PLASMA LENS INVESTIGATION FOR THE HEAVY ION ACCELERATOR AT ITEP

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Abstract

The problem of transportation and focusing of an intense heavy-ion beam is an important issue for heavy ion driven inertial confinement fusion and for investigating high energy densities in matter produced by heavy ion beams. 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. The description of the plasma lens and the results of the first experiments with this lens, designed for the heavy ion accelerator-accumulator facility TWAC-ITEP, are reported.

INTRODUCTION

An experimental device for physics investigations of high energies densities in matter is being created at ITEP on the basis of the accelerator-accumulated facility TWAC-ITEP [Terawatt accumulator][1]. When TWAC-ITEP reaches planned parameters, it will be possible to accelerate heavy ions up to ~0.7 GeV/nucleon and to accumulate them in quantity up to $\sim 10^{13}$ particles with further beam compression in time to 10^{-7}s. A plasma lens is planned to be used as the last stage of TWAC channel focusing.

The main advantage of the plasma lens in comparison with the quadrupole lens is that 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 to iron firing; neutralization of spatial beam charge takes place inside the lens; heavy ions focusing the beam rigidity decreases essentially because of ions peeling in plasma. Plasma lenses intensive investigations and elaboration started in the middle of 70-es last century [2]. Theoretical models of focusing of charged particles in the plasma lens have been developed [3,4]. The direct experimental observations of heavy ion focusing at GSI on SIS-18 accelerator have been carried out in 1994-1997 [5,6]. 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..

THE FOCUSING SYSTEM FOR A HEAVY ION BEAM BASED ON PLASMA LENS

The ion beam focusing in the plasma lens is carried out as shown in Fig.1. The discharge current produces an azimuthal magnetic field. Ions are injected along the lens axis, and the radial Lorentz force results in focusing of the ion beam.
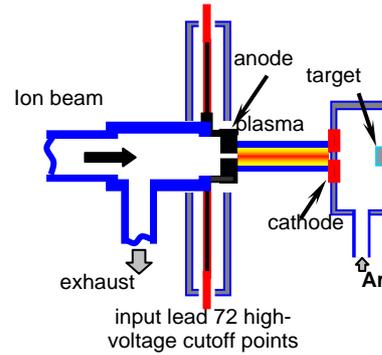
Figure 1: Scheme of the plasma lens for TWAC-ITEP.

There is a relationship $d_{min} \sim \varepsilon I^{-1/2}$ between the beam diameter d in the focal plane of the lens, the beam emittance ε, and the current in the lens I. The dependence of the spot radius of the focused ion beam on the discharge current is shown in Fig.2. To obtain high compression ratio of the beam, it is necessary to get currents of several hundreds kiloamperes.
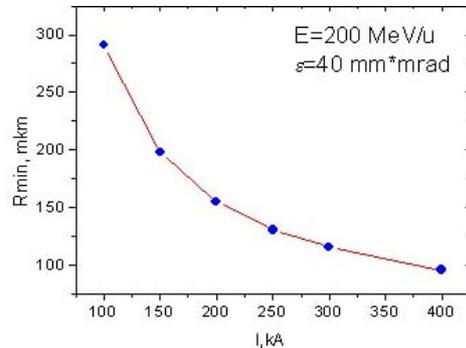
Figure 2: Dependence of calculated focal spot radius on discharge current in the lens.

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. Thyratrons TGI-2500/50 are used as commutating elements in the elaborated plasma lenses. The difference in the scheme is that it includes a permalloy inductor to receive unipolar pulses (Fig.3). 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.
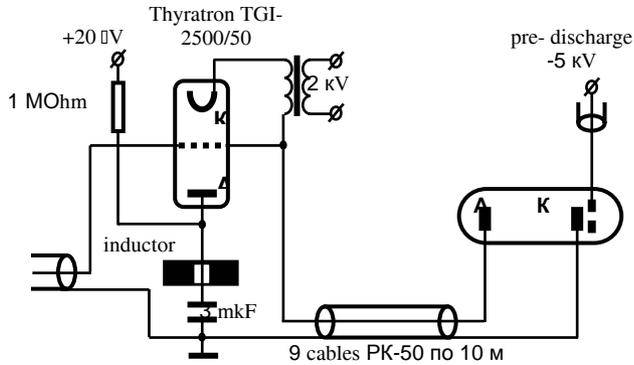
Figure 3: Scheme of current generator for plasma lens.

The preliminary magnetization of the inductor is performed by alternating current with the frequency 50Hz and amplitude up to 100A. 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 5-10 kV is applied to the ring electrode 5 μs before the discharge.

Test of the power supply system, which includes 8 thyratrons, was performed on the plasma lens model (Fig.4.).

Figure 4: Picture of the plasma lens on the measuring stand.

Pulse gas discharge (z-pinch) of the ITEP lens is executed in a ceramic tube (diameter 20mm, length 100mm), which is placed between the electrodes made of radiation-resistant graphite. The system generates current pulses 5μs long with amplitude 10kA for 1kV of charging voltage. The limiting value of the current is determined by the thyratron lifetime. A lifetime of $\sim 10^5$ pulses corresponds to a current of ~ 30kA from one thyratron, and a lifetime of $\sim 10^4$ pulses corresponds to ~ 40kA. Thus, the system of 8 thyratrons could supply the plasma lens with a current of 250-300kA during long period of work. Fig.5 shows the signal from the Rogovski belt, which depicts the discharge process in the plasma lens with the current amplitude of 200kA. The middle curve shows variation of the pre-ionization voltage. The lower curve shows variation of the discharge voltage.
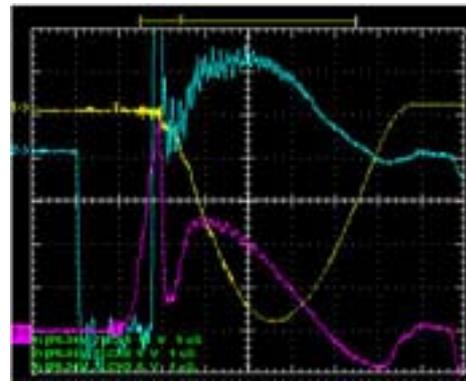
Figure 5: Oscillograms of the discharge current and voltage together with the pre-ionization pulse in the lens at a pressure of 3.5mbar.

OPTICAL DIAGNOSTICS OF THE PLASMA LENS

For optimal lens performance, it is necessary that the ion pulse arrives at the peak of the discharge current, and that the spatial distribution of the current density is homogeneous. But due to pinching of the plasma discharge its cross section and density change significantly during the current pulse. The process of plasma pinching could be controlled by changing composition, primary pressure of the working gas, and the diameter of the discharge tube.

A set of optical diagnostics, which do not disturb the lens plasma, is used to investigate the process of discharge pinching, to study the temporal behaviour 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. The second maximum of the discharge voltage (lower curve in fig.5) corresponds to the moment of maximum compression of the discharge plasma.
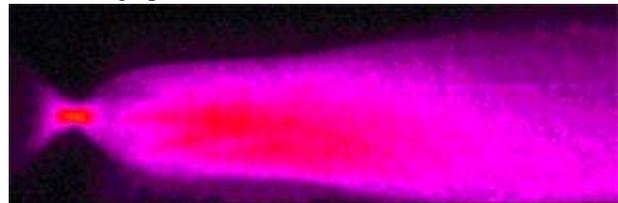
Figure 6: Time scanning of plasma luminescence at argon initial pressure 3.5 mbar and discharge current 200 kA (full length – 6 ms, cross section size – 2 cm).

Fig.7 shows oscillograms of the discharge current and the integral plasma luminescence. A sharp peak in the plasma luminescence signal corresponds to the moment of maximum compression.

Preliminary investigation of the spatial distribution of the plasma electron density for low currents in the range

of 10-60 kA with the help of Mach-Zehnder interferometer and interference imaging in the "time magnifier" regime have been carried out. A single mode (TEM$_{00}$) fixed-frequency solid-state laser with 50mWatt power output and diode pumping LCS-DTL-317 (λ=0.532mkm) was used as an emitting source. The mean electron density of the plasma at the maximum of the discharge current, obtained in the result of interferogram processing, was $2 \cdot 10^{18}$ cm^{-3} at the discharge current 20 kA and argon pressure 3mbar.
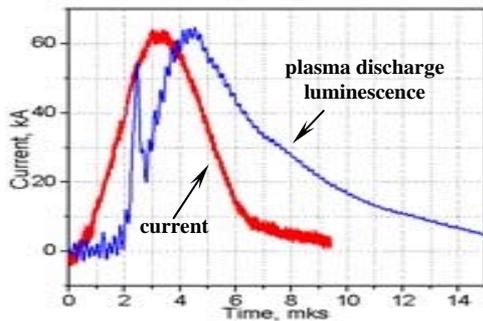
Figure 7: Oscillograms of the current pulse and integral plasma luminescence in argon at initial pressure 3.5 mbar.

CONCLUSION

At present time all the main elements of the plasma lens have been designed and fabricated. Study of dynamics of the space-time behavior of the plasma discharge has been started. Investigation of plasma discharge formation in the lens has shown efficiency of the engineering solution. In particular, lifetime of the commutation element reaches 10^5 pulses. It is assumed that the system with 8 thyratrons TGI-2500/50 will allow to obtain discharge currents in the plasma lens of up to 250 kA. Then the beam of ions with an energy of 300 Mev/amu could be focused onto a spot of 300 μm in diameter at a beam emittance of ~40π mm mrad.

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