

RESEARCH ON EMISSION OF CHARGED PARTICLE BEAMS FROM PF-360 FACILITY

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Abstract. The paper reports on experimental studies of pulsed beams of ions and electrons emitted by Plasma-Focus (PF) discharges performed at energy ranging from 113 kJ to 130 kJ. The results obtained with different diagnostic techniques are compared and discussed.

1. Introduction

Ion fluxes and fast electron beams generated in PF-type facilities have been investigated in different laboratories for many years. Studies of pulsed ion (e.g. deuteron) and electron beams are needed not only for the explanation of physical phenomena, which are responsible for the generation and acceleration of such charged particles, but also for application oriented research. In particular the investigation of energetic- and temporal-characteristics of the ion and electron beams are of interest for various applications of PF-type facilities to the ion implantation and surface modification of different materials.

2. Experimental Set-up and Diagnostic Equipment

A Mather-type PF-360 facility [1-2] was equipped with a 120-mm-diam. inner electrode and a 170-mm-diam. outer one. The both coaxial electrodes were 300-mm-long. A tubular ceramic insulator, embracing the inner electrode, was 80 mm in length. The most experiments were carried out at the energy level from 113 kJ to 130 kJ, at charging voltage equal to 30 kV. The initial filling pressure was changed from 4.0 to 6.2 mbar D₂. There were registered electrical signals corresponding to the total discharge current and interelectrode voltage. Time-resolved pulses corresponding to hard X-rays and fusion neutrons were obtained from a scintillation probe located side-on, at a distance of 410 cm from the electrodes outlet. To perform space- and time-resolved measurements of ion beams along the z-axis, the use was made of an ion pinhole camera with an entrance diaphragm placed at a distance of 62 cm from the electrode ends. The registration plate was equipped with miniature foil-filters and scintillators coupled with fast photomultipliers and oscilloscopes. Those scintillators were distributed

symmetrically at the radius $r = 10$ mm, at a distance of 102 cm from the electrode ends, and their energy threshold for deuterons was equal to 1.3 MeV (at 10- μ m-thick Al-filters). In order to measure the ion beam divergence there were applied three ion pinhole cameras placed one behind the other. The ion flux was registered with nuclear track detectors of the CN type, covered by foil filters. To study ions within two different energy ranges (500-700 keV and 3-5 MeV) the use was made of a magnetic analyzer equipped with small permanent magnets and miniature scintillation detectors. That analyzer was located at a distance of 112 cm from the pinch center.

To register fast electron beams emitted in the upstream direction, there were applied Cerenkov-type detectors equipped with diamond radiators [3, 5]. Those detectors were placed behind the main collector plate, at a distance of 51 cm from the plasma focus region. Electron energy spectra were measured with two different magnetic analyzers: one placed inside the inner electrode, and the second one located behind the main collector plate. Time-resolved measurements of X-ray pulses were carried out by means of XET analyzers equipped with different Al-filters and miniature scintillators of the optimized thickness [4].

3. Experimental results

To study correlation of the electrical waveforms and neutron signals with X-ray and particle pulses, all the diagnostic techniques were used simultaneously. A typical set of signals obtained from a single PF discharge is shown in Fig. 1.

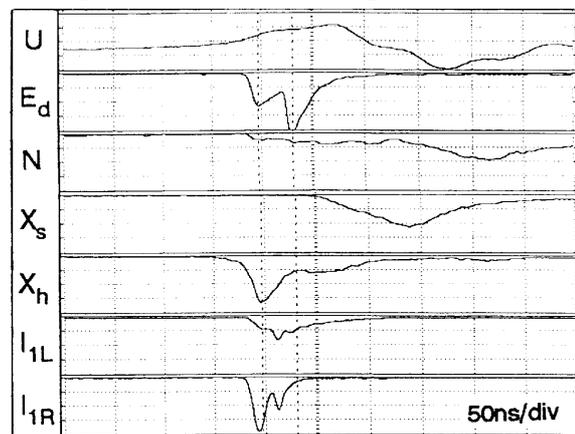


Fig. 1. Traces from a single PF shot at: $E_0 = 113$ kJ, $p_0 = 4.6$ mbar D_2 , $Y_n = 9.8 \times 10^9$. Notations: U - voltage, N -hard X-rays and neutrons, E_d - electron beam signal, X_s , X_h - soft and hard X-rays, I_{1L} , I_{1R} - ion signals from two scintillators placed at different position within the ion pinhole camera.

The ion signals suggest that the emission of high energy ions (with energy above 1.3 MeV) is strongly anisotropic. The registered ion peaks differed in intensity in the two measuring channels. In some cases the successive ion peaks did not appear in all the channels. A time delay between those signals and the $m = 0$ instant was equal to 15-40 ns, what suggested that the emission of high-energy ions appears 50-80 ns earlier than $m = 0$ instability or that the energy value of the ions registered is much higher than the threshold

value 1.3 MeV. The time-resolved signals from fast electron beams, as obtained from the Cerenkov-type detectors had FWHM = 20-30 ns and they were usually delayed in relation to the $m = 0$ instability instant by 20 to 70 ns. The waveforms of X-rays signals demonstrated that the emission of the hard X-rays ($E_x > 5$ keV) starts at the $m = 0$ instant, while the soft X-rays ($0.4 \text{ keV} < E_x < 20 \text{ keV}$) are emitted later.

Maps of the deuteron beams of energy higher than 700keV, emitted mostly along the main z-axis and registered with a set of three ion pinhole cameras placed one behind the other, are shown in Fig. 2. It was estimated that the deuteron flux density was diminished about 3 times per each 130-mm path within the deuterium gas. Within the first step (between plate A and B) the cross-section area of the investigated beam increased 2.6 times, and between B and C it decreased 2.1 times. In that case the spreading of the deuteron beam was relatively high.

The time-resolved ion signals, which were obtained by means of the magnetic analyzer, corresponded to two energy levels: 600 keV and 4 MeV. An example of such ion

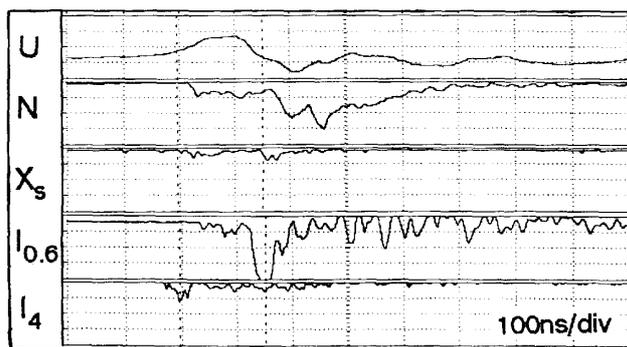


Fig. 3. Traces obtained from a PF shot at $E_0 = 113 \text{ kJ}$, $p_0 = 5.3 \text{ mbar D}_2$, $Y_n = 7.1 \times 10^9$. Notations: U - voltage, N - hard X-rays and neutrons, X_s - soft X-rays, $I_{0.6}$ and I_4 - ion signals from magnetic analyzer: 600 keV and 4 MeV.

of registered ions considerably. Time-integrated energy spectra of fast electron beams,

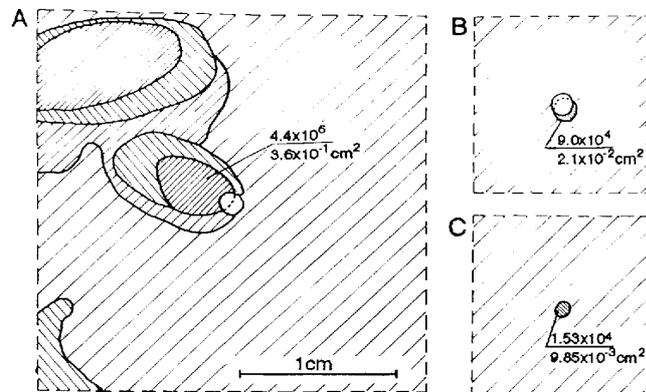


Fig. 2. Maps of ion beams registered with three ion pinhole cameras connected in series, as obtained from PF shots at $E_0 = 113 \text{ kJ}$, $p_0 = 4.2 \text{ mbar D}_2$. The CN-films were placed at a distance: A – 545 mm, B – 671 mm, C – 797 mm from the electrodes.

signals in correlation with other waveforms, is shown in Fig. 3. From the ion signal registered within the 600 keV channel, it can be concluded that the emission of such energetic groups of ions appears usually close to the $m = 0$ instability. The time shift varies from -40 ns up to +10 ns (in the relation to the $m = 0$ instant). The ion signal within the 4 MeV channel was measured seldom, because two pinholes within the analyzer inlet system reduced the number

emitted through the tubular central electrode in the upstream direction and measured with

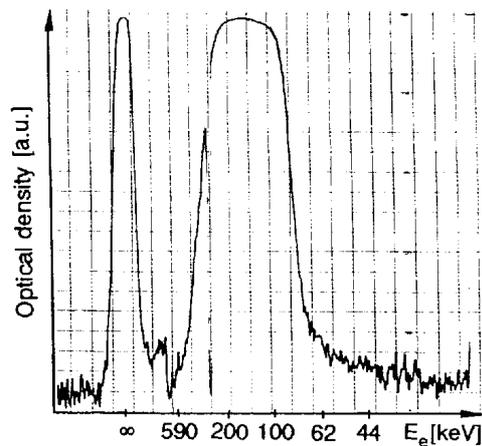


Fig. 4. Energy spectrum of electron beams from the PF-360 facility, as registered at $E_0 = 154$ kJ, $p_0 = 5.1$ mbar $D_2 + 0.26$ mbar Ar, $Y_n = 3.2 \times 10^9$.

magnetic analyzer behind the main collector plate, demonstrated that the maximum of these spectra lays between 80-200 keV, as shown in Fig. 4. Similar measurements, as performed with the other miniature analyzer placed inside the inner electrode of the PF-360 facility, showed that in that case the maximum of the electron spectrum appears within the energy range of 80-90 keV, as shown in Fig. 5.

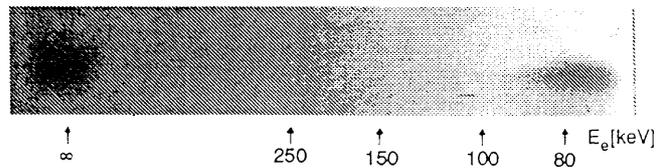


Fig. 5. Electron energy spectrum taken with a miniature magnetic analyzer placed inside the inner electrode, as registered for two PF shots at $E_0 = 113$ kJ and $p_0 = 4.4$ mbar D_2 .

4. Summary and Conclusions

Time-resolved measurements showed that energy of the registered ions amounted to several hundreds keV, and in some cases to a higher value. The data suggest that those energetic ions were emitted 50-80 ns before the $m = 0$ instability. The results obtained from the magnetic analyzer show that the ion emission time varied from -40 ns to $+10$ ns.

On the contrary to ions, fast electron beams appeared with a delay of about 60-70 ns to the $m = 0$ instant. The electron energy spectra measured inside the inner electrode showed that the most e-beams have energy equal to about 90 keV only, but the spectra measured behind the main collector plate showed the e-beams of energy up to about 500 keV. It results from differences in motion of ions and electrons. For electrons, influence of local magnetic fields is much stronger than for the ions, and the lower energy electrons are lost on their way.

References

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