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X-RAY RADIATION OF PLASMA FOCUS DISCHARGE ON PF-3 FACILITY

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It is known, that Plasma Focus (PF) discharge is an intensive source of various radiations. For achieving the best PF performance as soft X-rays radiant the neon is usually used as working gas. In particular, the best result was achieved on PF-3 facility at the energy input ~ 1 MJ [1]. Experiments have shown that the spectral distribution of radiation essentially depends on a mode of operation. The urgency of investigation of the radiation spectral distribution has increased at transition to the experiments with various plasma-producing substances [2]. In this case the considerable contribution to the total SXR yield may be supplied by the long-wave radiation. The aim of the study was examination of spectral and quantitative parameters of X-ray radiation in a wide spectral range from hundreds eV up to tens keV.

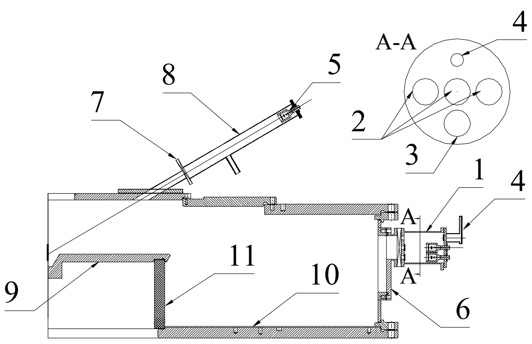

Fig. 1. Diagram of X-ray measurements: 1 – main detector unit; 2, 3, 5 –pin-diodes, 4 – pin-hole camera; 6, 7 – diagnostic ports, 8 – transitional tube, 9 – anode, 10 – cathode, 11 - insulator.

The diagram of measurements is shown on Fig.1. The main detector unit includes 4 pin-diodes (2, 3) with replaceable filters, allowing one to realize the measurements in the preset spectral ranges. Pin-diodes D2 are oriented on the zone of the pinch formation and see both the very pinch and anode surface. Detector D3 sees only part of the pinch: its bottom border of registration is at 1 cm above the anode plane. It allows: (i) to exclude the hard component of radiation from the anode surface and (ii) to investigate longitudinal dynamics of soft X-ray source. The pin-hole camera, allowing one to produce a two-dimensional image of the X-ray radiation zone, integral in time and in the spectrum, is located at the pos. (4). Additional pin-diode D5 is placed in pos. 5 at the angle of 60° to the system axis through port 7. Similar port (not shown on Fig. 1) was used for installing second pin-hole camera. If in the case of using the pin-hole camera installing in the main detector unit (1) the field of vision is cut by the anode plane, the pin-hole camera at position (5) "sees" the zone below the anode plane within the anode deepening. The example of the pin-hole pictures obtained in the discharge with neon is given in Fig. 2. One can see that the significant part of the pinch is in the conic deepening at the centre of the anode. Moreover, the temporary analysis of signals of pin-diodes D2 and D5 has shown that pinching first takes place in the deepening and only then, due to zipper-effect, pinch occurs above the anode surface (Fig. 2c).

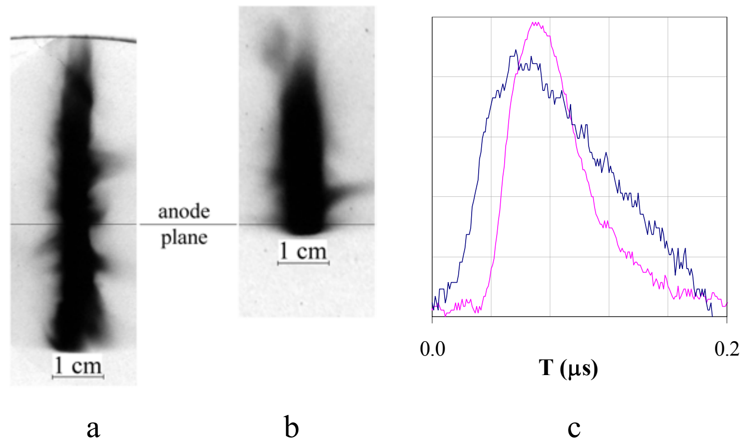

Fig. 2. Pin-hole pictures of the discharge in neon, W=540 kJ, P = 1 Torr: a) port 8 (60°), diaphragm 0.2 mm, filter Be 17 micron; b) port 6 (90°), diaphragm 0.4 mm, filter Be 10 μm and pin-diode signals (c): red beam –detector D2 (90°), blue beam –detector D5 (60°), filter Al 8 μm

By comparison between signals of detectors D2 and D3 (Fig. 3) this effect is also observed.

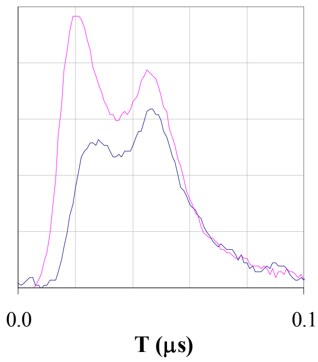

Fig. 3. Signals of D2 (red trace) and D3 (blue trace) detectors.

The analysis of experimental results has shown that influence of hard component of radiation on the indications of detectors D2 is small enough. Therefore these detectors were chosen as basic ones in our further studies. In case of large (~1.5 m) distance from pinch to detector absorption of radiation in working gas is very high. Nevertheless, at the pressure 1 Torr, we recorded reliably lines in the long-wave part of radiation with the grazing incidence spectrograph. A sample of the spectrum in long wavelength area is given in Fig. 4. The spectrum was recorded on the film UF-4 without a filter at the angle of 60° to the system axis. Six shots were done for obtaining this spectrum. The region of the luminescence of the continuum and the spectral lines Ne VIII with the excitation energy from 140 up to 230 eV is clearly apparent. This area is identified with area of maximum compression of plasma, including its possible displacement for 6 shots. It is the area of the hottest plasma. The lines with low excitation energy are visible at the significant distance from the pinch axis. It means that they are radiated by the plasma sheath at the stage of converging to the axis. Almost all lines, emitted by plasma sheath before the moment of PF formation, belong to the lithium - like ions Ne VIII. It is possible also to identify some lines Ne VII. Two of them (the brightest) are indicated on the spectrum. The lines of the ion $Ne6^+$ (Ne VII) with a potential of ionization 207 eV are represented poorly, but there are a lot of lines of the ion $Ne7^+$ (Ne VIII) with a potential of ionization of 239 eV. This fact testifies about higher electron temperature and ionization degree at the sheath position of 2 - 3 cm from the PF axis than it was assumed before.

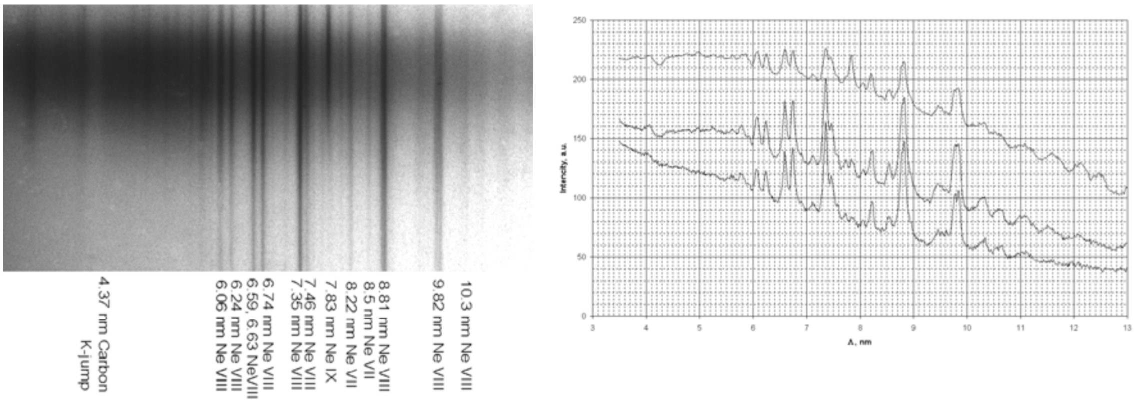

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Fig.4. Spectrogram obtained for 6 shots at P=1 Torr and the spectrograph disposition at 60° to the system axis (a) и densitogram of this spectrum (b); the upper, middle and lower curves show a spectrum on distances 0; 4.5 and 9 mm from the pinch axis, respectively.

A further task was the selection of the optimal pair of filters to single out the long-wave part of the radiation at X-ray registration with pin-diodes. Such an optimum pair is Ag and Al filters. Pin-diode with the filter Ag has high sensitivity in the range of 100 – 350 eV, and the sensitivities of both detectors in the range between 400 eV and 1.5 keV approximately coincide. A difference in the sensitivity at the energy higher than 1.5 keV is a mere detail, since the absence of noticeable radiation in this spectral range has been shown in our previous experiments. So the energy range of interest (100 – 350 eV) can be determined as a difference in the detector indications.

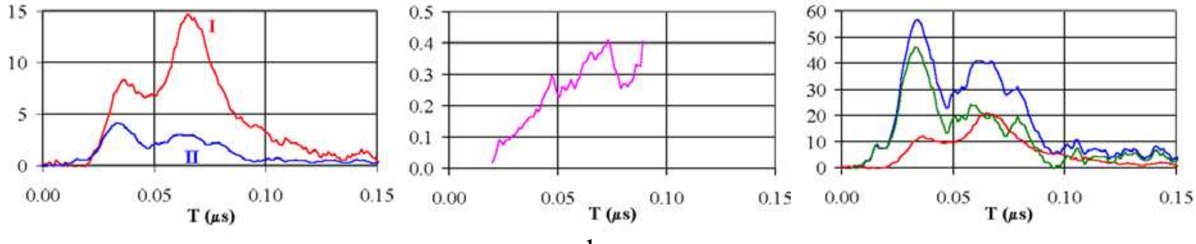

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Fig.5. a) pin-diodes signals: I – filter 8μm Al, II – 0.25 μm Ag ; b) signals ratio taking into account the condition of registration; c) “recalculated” signals: — Al 8 μm ; — Ag 0.25 μm; — signals difference. P=1 Torr of neon, W=160 kJ

On Fig. 5a the traces of pin-diode signals obtained through 8 μm Al and 0.25 μm Ag are given. Two well-pronounced peaks in X-ray pulses are characteristic for operation at 1 Torr and at not very high bank energy. The ratio of the intensity in the first and the second peaks are different. It can be caused by a change of radiation hardness during the discharge. Taking into account the filters absorption and different conditions of registration, it is possible to estimate the change of "effective" energy of radiation in time. It is worth noting the increase of radiation hardness during the pulse (Fig.5b). "Effective" energy of radiation at each instant is lower than 1 keV. This effect can be caused by presence of the long-wave radiation. Results of the signals treatment made with taking into account the conditions of measurements (filter thickness, aperture, attenuating grids etc.) are shown on Fig. 5c. One can see that long-wave radiation makes up a significant part in the total radiation coming to the detector input. The radiation in the range of 100-360 eV makes up to 70 % of the total yield. Precise calculation of energy radiated by the pinch is difficult because of an unknown working gas distribution in the vacuum chamber, which depends, in particular, on plasma sheath dynamics and “snow plough” efficiency.

The experiments with liners (foam liner, wire array) were carried out at higher pressure and bank energy. For these modes of operation one-peak signal is typical. Besides there is a long "afterglow" appears on the signal of the detector with the silver filter. The nature of this radiation is not clear now. Probably, this part of the pulse is caused by the characteristic radiation of the anode material (K_α Cu). In the experiments with liners the share of the long-wave radiation essentially grows (Fig. 6). Duration of the radiation also increases. The front sharp peak on the detector with silver filter is stipulated, apparently, by PCS braking on the foam liner. We have not seen this effect in the experiments with wire arrays. The total output usually is lower than that was obtained in the shots in pure neon. Probably we have a softer spectrum, effectively absorbed in the neon at high pressure.

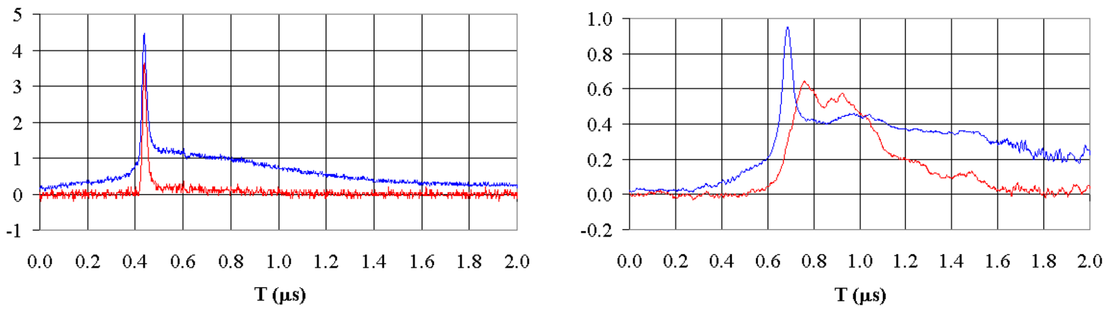

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Fig.6. Pin-diode signals, filters Al 8 μm (red beam) and 0.25 Ag (blue beam): a) without liner, P=3 Torr, W=645 kJ); b) foam liner 0.6 mg/cm, P=3.5 Torr, W=645 kJ

References

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[2] V.I.Krauz, Plasma Phys. Control. Fusion, **48** (2006), B221.