STUDY OF CURRENT SHEATH DYNAMICS AND CHARGED PARTICLE EMISSION FROM PF-1000 FACILITY

M. Scholz, L. Karpinski, T. Pisarczyk, **M. Sadowski[1]**, L. Jakubowski[1], A. Szydlowski[1], A.Ya. Faenov[2], S.A. Pikuz[3], and V.M. Romanova[3]

Institute of Plasma Physics and Laser Microfusion (IPPLM), 00-908 Warsaw, Poland

Abstract: The paper presents results of recent experimental studies carried out with the PF-1000 plasma-focus facility operated at energy levels from 250 kJ up to 400 kJ. Observations of current sheath motion, as well as measurements of the X-ray and charged particle emission are reported.

1. Introduction

The large PF-1000 facility was put in the operation at IPPLM about four years ago [1]. Up to now several diagnostic techniques have been prepared and used for investigation of PF discharges within an experimental set up [1,2].

The main diagnostic tools applied for studies of current sheath dynamics were fast frame- and streak-cameras. In order to study soft and hard X-rays the use was made of scintillation probes, time-integrating and time-resolving X-ray cameras, and an X-ray spectrometer equipped with a concave (spherical) crystal. To investigate pulsed ion and electron beams there were used a Thomson parabola spectrometer, magnetic analyzers, and ion pinhole cameras equipped with solid-state nuclear track detectors. Some results of previous studies were presented at the 1997 IEEE Intern. Conference [2] and The Intern. Symposium PLASMA'97 [3]. This paper reports on results of experiments performed with the PF-1000 facility recently.

2. Experimental results

Several recent series of experiments within the PF-1000 facility were performed using the working gas composed of hydrogen and argon admixture. The partial pressure of argon was varied up to 20%. The PF shots were performed within the energy range from 250 kJ to 400 kJ. In order to investigate dynamics of the current sheath two high-speed cameras were applied. The first camera had an entrance slit perpendicular to the z-axis, while the second one had a slit parallel to this axis. Some examples of the smear pictures have been shown in Fig. 1.

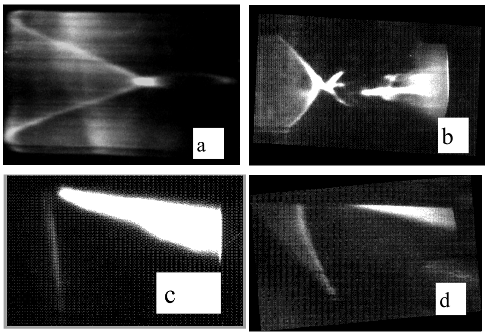

Fig. 1. Streak-camera picture (upper) taken through the radial slit, (lower) taken throught axial slit: (a,c) for pure H_2 -shot and (b,d) for H_2+Ar - shot.

The pictures taken with the first camera show a fast collapse of the current sheath towards the axis of symmetry with an average radial velocity of about $1.3x10^7$ cm/s, and simultaneous motion along the z-axis with an average axial velocity equal to about $1.8x10^7$ cm/s (at r = 0). The streak pictures taken by the second camera with an axial slit (Figs. 1c,d) demonstrate a relatively fast motion of the current sheath in the axial direction (about $1.8x10^7$ cm/s) and a slower movement of a material vaporized from the electrodes (with an average axial velocity of about $4x10^6$cm/s).

In order to register X-ray images there were used two different pinhole cameras equipped with thin Be-filters. The first X-ray camera with two pinholes covered with 10-μm and 25-μm Be-foils, respectively, was used to take time-integrated X-ray pictures, as shown in Fig. 2a. The second X-ray camera, equipped with one pinhole but a regulated distance from the focus region, made possible to take time-integrated images registered upon an X-ray film or time-resolved pictures registered with a micro-channel plate (as shown in Fig. 2b). The X-ray pictures enabled a structure of the pinch column and some hot-spots to be observed.

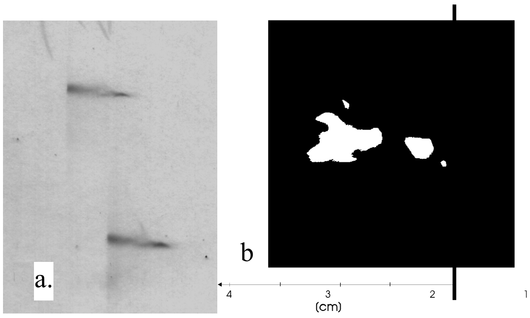

Fig. 2. Soft X-ray pinhole pictures from obtained PF-1000 facility , a) with two pinhole for pure H2 shot, b) with one pinhole and micro-channel plate.

The X-ray pictures obtained with the pure hydrogen filling were considerably different from those registered with the argon admixture. The pure hydrogen shots gave quasi-continuous pinch pictures showing a few hot spots only, while the hydrogen-argon discharges demonstrated strong X-ray emission at the inner electrode and very irregular structures located at z = 10-15 mm. It should be noted that the x-ray emission from hydrogen-argon shots was about two orders of magnitude higher than that from pure

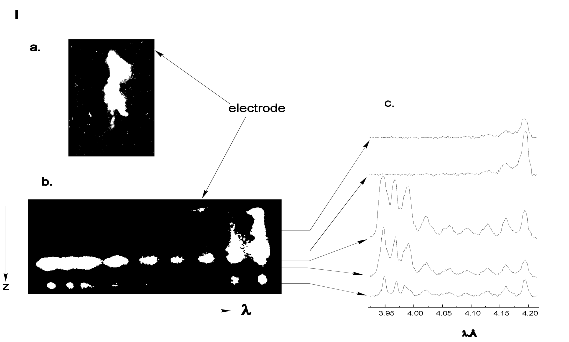

Fig. 3. Two-dimensional images of Ar focus plasma. a-pinhole images; b-spherical spectrograph images; c-densitogram of the spectrum on the different distance from the anode.

hydrogen discharges. Time-integrated but space-resolved X-ray emission spectra were measured by means of a spectrograph equipped with a spherically bent mica crystal with 2d = 19.94 Å and a curvature radius of 186 mm. It was installed side-on, at a distance of 1250 mm from the electrode axis. The analyzed spectral range was 3-4 Å, and the use was made of the 3rd and 4th reflection order. The spectral resolution was below 0.03 Å/mm. The direction of th dispersion was parallel to the z-axis. The focussing of the spectrum occurred in the same way as for a crystal bent along a cylindrical surface, i.e. on the Rowland's circle coinciding with the meridian plane of the crystal applied. Thus, the spectrograph was operated in an ordinary Johann scheme, but with a partial space focussing (because of a large distance between the plasma and the spectrograph) perpendicularly to the dispersion direction, as shown in Fig. 3.

On the basis of relative intensity of the dielectronic satellites *1s2l2l'* (3.98-4.00 Å) to the He-like resonance line $1s^{2\,1}S_0 – 1s2p\,^1P_1$ was estimated to be 690, 450, and 770 eV, respectively. An electron concentration was determined using the ratio of the resonance line broading to that of the intercombination line (because for expected plasma parameters the intensity ratio of those lines is not sensitive to the electron density), but only spectra registered in the 4th order (with better spectral resolution) were considered. The value of the electron concentration was found to be about 10^{20} cm^{-3}.

To study ion beam emission there were applied nuclear track detectors (NTDs) placed in front of the electrode outlet, and distributed upon a semicircular support of a 15-cm radius. Analyzing NTDs irradiated at different angles to the z-axis, there was determined an angular distribution of fast ions (mainly primary protons and impurity ions), shown in Fig. 4. That distribution confirmed some asymmetry in the ion emission and a characteristic local minimum at the pinch axis [4].

To perform a mass- and energy-analysis of the ions emitted along the z-axis there was installed a Thomson-type spectrometer equipped with a long drift tube pumped differentially. Because of some difficulty with a good axial adjustment the entrance system the ion spectra have not been registered so far, but the entrance system was used as an ion pinhole camera. Pulsed beams of high-energy ions have been registered and their parameters are to be determined [4].

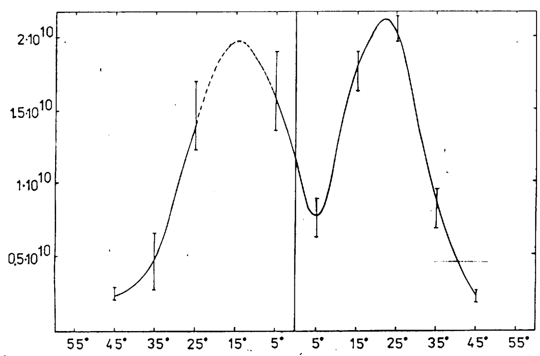

Fig. 4. Angular distribution of fast ions (mostly protons) emitted from the PF-1000.

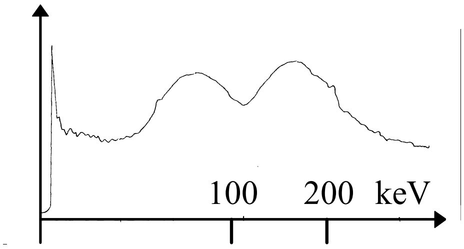

Fig. 5. Energy spectrum of electrons emitted through the tubular inner electrode.

Fast electron beams emitted in the upstream direction were measured with a miniature magnetic analyzer placed behind the main collector plate. The analyzed e-beams were deflected by 1800 and registered with an X-ray film. An electron energy spectrum was determined, as shown in Fig. 5. There were observed two distinct peaks at about 60 keV and 160 keV, although the spectrum ranged up to above 300 keV.

3. Summary and conclusions

Experimental results obtained from numerous PF shots were compared and analyzed. The high-speed streak-camera pictures gave information about the radial collapse and axial motion of the current sheath. The X-ray pinhole pictures showed that the pinch column has regions of different brightness and stability (hot-spots). Time-integrated space-resolved X-ray spectra demonstrated that there are formed sources of three different types. The appearance of Ar-lines can be explained by the generation of pulsed electron beams, as measured with the magnetic analyzer. The e-beams are accompanied by the fast ion beams emitted mostly along the z-axis. In general, the data obtained remain in agreement with those from other large PF experiments [5].

References

[1] M. Scholz, M. Borowiecki, et al.: *Proc. 2nd nat. Symp. PLASMA'95*, p.15 (Warsaw 1995).

[2] M. Scholz, et al.: *Proc. 1997 IEEE Intern. Conf. on Plasma Sci*., p.176 (San Diego 1997).

[3] M. Scholz, et al.: *Proc. Intern. Symp. PLASMA'97*, p.125 (Jarnoltowek 1997).

[4] A. Szydlowski, M. Sadowski, M. Scholz: *Proc.Intern.Workshop PF'98* (Kudowa 1998).

[5] H. Herold, J. Zebrowski, et al.: Plasma Phys. Contr. Fusion **30**, 763 (1988).

[1] Permanent address: *Soltan Institute of Nuclear Studies, 05-400 Otwock-Swierk, Poland.*

[2] Permanent address: *Multicharged Ions Spectra Data Center (VNIFTRI), Mendeleevo,Russia.*

[3] Permanent address: *P.N. Lebedev Physical Institute, Moscow, Russia.*