same time, inside the potential chamber (cathode) the X-ray radiation was not recorded at 200-pulse exposure. Near the grounded blade anode the photographic film was blackened by the X-ray radiation flow.

4. Results and discussion

The following was deduced from the experiments done on registration of X-ray radiation generated by runaway electrons in a diffuse discharge, as well as gap discharge form observations.

In a wide range of the experimental conditions, either in electrode configuration 1 or 2, without regard to polarity of a voltage pulse applied to the gap, as it is shown in Figs 3 and 4, a volume discharge is forming in the gap in the form of diffuse cones. It follows from the experiments that presence of X-ray radiation behind the anode in air atmosphere is the regular sequent of formation of volume discharges with nanosecond duration of a voltage pulse rise time, being not dependent on geometry and sizing of a gap.

A flow of X-ray radiation being fixed in configuration 1 from the anode window maybe explained as runaway electrons bremsstrahlung in air atmosphere outside the anode surface.

Discharge form observations in a gap gave geometrical ratio between the basis and height of a diffuse glowing, as it was earlier stated as about 1:2. Such dependence was not checked in a point – plane geometry. We suppose that such ratio has the specific character, since in our experimental conditions a blade electrode and an electrode with cylindrical surface formed the electric field.

5. Conclusion

Thus the experimental results on X-ray radiation observations as associated to` an electron flow of runaway electrons, generated by a diffuse discharge in a two-electrode gap with a potential anode under atmospheric air. Nanosecond voltage pulses with subnanosecond rise time were applied to a discharge gap with a non-uniform electric field. The X-ray radiation as a result of interaction of an electron flow with anodic material, and with air as well, was recorded behind the effective area and in the output window of the anode. The results obtained agree with the experimental data presented in [3,4,5,9,10], where a geometry "negative point - to – plane" with the discharge gap value over 10 mm was used. It has been shown experimentally that despite the polarity of a voltage pulse applied to a two-electrode gap with various configurations a diffuse discharge is forming with almost identical form of glowing.

It has been settled that the discharge glowing consists from two areas, the first area has bright glowing, as is shown in Figs. 2 and 4, and the second one has weak glowing but occupies essentially larger area. At that film light striking by X-ray radiation is observed both opposite to the area with bright glowing and opposite to the discharge with weak glowing.

The studies carried out in this work are of qualitative character. Further experiments are scheduled to get quantitative data on ionizing radiation, i.e. exposure doze, duration of radiation, spatial distribution, etc.

6. References

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