Plasma Focus as a lens for intense ion beam focusing

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Abstract Experimental investigations were performed to evaluate the focusing properties of the plasma focus for high-energy intense ion beams manipulating. Magnetic probes and optical spectroscopy were used for temporal and spatial plasma geometry investigations. Ion beam portrait was determined at the luminescence screen. In the experiments performed, the focusing coefficient was obtained as the ten times beam compression at the 30 cm length. By variations of the gas volume input, gun voltage, time delay, magnetic field value etc. the dependence of focused ion beam diameter upon various parameters of the plasma focus lens has been investigated. It was revealed that the main focusing effect was caused by the azimuthal magnetic field of the currents carried by the plasma.

Key words intense MeV proton beam accelerator • plasma focus • plasma lens

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Introduction

Some fundamental problems of high energy physics (beam emmitance decrease and luminosity enhancement in TeV-colliders) and technological applications (nuclear microprobe, material modification) challenge the elaboration of nonconventional schemes for ion beams focusing with the use of plasma, especially for intense beams with space charge repulsion [1–3]. In the present work, it is proposed to use a coaxial plasma source (CPS) for focusing of ion beams in the wide range of energies and currents. The current between the inner and outer electrodes leads to the creation of a large azimuthal magnetic field. This field causes plasma focusing and the formation of the so called plasma focus. Azimuthal magnetic field of the current in this plasma formation may be used for focusing of ion beams of high energy. Theoretical and experimental investigations of the focusing processes of intense ion beam of MeV energy range by means of the plasma focus have been carried out. Proton beam was produced by a proton accelerator "Ural-5" that provided an intense beam current due to the radio frequency quadruple radial-phase focusing. A plasma lens was formed during the plasma focus formation in a coaxial plasma gun and the plasma flow penetrating into magnetic field of a short coil.

Experimental set-up and diagnostics

The installation is shown in Fig. 1. The accelerator "Ural-5" generates a proton beam of energy 5 MeV with a pulsed beam current of 100 mA (in experiments 10–30 mA), pulse duration 10 μs, and modulation frequency 148.7 MHz. A coaxial plasma source consists of copper

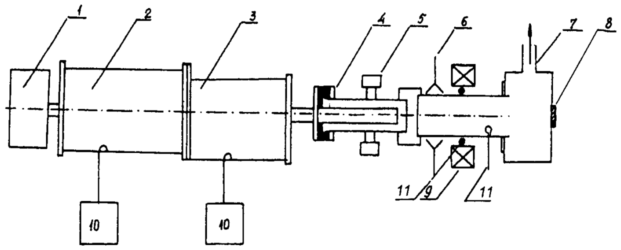

Fig. 1. Scheme of the installation. (1) proton injector; (2) initial stage of accelerator; (3) final stage; (4) plasma gun; (5) gas valve; (6) horn antenna; (7) chamber; (8) luminescent screen; (9) solenoid; (10) RF sources; (11) magnetic field probes.

electrodes of length 40 cm and of inner and outer diameters 30 and 70 mm, respectively. The voltage at the electrodes was supplied with a battery of capacitors (30 μF, 15 kV), using a vacuum switcher. The parameters of the plasma were the followings: plasma density 10^{11}–10^{15} cm^{-3}, temperature 1–3 eV, and time duration 500 μsec. The proton beam moved through the hollow internal electrode (with the hole diameter equal to 25 mm) into a glass chamber of length 50 cm and 10 cm in diameter. The longitudinal external magnetic field 500–1000 Oe was created by a coil of length 15 cm and inner diameter of 18 cm. Plasma diameter at the exit of the plasma source, propagation velocity of plasma formation, and longitudinal and radial distributions of the azimuthal magnetic field of the plasma source current were determinated with the use of magnetic probes, 3 mm in diameter and a spectrograph ICP-51. The value of beam current and the changes of its diameter were measured by a double Faraday cylinder (the diameter of outer cylinder was 4 cm, the diameter of inner cylinder was 1.6 cm) and by a luminescent screen.

Experimental results

Variations of plasma diameter and the value of amplitude of the azimuthal magnetic field B_φ, measured at a distance of 3 cm from the plasma source exit in dependence on the electrode voltage, are shown in Fig. 2. These data were obtained with the use of magnetic probe, placed at the boundary of plasma formation, determined by a maximum amplitude of B_φ for each voltage at the electrodes. The control point on the curve corresponds to plasma diameter at the electrode voltage U=6 kV, which was determined from the Stark broadening of hydrogen lines H_β and H_γ. From

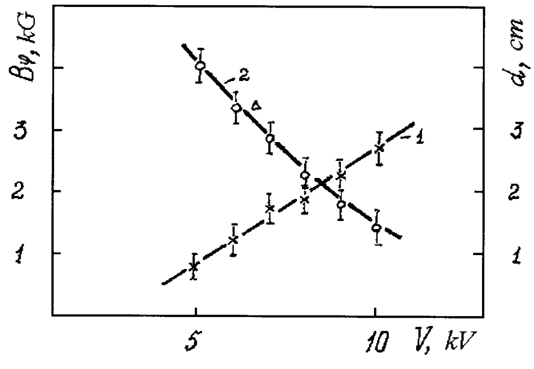

Fig. 2. Dependence of the azimuthal magnetic field Bφ (1) and plasma diameter *d* (2) at the distance of 3 cm from the end of the plasma source upon the electrode voltage.

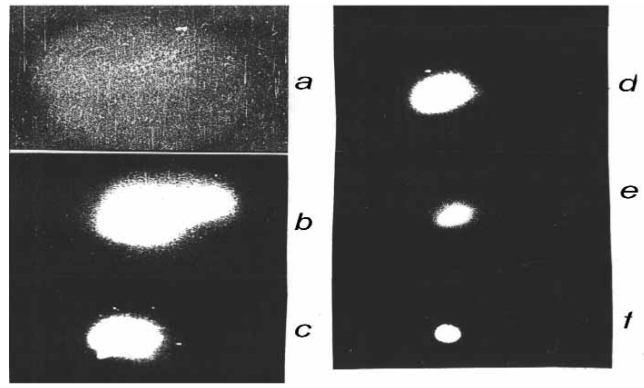

Fig. 3. Photos of beam diameter in the absence of plasma (a) and after beam passing through the plasma for different voltages on electrodes of plasma source: b - U = 5 kV, c - U = 6 kV, d - U = 7 kV, e - U = 8 kV, f - U = 9 kV.

the probe data, it was concluded that the plasma formation was of the type of hollow cylinder near the end of the plasma source and of the type of solid cylinder at a distance longer than 2 cm. It was found that by increasing the voltage at CPS electrodes from 5 kV to 10 kV the plasma diameter decreased from 4 cm to 1.5 cm, respectively.

The beam portraits obtained on the luminescent screen by bombardment with a proton beam of energy 5 MeV are shown in Fig. 3 for different voltages at CPS electrodes. At the beam portrait in the absence of plasma is shown in Fig. 3a. The luminescent screen and Faraday cylinder were placed at the same distance from the end of the plasma source. One can see from Fig. 3 that for the voltage at the electrodes U_d=9 kV, the focusing coefficient, defined as the ratio of beam diameter in the absence of plasma to the beam diameter after passing through the plasma, is $K=d_1/d_2\approx10$. It is equal to the ratio of the currents for these two cases, measured by the Faraday cylinder of a small diameter.

Summary

From the experimental results on the focusing of high-energy (5 MeV) intense (10–30 mA) proton beam by the plasma focus of the coaxial plasma source one can conclude that this plasma configuration serves as an effective plasma lens for intense ion beams focusing.

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