

Recent Observation of X-Rays and E-Beams in Plasma-Focus Discharges

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The polarization of some X-ray spectral lines is closely connected with the appearance of directed electron beams. Complex studies of these phenomena have recently been performed within the MAJA-PF facility.

1. Introduction

Computations of some basic parameters of a high-temperature plasma, e.g. its electron temperature, require an assumption about the maxwellian distribution of electron velocities. On the other hand, it is known that within pulsed discharges of the Z-pinch and Plasma-Focus (PF) type, there are formed tiny region of an increased X-ray emission (so-called "hot-spots"), which emit pulsed electron beams [1]. Recent spectroscopic studies of the X-ray emission have also revealed differences in the polarization of some X-ray spectral lines [2-3]. These polarization effects can be explained by an influence of some important factors disturbing the maxwellian distribution. Such factors can be relativistic electron beams produced inside hot-spots or in their close neighborhood.

This paper reports on detailed measurements of X-ray spectra, showing the polarization effects, as well as on complex studies of pulsed electron and ion beams from PF discharges.

2. Experimental results

The experimental studies have been performed within the medium-size PF facility (MAJA-PF machine [1]) operated at an energy level of 45 kJ. The main condenser bank was charged up to 35 kV and it was able to generate pulsed discharge currents of an amplitude reaching about 500 kA, with a quarter-period $T_{1/4} = 3 \mu\text{s}$. In order to obtain intense plasma discharges with distinct hot-spots, the main experimental chamber was filled up with a gaseous mixture of deuterium and argon (up to 20%). All the results presented in this paper refer to a single PF-shot No. M8040106.

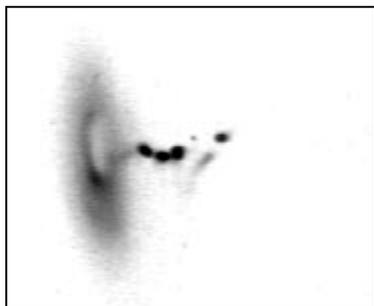


Fig.1. X-ray pinhole picture (scale 1:1) taken during a single shot within the MAJA-PF device

a) Pinhole camera measurements

In order to determine positions and dimensions of hot-spots the use made of an X-ray pinhole camera equipped with an input diaphragm of 100 μm in diameter, which was covered with a 10 μm -thick Be-foil. The X-ray pinhole image, as obtained side-on the pinch column is presented in Fig. 1. It can be seen that the distinct hot-

spots can be formed on and at the symmetry axis of the discharge, at the electrode outlets, and dimensions of the brightest hot-spots are below 100 μm .

b) Measurements of X-ray spectra

The observed hot spots are sources of high-intensity X-ray emission. To measure spectra of this emission there were applied two almost identical Johann-type spectrometers equipped with concave (cylindrical) quartz crystals. Those crystal were placed upon a circle of 500 mm radius, and their inter-layer constants (2d) were equal to 0.812 nm and 0.667 nm, respectively. The spectrometers were assembled in such a way that their dispersion planes were mutually perpendicular. An exact adjustment of the both spectrometers made possible the observation of a single hot-spot formed on the z-axis. The X-ray spectra, obtained during one PF shot, are presented in Fig.2.

It can be seen that within the spectrometer with the dispersion plane parallel to the z-axis

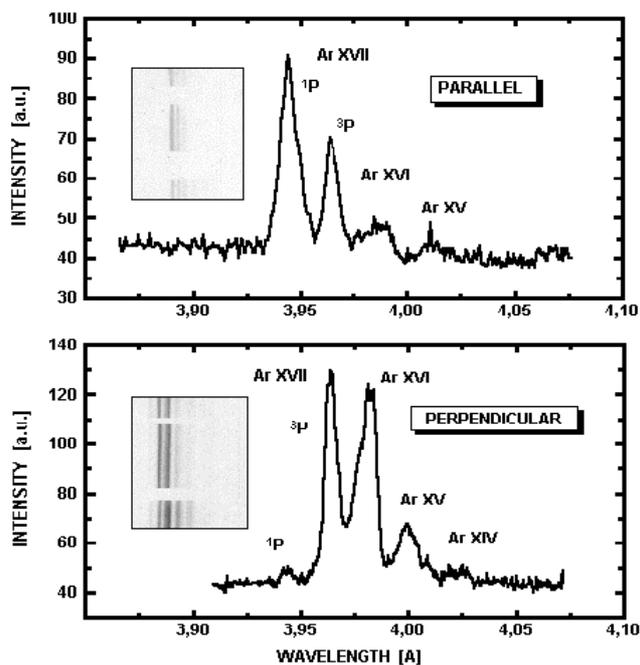


Fig.2 X-ray lines of highly ionized argon, as registered by means of two crystal spectrometers with their dispersion planes oriented parallel and perpendicular to the z-axis. Inside the rectangular inserts there are shown fragments of the spectra registered on the X-ray films

intensity of the resonance line (ArXVII-¹P) was higher than that of the intercombination line (ArXVII-³P). On contrary, with the spectrometer with the perpendicular dispersion plane intensity of the resonance line was considerably lower than that of the intercombination line. This effect can be explained by different polarization of the considered X-ray lines. It should be noted that in a control experiment, when the both spectrometers had the same orientation in relation to the z-axis, there were registered X-ray spectra with almost identical relative intensities of the same X-ray lines [4]. It was suspected that differences in the polarization of X-ray spectral lines can be induced by strong local electromagnetic fields and corresponding disturbances of the maxwellian distribution of electron velocities. This hypothesis is

supported by observations of high-intensity electron beams emitted from PF discharges.

c) Electron beams measurements

Due to the positive polarity of the central electrode the main electron stream is emitted in the up-stream direction (180°). In order to make possible measurements of those electrons a 10-mm-diameter hole was drilled in the front plate of the inner electrode, and electron detectors were placed behind the main collector plate, at a distance of about 50 cm from the pinch region. To get time-resolved electron signals the use was made of Cerenkov-type detectors equipped with rutil radiators, which made possible measurements of electrons of energy above 50 keV [5]. Previous studies of fast electrons beams [1] have shown that the electron pulses last 7-10 ns and they are well correlated with the appearance of hot-spots. To investigate energy spectra of the electron beams there was applied a magnetic spectrometer

with a 180° deflection angle. Detailed measurements have shown that the electron energy spectrum extends from about 5 keV to about 600 keV, with the maximum at about 50 keV, and it has several peaks. Such local maxima suggest the appearance of small sources emitting electrons within narrow energy bands [3].

To investigate temporal changes in the emission of pulsed electron beams the use was made of miniature scintillation detectors, which were installed within selected energy regions

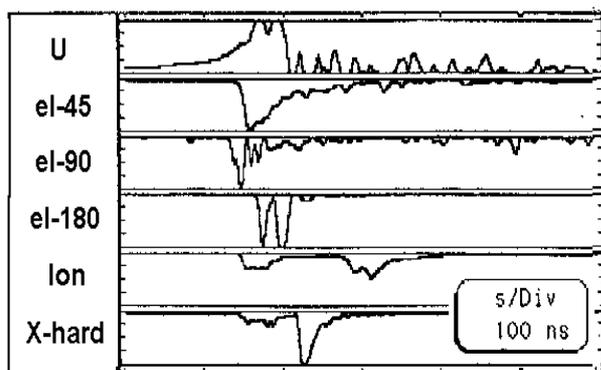


Fig.3. Voltage waveform (U) and electron induced signals (el), obtained at different angles to the z -axis (45 - 180°), in a comparison with ion and X-ray

inside the magnetic spectrometer. Those scintillators generated time-resolved signals corresponding to the chosen energy values with accuracy $\pm 10\%$. That energy spread was caused by geometrical dimensions of the applied scintillators.

Time-resolved electron signals, as obtained at different angles to the z -axis, are shown in Fig.3. The electron signals have been compared with the inter electrode voltage waveform as well as with ion induced signals and hard X-ray pulses. It should be noted that the upstream detector (denoted as „el-180”) registered all electrons of energy equal to

50 ± 5 keV. Time-resolved signals corresponding to electrons of different energy are presented in Fig.4. The comparison of the registered signals suggests that individual electron pulses have been emitted from different hot-spots, which appeared with some time delays. Analyzing the registered signals one can conclude that the first and second hot-spot (counting from the electrode outlet) emit electrons within energy range of 20-50 keV, while the third hot-spots generates electrons within the whole measured energy range (20-500 keV), and the fourth one emits high energy (200-500 keV) electrons only. Those observations have also been confirmed by a non-uniform blackening of the X-ray film used for time-integrated measurements with the same magnetic spectrometer.

It should also be noted that the Cerenkov-type detectors, as placed at the angles of 45° and 90° in relation to the z -axis, registered weaker electron pulses (see Fig. 3, traces „el-45”, and „el-90”). These electron streams were emitted about 30-50 ns before the voltage maximum which correlated with the appearance of the discharge current peculiarity. Those electrons were emitted when the current sheath (CS) layer achieved the edges (ends) of the coaxial electrodes, inducing probably the emission of secondary electrons. It seems that such electron pulses should have no correlation with high-intensity electron beams, which are emitted from hot-spots formed within the pinch column later-on. In a few cases, however, some correlation has been observed and it requires further investigations.

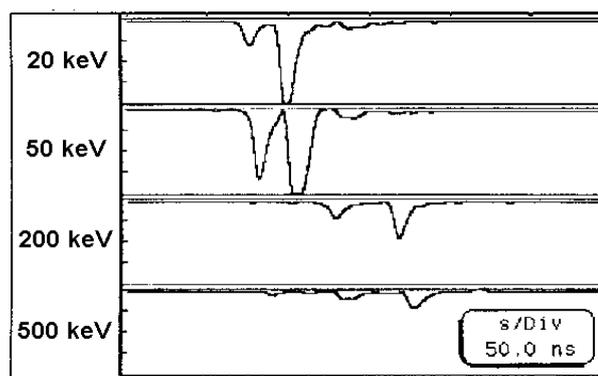


Fig.4. Time resolved electron signals within different energy bands (20-500keV), as registered for a single PF-shot performed with the MAJA-PF device. The pulses seem to correspond different hot-spots of various emission characteristics

d) Measurements of ion beams

In order to investigate ion (mostly deuteron) streams (or beams) emitted from the pinch column there was applied a scintillation detector, which was placed on the z-axis, at a distance

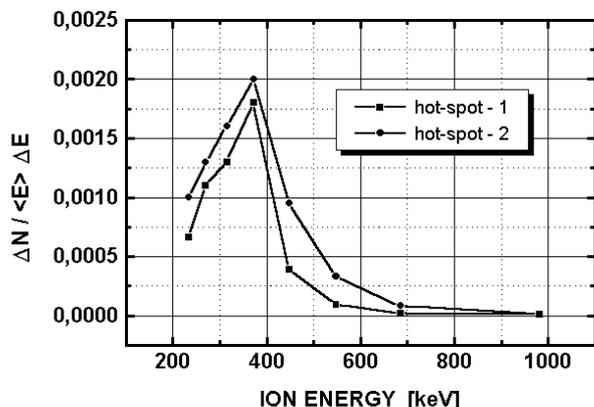


Fig.5. Energy distribution of deuterons as computed from ion signals registered for different hot-spots

(Fig.4), which in turn were induced by fast electron beams accelerated in the opposite direction to the ions. The computed energy spectrum of deuterons is presented in Fig.5.

3. Conclusions

The most important results of these studies can be summarized as follows:

1. The registered X-ray spectra show that the spectral lines (emitted by highly-ionized argon ions) demonstrate considerable differences in the polarization, which might be due to strong local electric fields and directed electron beams.

2. The pulsed electron beams, as emitted mostly in the upstream direction, are possibly generated from different hot-spots. Such local sources can emit electrons within relatively narrow energy bands.

3. The emission of electrons at different angles (e.g. 45° and 90°) to the z-axis has been confirmed and it is explained by interactions of the CS layer with electrode edges.

4. The energy spectrum of deuterons emitted from PF-shots was estimated to extend from 200 keV to about 700 keV, with the maximum appearing at about 350 keV.

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