Spatial distributions of X-ray radiation during ferrite surface breakdown

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Abstract. Spatial properties of the radiation induced by a ferrite surface flashover supported by a 300 kV and ~1 ns rise time pulsed voltage source were studied. Peak value and rise time were obtained for the discharge current.

1. Introduction
Radiation above ferrite surface in pulse discharge along it was researched in many works, such as, for example, [1-5]. However, only in [6] properties of radiation directed along the discharge on BIN experimental setup [1, 6] were studied. In [6] a short (~2 ns) directional (~3°-5°) X-ray (> 1 keV) pulse was observed during the pre-discharge stage, with pulse intensity increasing as square of the discharge gap length. Discharge parameters were as follows: ~300 kV voltage (~20 ns rise time) and ~270 kA current. Results shown in [6] present great interest for creating coherent X-ray sources.

Radiation appearing in pre-discharge state suggests that phenomenon observed in [6] is not a consequence to discharge current. This article studies spatial properties of radiation induced by a ferrite surface flashover supported by a low power pulsed voltage generator [7] with peak voltage up to 300 kV of ~1 ns rise time.

2. Experimental setup
Schematic 3D layout of the experiment is presented in Fig. 1, and an in-depth description of the setup and measuring techniques are outlined in [7]. An original block (a heavily modified X-ray device «Pamir-300», peak voltage ~300 kV, voltage rise time ~1 ns) was used to power the discharge. High negative voltage was applied through a copper electrode to a wide surface of a rectangular ferrite prism (brand M1000NN) with cross section of 10x20 mm². Anode, made also of copper plate, was mounted at a distance of 45 mm from the cathode in a deepening in the ferrite so that it didn’t stand out above ferrite surface. Two independent methods were used to measure the discharge current: using a 0.018 Ω shunt and a single-turn Rogowski coil. Both these components were mounted between anode 3 and ground.
Figure 1. Experiment layout: 1 – ferrite of brand M1000NN; 2 – cathode; 3 – anode; 4 – plasma filament; 5 – neodymium magnet; 6 – scintillator.

The part of the setup responsible for the discharge as well as recording equipment and partly the high voltage source were placed in a spherical stainless steel vacuum chamber 50 cm in diameter. Pumping system consisting of a Leybold Turbovac 350 turbomolecular pump, an Anest Iwata ISP90 spiral vacuum pump and a Leybold IONIVAC ITR 90 combined pressure sensor provided pressure of $\sim 10^{-5}$ Torr in the chamber.

The radiation along ferrite surface was registered from the anode side (XY plane, see Fig. 1) using a circular quartz optic fiber ~1 mm in diameter and ~60 m in length, connected to a FEU-87 photomultiplier, which provided ~2 ns of time resolution. Photomultiplier signal was observed on a 300 MHz bandwidth TDS 3032 oscilloscope. To register X-ray radiation the free fiber end was connected to a scintillator (6 in Fig. 1) placed inside a lead tube collimator. The $10\times2\times2$ mm$^3$ piece made of polystyrene doped with $\pi$-terphenyl and POPOP had its response time measured separately with use of a phase shift method utilizing a MFLI (Zurich Instruments) lock-in amplifier. It was established to be $1.8\pm0.1$ ns (at the excitation by 365 nm LED emission), well consistent with the time resolution of the receiving path. Visible light from discharge was prevented from reaching the photomultiplier by placing a 4 $\mu$m filter made of polypropylene with aluminum cover in front of scintillator.

An original two-dimensional motorized translator controlled programmatically from a personal computer was used to obtain a spatial distribution for the studied radiation. Optical fiber end with the scintillator was attached to its moving part at a distance of 76 mm from the anode side of the ferrite prism. The system allowed to position the radiation receiver in an area of $10\times10$ cm$^2$ with an accuracy of 0.1 mm for each axis.

Electron beam formed in discharge was separated from X-ray radiation by placing a 0.3 T $4\times2\times1$ cm$^3$ neodymium magnet (5 in Fig. 1) between ferrite and scintillator. Magnet location and orientation were chosen so that the electron beam would be diverted considerably «down» relative to the ferrite surface. A simple estimate was made for beam image shift in the measurement plane using a self-written integrator. A modified Euler method was implemented to calculate electron trajectory with account for relativism and using a varying time step ($\tau_i \propto 1/v_i^{-1}$, where $v_i$ - 1 is electron velocity at the previous step) to ensure sufficient accuracy. A set of coils with current was used to roughly model magnet’s field. The integrator was implemented inside Godot engine using built-in scripting tools in order to simplify real-time visualization process and problem parameters setup. Estimates made with it for electrons with energies of 150 keV, 300 keV and 600 keV show that in measurement plane the beam image center in each case would be shifted by more than 15 mm in the negative Y direction.
This, as will be shown later, is right on the edge of measurement area and should not interfere with main obtained results. The ferrite surface was polished, and then copper paste was applied to it to create a conductive path close to one of its edges (4 in Fig. 1) which corresponded to the X coordinate of -7 cm in the plane of translator. The discharge was photographed during the breakdown, one of the photos can be seen in Fig. 2. The photos demonstrated that the path didn’t deform throughout all of the experiments described in this work and that the discharge always stayed right on it. More in depth description of the discharge propagation mechanism along the conductive path over ferrite surface was described in [2].

![Image of ferrite surface discharge](image)

**Figure 2.** Photo of a ferrite surface discharge along a conductive path.

### 3. Experimental results and discussion

In the first stage, discharge current dynamics and peak value were studied. This is necessary to determine the income power and to later establish relations between radiation processes and high-voltage discharge dynamics. As described earlier, current values were obtained through two independent means: a shunt, and a Rogowski coil. The results obtained by both are consistent between each other (see Fig. 3), peak current measured is ~1 kA.

![Current measurements graph](image)

**Figure 3.** Ferrite surface flashover current measurements: 1 — using a Rogowski coil; 2 — using a shunt.
The next step were spatial radiation distribution measurements. In Fig. 3 intensity distributions along $y$ axis (perpendicular to ferrite surface, see Fig. 1) opposite to the plasma channel ($x=-7$ cm) and to the side of it ($x=7$ cm) are shown. Each data point on the graph represents an average of at least 3 independent measurements. These results allow, similar to [6], angular divergence of observed radiation. At $x=7$ cm it is ~4°, and a little wider in from of discharge. It is probably due to structural damage to ferrite surface (as described in [2], it becomes amorphous) during discharge along a specified path. Change in structure as well as increased roughness lead to increased dispersion. Peak intensities differ by ~20%, which may be related to a higher electron density in front of the discharge path. If angular distribution of radiation along the $y$ axis corresponds to the results of [6], then along the ferrite surface (the $x$ axis) this distribution does not have a narrow direction [7].

![Spatial distributions of radiation along the ferrite surface](image)

**Figure 4.** Spatial distributions of radiation along the ferrite surface.

4. Conclusion
Current dynamics in a discharge were studied with rise time of ~1 ns and up to 1 kA peak. Spatial distribution for radiation, induced by a ferrite surface flashover, is obtained in the direction along discharge axis. Angular diversion of the radiation to the side from discharge is ~4°. Obtained results correspond well with the results from the high-current experiments with a similar geometry [6].

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