DIAGNOSTICS OF PULSED PLASMA-ION STREAMS EMITTED FROM RPI-TYPE DEVICES

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Abstract - The paper presents different diagnostic techniques designed for time-integrated and time-resolved measurements of pulsed plasma-ion streams produced by Rod Plasma Injector (RPI) devices and other plasma guns. Particular attention is paid to special Faraday-type single- and double-probes, which have been developed recently. Such probes have appeared very useful for studies of pulsed plasma streams produced in different facilities, ranging from various RPI devices to different Plasma-Focus (PF) machines. Simultaneously with the probe measurements, there were also performed some optical studies by means of a spectrometer (for time-integrated measurements) and monochromator-pmt sets (for spectrum- and time-resolved studies).

1. Introduction

The Rod Plasma Injector (RPI) facilities [1] are intense sources of ion and electron streams. In the 80s there was noticed that at the deuterium filling for long delay times an average neutron yield (Y_n) rises several times. At the same time, using a Thomson-type mass-spectrometer, it was observed that an average value of deuteron energy is relatively low, e.g. it amounts to a few keV only [2]. Soft X-ray pictures of RPI discharges, which were taken under such experimental conditions by means of an X-ray pinhole camera equipped with a 10-μm-thick Be-filter, revealed the appearance of a spherical plasma structure formed close to the electrode outlet [2]. In those cases the plasma discharges did not emit high-energy X-rays, which appear at short delay times.

An increase in the neutron yield at the long delay times could be caused by: 1^0 – a considerable rise of the local plasma concentration, 2^0 – the achievement of the local thermal equilibrium (LTE) state within the produced plasma structure. In the first case strong electric fields (due to charge polarization) could appear locally, and they should form sources of high-energy ions (deuterons). Such energetic ions should be easily detected, but in the investigated discharges they were not registered. It means that the second case was more probable. The main aim of this work was to explain this phenomenon.

2. Experimental setup

To perform experimental studies the use was made of the IBISEK facility [3], which was equipped with an RPI-type plasma gun powered by a 12 kJ, 30 kV, condenser bank. The working medium was nitrogen injected by a fast-acting electromagnetic gas-valve placed on the z-axis. The measurements of ions have been performed mostly with active Faraday-type probes located at different angles to the z-axis and at various distances from the electrode outlet. Kinetic energy of ions was estimated by means of a time-of-flight (TOF) method. The measurement basis was a distance between two collectors of a special double-probe of the Faraday type [4].

In order to perform spectroscopic measurements the use was made of an optical spectrograph of the ISP-51 type, and a YM-2-type monochromator equipped with a fast XP-

2020 photomultiplier. The optical equipment was placed side on the main experimental chamber. The arrangement of the system is shown in Fig.1.

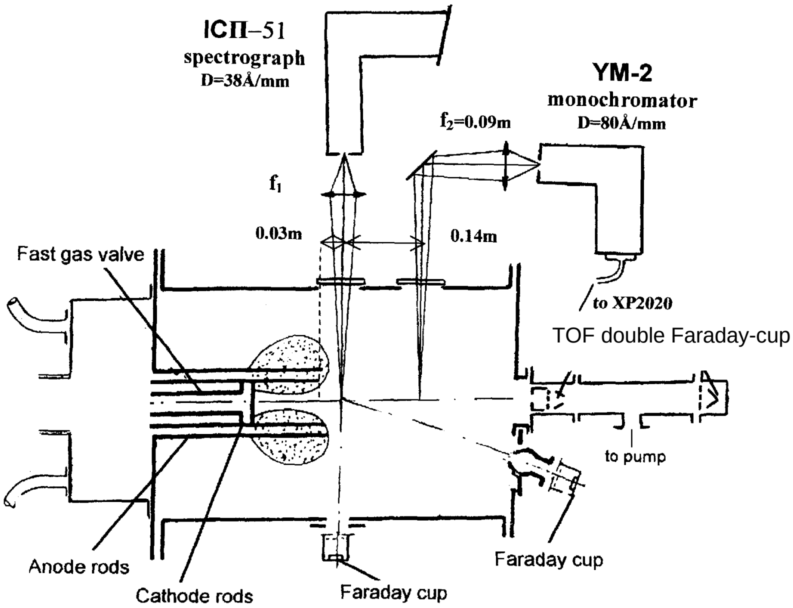

Fig.1 Scheme of the IBISEK experimental facility equipped with different Faraday-type detectors, an optical spectrograph, and a monochromator coupled with the photomultiplier.

3. Experiment

The experimental investigations were carried out mainly for the high-pressure mode, observed for relatively long time delays (τ) between the injection of the working gas (nitrogen) and the application of a HV pulse. In the experiments described below the τ value was changed within a range from 200 μs to 300 μs. Under such conditions, the nitrogen ions were single-ionized and their kinetic energy was about several keV, but plasma achieved the LTE state, due to its relatively high density. For a comparison, there were also performed experiments with pure hydrogen. An example of a voltage waveform and the ion signals from different Faraday cups has been presented in Fig.2.

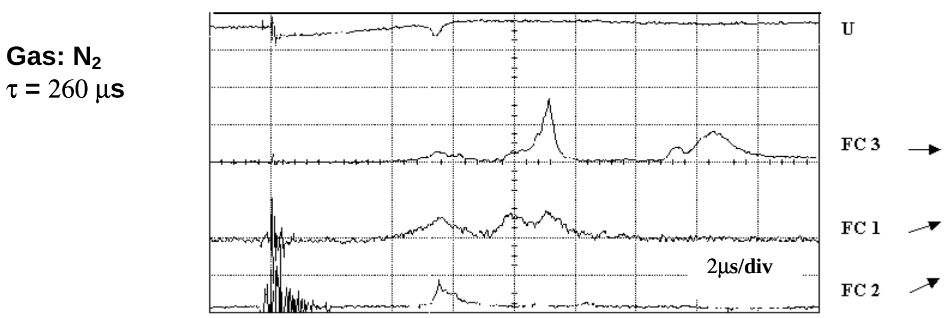

Fig.2. Typical high-voltage waveform (U) and the ion signals (FC), which were registered for a discharge performed within the IBISEK facility with the N_2 - filling and τ = 260 μs.

The voltage value (U) was measured between the main collector plates. The double Faraday-type probe (giving FC1 and FC2 signals) was placed at a distance of about 70 cm from the multi-rod electrode outlet, and it was oriented at an angle of 15^0 to the electrode axis. The single Faraday cup (giving FC3 signal) was placed also at the distance of 70 cm, but it was adjusted along the z-axis. It was assumed that for the investigated experimental conditions, within a plasma stream at a distance of 70 cm from the electrodes there appear single-ionized nitrogen ions only. Under that assumption the first distinct maximum, as observed after an UV-induced peak (correlated with the over-voltage signal) in the FC3 waveform, corresponds to N^{+1} ions of energy equal to E_i = 3 keV. It should be noted that the corresponding maximum in the FC1 waveform was several times lower, i.e. the ion stream was directed mainly along the z-axis.

For a comparison there were also performed discharges with the working gas, which was a mixture of 90% nitrogen and 10% hydrogen. In addition to ion signals there were also registered optical signals showing to the emission of selected NII lines. Corresponding traces have been presented in Fig.3.

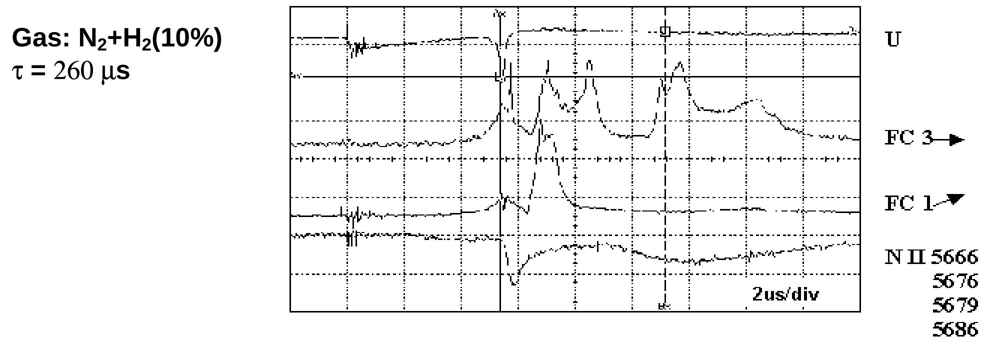

Fig.3. High-voltage waveform (U) and the ion signals (FC1 and FC3), which were registered for a single discharge performed within the IBISEK facility with a gas mixture (N_2 + H_2). The lowest trace corresponds to intensity of four NII lines.

On the basis of a comparison of the FC3 and FC1 signals in Figs.2 and 3 one can easily observe a considerable difference in behavior of the investigated plasma-ion streams. It was estimated that in Fig.3 the first two distinct peaks (after the UV peak) of the FC3 signal corresponded to protons of kinetic energy E_i = 14 keV and 1.2 keV, respectively. The other peaks, alike as in Fig.2, corresponded to nitrogen ions. For those ions the values of kinetic energy were comparable with those obtained from pure nitrogen discharges.

It should, however, be noted that in the FC3 trace one could also observe a narrow peak about 200 ns after the over-voltage and the UV peaks. It was estimated that the over-voltage value was then about 60 kV, and the narrow ion peak could be identified with very energetic protons. A small FWHM value of that peak and its absence in the FC1 signal suggest that under the investigated experimental conditions the plasma-ion stream had a beam-like character, and it was well focused along the z-axis. The appearance of relatively low-energy (1.2 keV) protons suggests that some heating of the ionized gas mixture could occur, probably during later phases of the investigated discharge. One should, however, note that the hydrogen ions could be partially thermalized (and observed at an angle of 15^0 to the z-axis), while the nitrogen ions were emitted mainly along the z-axis. Otherwise, one can say that the nitrogen ions behave like a focussed beam.

Simultaneously with the Faraday-probe measurements described above, there were also performed additional spectroscopic studies with the optical spectrometer (for time-integrated observations), and by means of a monochromator-photomultiplier set (for spectrum- and time-resolved measurements). Particular attention was paid to heavy impurity ions originated mainly from the electrode rods. The time-resolved measurements were carried out behind a slit placed at the plane z = 14 cm (from the electrode ends). Since the molybdenum rods were used within the electrode set, there were observed MoI neutrals and MoII ions. From the measured MoI and MoII radiation it was possible to estimate velocities of the investigated ions. Some results have been presented in Fig.4.

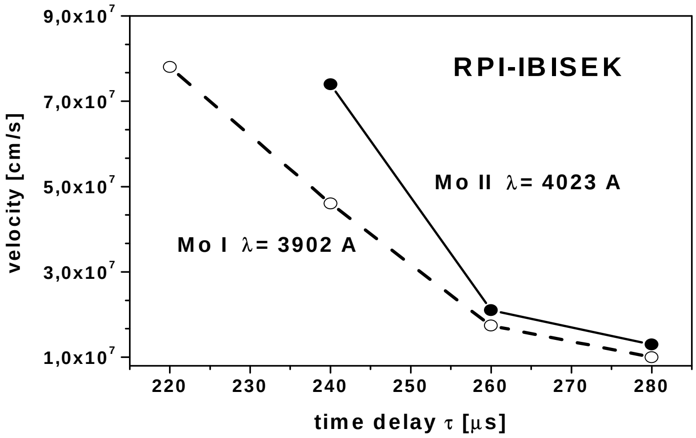

Fig.4. Velocity of the MoI neutrals and MoII ions as a function a time delay (τ) value, as measured within the IBISEK facility.

It can be seen that at a time delay τ = 260 μs the velocities of the two observed components were almost identical. It could be interpreted that under the determined experimental conditions the charge equilibrium was achieved, and plasma-ion streams motion was determined mainly by laws of ballistics.

4. Summary

The most important results of this work can be summarized as follows:

- Capabilities of the described diagnostic techniques have been illustrated by results of the recent experimental studies carried out within the IBISEK facility;
- It has been demonstrated that under the determined experimental conditions the RPI-type facility can produce plasma-ion streams within the LTE state;
- It was also shown that, when a mixture of different gases is used, each component can behave in a different way, and the LTE state can be achieved relatively easily when light gases (hydrogen or deuterium) are applied.

References

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