PLASMA LENS OF THE ITEP HEAVY ION ACCELERATOR*

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Abstract

The problem of focusing of intense heavy-ion beams is an important issue for investigating high energy densities in matter. Application of a plasma lens to this area of research has a number of essential advantages in comparison with the traditional system on the basis of quadruple lenses. At ITEP the plasma lens has been designed and installed into the exit channel of the TWAC accelerator complex. The description of the plasma lens and the results of the first experiments with this lens are reported.

INTRODUCTION

An experimental facility for investigation of the physics of high energy densities in matter is being created at ITEP on the basis of the accelerator-accumulator complex TWAC (Terawatt accumulator) [1]. A plasma lens is planned to be used as the last stage of the TWAC focusing channel. The ion beam focusing in the plasma lens is carried out as shown in Fig.1.

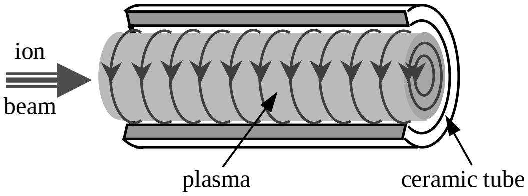

Figure 1: Ion focusing in a plasma lens.

The discharge current produces an azimuthal magnetic field. Ions are injected along the lens axis, and the radial Lorentz force focuses the ion beam. The main advantage of a plasma lens as compared to the quadrupole lens is that the focusing forces correspond to magnetic field strength in the first order of its magnitude for the two axial coordinates simultaneously. Besides, there is no limitation for field magnetizing force connected with iron firing; neutralization of spatial beam charge takes place inside the lens; by heavy ions focusing the beam rigidity decreases because of ion stripping in plasma. The direct experimental observations of heavy ion focusing at GSI on the SIS-18 accelerator have been carried out in 1994-1997 [2]. The beam of neon (Ne^{10+}) ions with the energy of 300 MeV/amu has been focused onto a spot with a diameter of ~300 µm at lens currents of up to 350 kA.

DESIGH OF PLASMA LENS

In accordance with the principal goals of this project, the following activities have been undertaken [3]. A pulse-power generator (Fig.2) has been developed withtwo unheated thyratrons (pseudospark switches) TDI1-150k/25 and a stable discharge with a current of up to 250 kA and duration of 5 µs was achieved in the discharge tube of the plasma lens. The usually used scheme of high-current generator in the lens is a LC-chain with a high-current commutator. The time dependence of the current in the plasma lens has a form of relaxation oscillations. Oscillating character of the current reduces resources of the lens commutator and the discharge tube. The difference in the scheme is that it includes a permalloy inductor to receive unipolar pulses. During the discharge the inductor has a very low inductance for the direct polarity of the current, while for the current in the opposite direction the inductance becomes so high that the current is practically stopped.

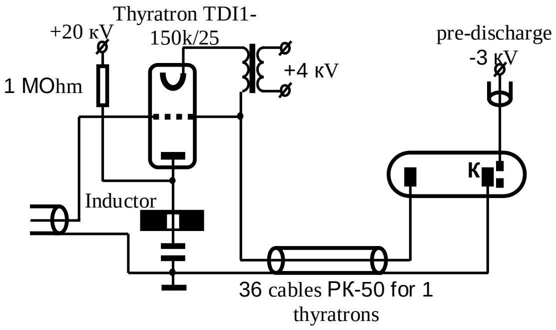

Figure 2: Scheme of current generator for plasma lens.

Figures 3, 4 show the pictures of the constructed plasma lens. The principal supporting element is a solid

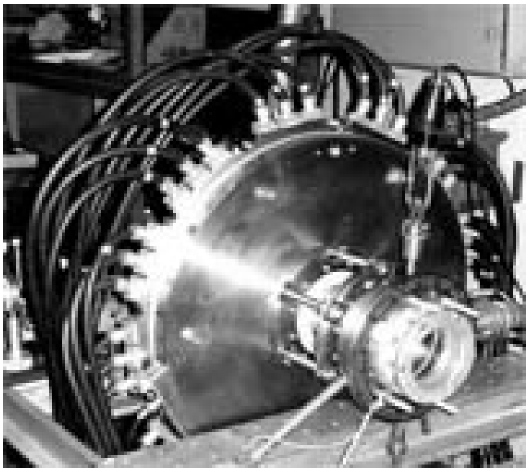

Figure 3: The plasma lens on the test bench.

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disk of stainless steel. On one side it is adjoined by a current receiving unit, which collects the current cables. On the opposite side, the anode-cathode unit is sitting, which has a gas-discharge ceramic tube (diameter 20mm, length 100mm), placed between two graphite electrodes.

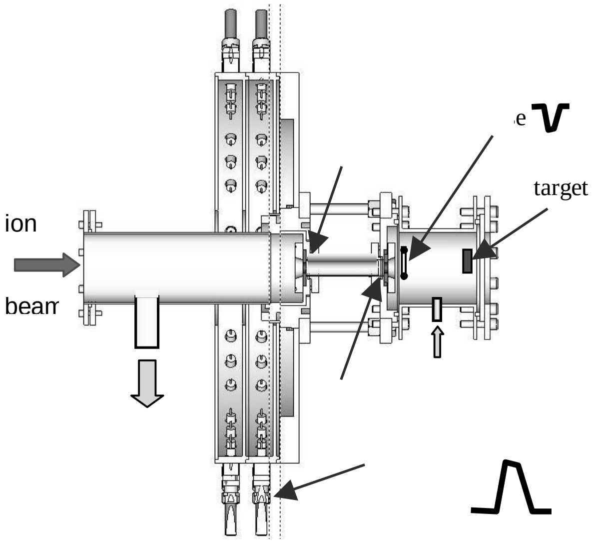

Figure 4: Scheme of plasma lens.

Pre-ionization of the working gas is used to stabilize the discharge ignition. For this purpose, a ring electrode is placed into the pre-cathode area. A negative pulse with a voltage of 3 kV is applied to the ring electrode 3 µs before the discharge.

Fig.5 shows the signal from the current transformer, which depicts the discharge process in the plasma lens with the current amplitude of 200 kA. The middle curve shows variation of the pre-ionization voltage. The lower curve shows variation of the discharge voltage

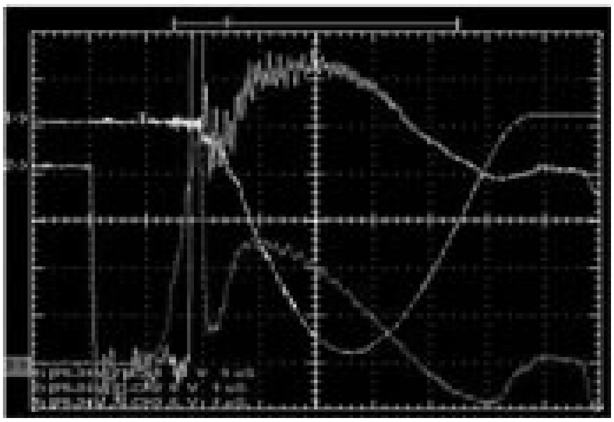

Figure 5: Oscillograms of the discharge current and voltage together with the pre-ionization pulse in the lens.

EXPERIMENTAL STUDY AND SIMULATIONS OF THE LENS PERFORMANCE

A set of optical diagnostics, which do not perturb the lens plasma, is used to investigate the process of discharge pinching, to study the temporal behavior of the electron density and its spatial distribution. Investigation of the discharge structure and dynamics was carried out by measuring the plasma luminescence in the direction transverse to the discharge axis with the help of an electron-optical image intensifier in the slit scanning regime. The results of time scanning of the plasma luminescence and the cross-section size at a discharge current of 200 kA are shown in Fig.6.

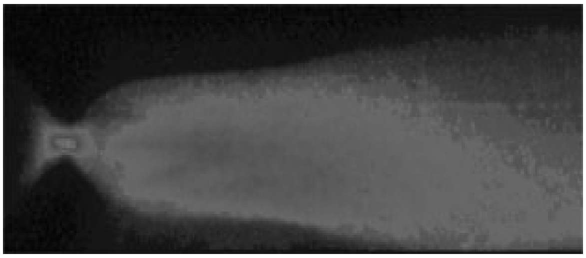

Figure 6: Time scanning of plasma luminescence at argon initial pressure 3.5 mbar and discharge current 200 kA (full length – 6 µs, cross section size – 2 cm).

The second maximum of the discharge voltage (lower curve in Fig.5) corresponds to the moment of maximum compression of the discharge plasma.

To elucidate the key physical processes, which govern the plasma dynamics and the current density distribution inside the discharge tube, a series of model numerical simulations with the one-dimensional MHD code NPINCH [4] have been carried out. Different models have been tried for plasma interaction with ceramic walls of the discharge tube. It was found that a qualitative agreement with the experimental data can only be achieved when evaporation of the wall material is taken into account. Visible expansion of the discharge region can be explained as a result of collision of the wall plasma with the central argon pinch. The simulations show (fig. 7) that the two plasma parts carry over comparable portions of the total discharge current.

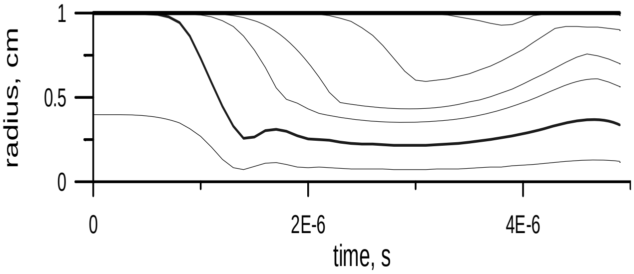

Figure 7: Trajectories of radial plasma motion (the interface between the argon and the wall-material plasma parts is shown as a thick blue line).

EXPERIMENTS AND RESULTS

The plasma lens has been installed into the exit channel of the TWAC accelerator complex (Fig.8), and its testing began by focusing of a carbon ion beam. The beam spot was observed by using a quartz scintillator. The emitted scintillator light was monitored by using CCD framing photography. As one of the first results, for a C^{+6} beam with the ion energy 200 MeV/a.u.m., a minimum focal spot diameter of 350 µm FWHM mhas been measured at a target distance of 50 mm from the end of the discharge tube (Figs. 9, 10 and 11). These results yield an emittans by 40 mm mrad.

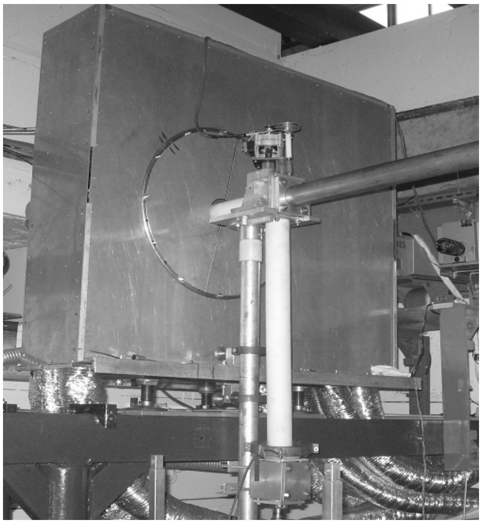

Figure 8: The plasma lens.

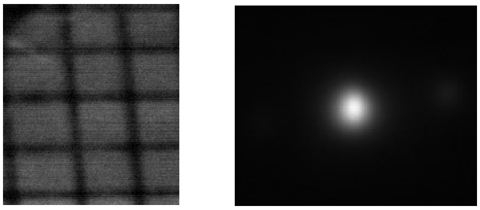

Figure 9: Beam spot photography (grid spacing –1mm).

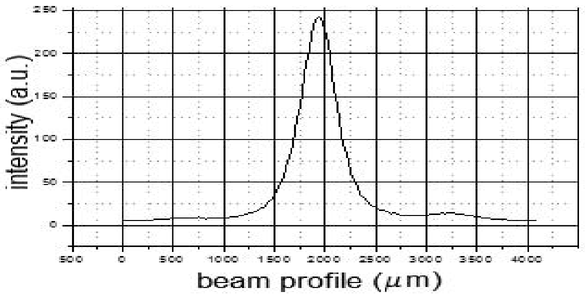

Figure 10: The transversal profile of the focused beam.

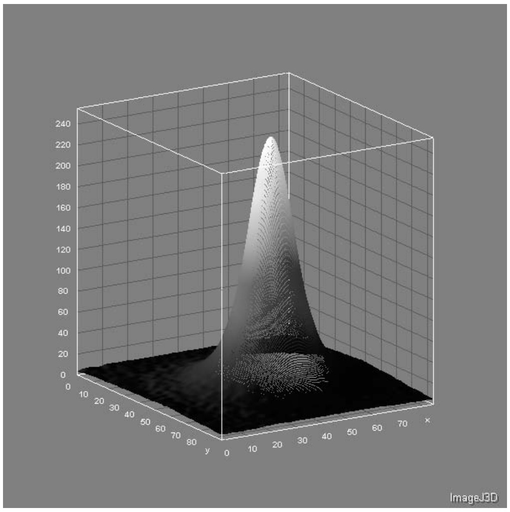

Figure 11: The two-dimensional beam profile.

The lens parameters were as follows: capacitance - 24 µF, discharge current - 150 kA, current half-wave - 5 µs, argon pressure - 3 mbar. Ion beam current pulse length – 800 ns.

CONCLUSION

At present time the plasma lens has been designed and fabricated. Study of dynamics of the space-time behavior of the plasma discharge has been started. Investigation of plasma discharge formation has been conducted and the range of parameters has been determined where the spatial distribution of the current density is homogeneous. The accomplished investigation of the lens performance allows transition to the next stage of optimization efforts aimed at reaching the required focusing ability of the plasma lens. Systematic lens testing has begun by focusing of carbon ion beams.

Even in the first test shots we were fortunate to demonstrate the focal spots that are close to those of the pioneering work at GSI on the SIS accelerator.

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