Powerful X-ray plasma radiation as a result of high-energy plasma flows collision

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1. Introduction

One of the possible applications of pulsed plasma accelerators [1] is the creation of the X-ray sources on the base of such accelerators and subsequent utilization of this radiation for various scientific and technical applications. The first results obtained in the experiments on the head-on collision of two powerful plasma flows formed by electrodynamics coaxial accelerators with a pulsed gas injection were presented previously [2, 3]. After exiting the accelerators, the plasma flows moved with velocity of $(2\div4)\times10^{7}$ cm/s in a longitudinal magnetic field 1÷2 T towards each other and collided in the center of the vacuum interaction chamber. The ion density of the plasma flows was $(2\div4)\times10^{15}$ cm^{-3}, and the electron temperature was several eV. Quasistationary plasma formation was produced inside the interaction cylindrical chamber as a result of the flows collision, and the essential part of the flows kinetic energy was converted into the plasma thermal energy. As the main part of the flows kinetic energy was enclosed in the ion kinetic energy therefore the ion temperature achieved several keV in the collision zone [4].

Main results of the previous investigation [2, 3] can be stated as follows:

- in experiments with various plasma-forming gases the total radiation energy emitted by quanta with an energy of more than 100 eV, was up to 2 kJ in the case of neon with deuterium mixture and up to 10 kJ in the case of nitrogen. The pulse duration was 10÷15 mcs in both cases;
- in the experiments with the neon-deuterium mixture most energy radiated from the collision region of the plasma flows falls on the 9.8 nm and 8.8 nm lines of Li-like neon ions and the 1.34 nm line of the He-like neon ions. In the experiments with nitrogen as the plasma-forming gas most part of the energy was highlighted from the collision zone by resonant lines of He- and H-like nitrogen ions (wavelengths of 2.88 nm and 2.48 nm, respectively);
- by comparing the experimental and calculated data on the spectral distribution of the line radiation of multiply charged ions, it was found that in the case of the nitrogen plasma its electron temperature in the central part was 120 eV, as in the case of neon-deuterium plasma – 160÷170 eV. The plasma electron density in the collision zone was at the level of $10^{16}\div10^{17}$ cm^{-3}.

The paper presents some additional results concerning the plasma heating dynamics in the flows collision zone. The data were obtained with the help of magnetic probes and X-ray detectors.

2. 2MK-200 facility

The experiments were carried out at 2MK-200 facility [2–6]. It consists of two coaxial pulsed plasma accelerators and a cylindrical vacuum chamber, in which a longitudinal magnetic field 1÷2 T is creating by multi-turn solenoids. Each accelerator is powered by the bank of capacitors with the 1080 μF value. The bank charge voltage varied in the range of 20÷23 kV, which corresponded to the change in the initial energy storage in the range of 216÷260 kJ.

Absolute measurements of the X-ray plasma emission intensity were performed with 0.02 mcs time resolution using FDUK-8UVSK photodiodes developed at the Ioffe Institute (St. Petersburg, Russia). The known spectral sensitivity of the diodes in a wide wavelength range [7] makes it possible to perform absolute measurements with an accuracy of better than 10%.

Three magnetic probes were placed near the inner wall of the vacuum chamber. Two of them were at a distance of ±40 cm from the central section of the chamber where the third probe was located. The probes data enabled to estimate parameters of plasma flows and of the plasma created as the result of flows collision.

3. Experiments results for the plasma flows collision of different ion composition

The data of magnetic probes, as already discussed in [3], allows us to estimate the size of the plasma formation, its internal energy and dynamics. Particularly, these data allowed to conclude that as a result of the interaction and thermalization of the colliding plasma flows, a plasma formation of at least 80 cm long and about 18 cm in diameter was created inside the vacuum interaction chamber. The characteristic lifetime of the plasma column was 15÷20 mcs.

In this report we present the signal correlation analysis of magnetic probes and X-ray detectors signals during plasma flows interaction. These detectors were located in the central section of the vacuum chamber. The signals of magnetic probes characterized the formation of plasma in the collision zone, while the X-ray signals characterized the heating of its electronic component. Figures 1A and 1B show signals of magnetic probes and photodiode signals recorded behind varying thickness filters in experiments with a mixture of neon and deuterium (partial pressures of 75% and 25%, respectively) and pure nitrogen as working gases. As we can see, in the first case, the signals of the probe and X-ray detectors begin almost simultaneously, whereas in the second case, the delay of X-ray signals reaches 4÷5 mcs.

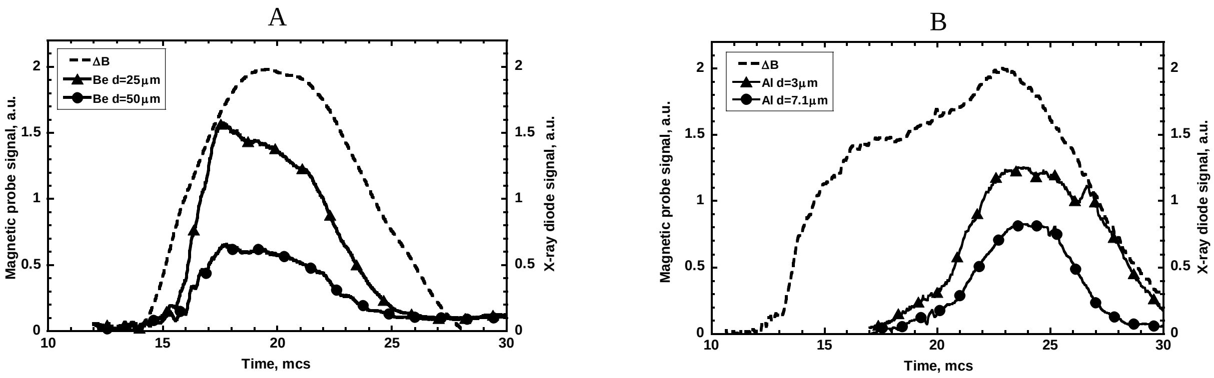

Fig.1 The signals of the magnetic probe and x-ray detectors, recorded in experiments with a mixture of neon and deuterium (A) and nitrogen (B) as working gases. The materials and thickness of the filters used are indicated in the figures. In case (B), the signal amplitude behind a thicker aluminum filter is increased by a factor of 7.2 for the convenience of presentation. The time is counted from the moment the accelerators start.

The material and thickness of the filters used provided almost complete absorption of line radiation of multiply charged ions, which allowed the filter method [8, 9] to determine the time course of the electron temperature during the interaction of the plasma flows and a thermalization of their directed kinetic energy (see Fig. 2A and 2B) . It is noteworthy that in the region of their maximum values, the plasma electron temperature in both cases changes insignificantly (within the accuracy of measurements) in the time interval 6÷8 mcs, i.e. the plasma behavior is characterized as quasistationary. Note that the electron temperature of the neon-contained plasma determined in that way slightly exceeds the value obtained by the X-ray spectral method [3], while in the case of a nitrogen plasma, the divergence of these values is more significant.

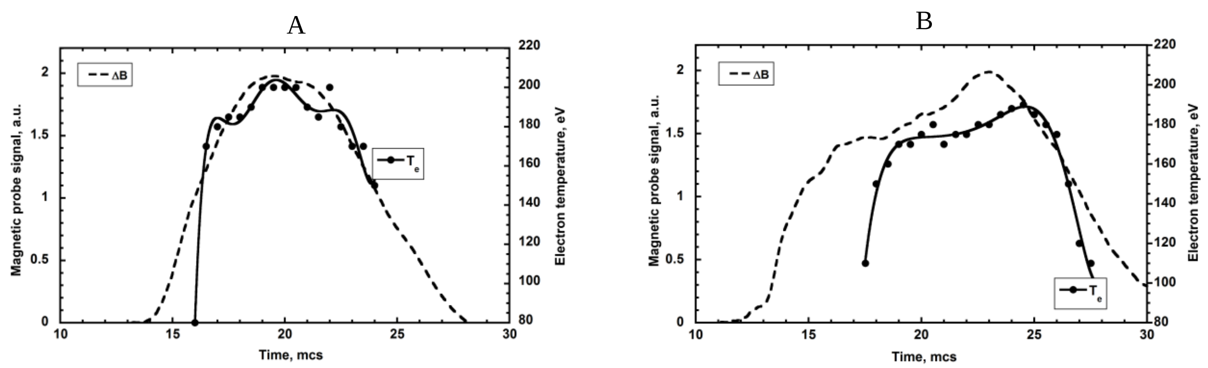

Fig. 2. The time dependence of the electron plasma temperature determined by the filter method in experiments with a mixture of neon and deuterium (A) and nitrogen (B) as working gases. The error in determining the temperature is ±15%.

So, we see that in the experiments with a mixture of neon and deuterium, the plasma formation as a result of flows collision is characterized by an almost simultaneous increase of its density, ion and electron temperature. In the case of the interaction of nitrogen fluxes, the onset of plasma electron temperature lags significantly (by 4÷5 mcs) from the beginning of the magnetic probe signal, i.e. in this case, the ion temperature and the plasma density primarily increase. Currently, it is planned to conduct new experiments to find out the reason for such a difference in the behavior of the electron plasma temperature.

4. Conclusions.

The data of magnetic probes were used to obtain the information on the dynamics of the energy content of the plasma bunch formed in the collision of high energy flows.

The time dependence of the electron temperature of the plasma formed in the central zone of the oncoming collision of high energy nitrogen and neon-contained plasma flows was determined. It was shown that in both cases, in the time interval of 6÷8 mcs, the temperature changes insignificantly: in nitrogen plasma – 160÷180 eV, in neon-containing plasma – 180÷200 eV. Thus, the state of the plasma in the zone of flows collision is characterized as quasistationary.

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9. The special program was used to determine the plasma electron temperature. The program was created by I.K. Fasakhov, for which the authors are sincerely grateful.