

INSTALLATION FOR THE RESEARCH OF Z-PINCH PLASMA INITIATED BY THE ELECTRON BEAM

A. Drozdovsky, A. Bogdanov, S. Drozdovsky, R. Gavrilin, A. Kantsirev, V. Panyushkin, I. Roudskoy, P. Sasorov, S. Savin, V. Yanenko, SSC RF Institute of theoretical and experimental physics, Moscow, Russia

Abstract

For researches on plasma physics has been designed and constructed the electronic gun with the cold cathode on energy to 300 keV. The gun has the parameters: time width of pulses -100 ns, current amplitude - 100 A. The adiabatic plasma lens is developed for transportation and compression of the received electron beam. Results of researches are presented.

INTRODUCTION

At the present time, active works are underway for creating compact laser (electron and proton) accelerators [1]. For them, it is timely to solve problems of transportation and focusing of beams in discharges of the Z-pinch type, and it requires a thorough study of methods for forming such discharges. The goal of this work is to create a test installation for studying the dynamics of Z-pinch plasma with the discharge initiation by an electron beam. Typically, the discharge process begins after the high-voltage supply to the discharge tube, with the breakdown over the tube surface. It is also of interest to study the pinch development for the case when a breakdown is induced directly by an electron beam injected at the time of the application of high voltage.

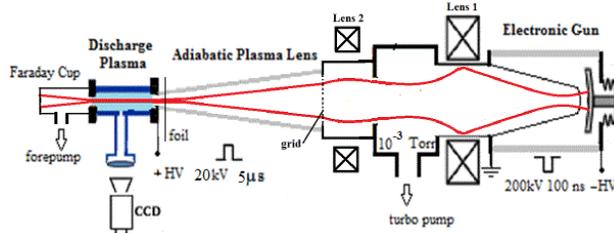


Figure 1: Installation for the research of z-pinch plasma initiated by the electron beam

THE INSTALLATION

The installation (fig. 1) consists of the electron gun [2] with magnetic lenses, experimental chamber with the scintillators located in it. Vacuum pumping of an electronic gun is conducted by the turbomolecular pump, and of plasma part of installation - the roughing-down pump. The electron beam is injected through the dividing foil into the experimental channel at a pressure of ~1 mbar. Inside the channel, the beam is compressed in the adiabatic plasma lens and then injected into the chamber of Z-pinch formation. For creation of the accelerating voltage was accepted the scheme of the generator on

cable lines with use of the double forming line of Blumlein and the cable transformer of Lewis. Figure 2 shows oscillograms of the beam current and the voltage obtained on the Blumlein line with the 25 kV amplitude. The amplitude of beam current is 50 A and duration of the beam at the peak is 60 ns.

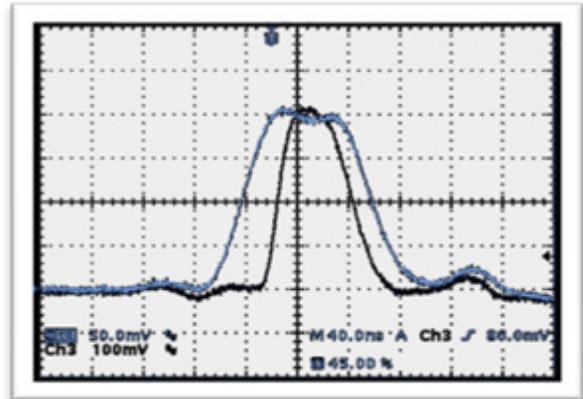


Figure 2: The electron beam current (black curve) and DFL voltage pulse signals.

Fig. 3 represents simulation results of the electron beam propagation from cathode to adiabatic plasma lens (APL). Emission current of 100 A and 50 mm cathode-anode gap under voltage of 250 kV were assumed during calculation. The simulation was performed using numerical code PICSIS-2D [3] based on use of Vlasov-Maxwell equations system with calculation of collisions of particles by Monte-Carlo method. The program enables to calculate a transportation of relativistic charged particles in arbitrary 2D electromagnetic fields taking into account its space charge and self-magnetic field.

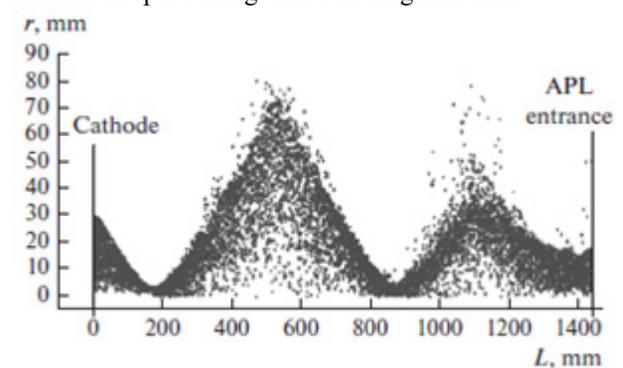


Figure 3. Calculation results of beam propagation. Concentration of dots is the product of the beam density $n(r)$ and the coordinate r .

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ELECTRON DIAGNOSTICS

The Kuraray company scintillators are used for obtaining of a beam density distribution. A scintillators luminescence are registered by CCD television cameras. The last together with operating computer are in the iron boxing providing an electromagnetic shielding. Information to the central computer is transferred on optical communication. An electron beam current was measured by the current transformer which has been built in the transport channel. All measuring systems, as well as start systems, are equipped with fiber-optical devices [2].

ADIABATIC PLASMA LENS

Focusing of a charge particle beam in a plasma lens is carried out as follows (fig. 4): the z-discharge plasma current creates an azimuthal magnetic field which focuses a beam passing through the discharge tube. If a discharge tube conic, a magnetic field increase with reduction of a tube radius [4]. This of focusing can be achieved by a slow, or ‘adiabatic’. Then reduction ratio of the final beam oscillation radius r_f to the initial r_i :

$$r_f / r_i = (R_f / R_i)^{1/2}$$

where R_f / R_i is the reduction ratio of final to initial diameter of discharge tube.

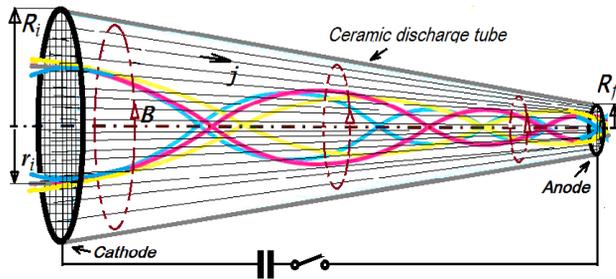


Figure 4: Schematic drawing of the principle and geometry of an adiabatic plasma lens.

Because of technological problems decided to replace a conic discharge tube with a set of cylindrical tubes. The set of tubes has length of 100 cm and their diameter decreases from 100 to 30 mm. The pulse generator with thyatron TDI1-150/25 as the switchboard on current to 30 kA was created. The current impulse duration is 5 microsec.

To choose the adiabatic plasma lens optimum operating mode were carried calculations by means of the NPINCH code [5]. It have shown (fig.5) that at peak current of 1 kA the optimum initial pressure of argon at this design of a lens lies in the range of 1-10 mTorr.

Computations of the electron beam through the APL were performed using of the data obtained on the plasma states in the applied cylindrical tubes. In a figure 6 an electron beam envelopes are given with different amplitudes of current in APL. Steps of the value decreasing from right to left correspond to the APL tubes

sequence. The beam coordinate at the entrance is 900 mm and the exit coordinate is 100 mm.

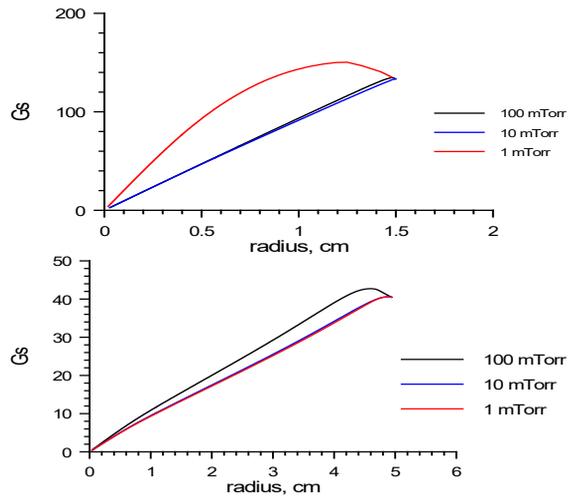


Figure 5. Azimuthal magnetic field strength (Gs) as function of radius at the time of a current maximum for a tube of diameter of 30 mm (the top drawing) and 100 mm (lower)

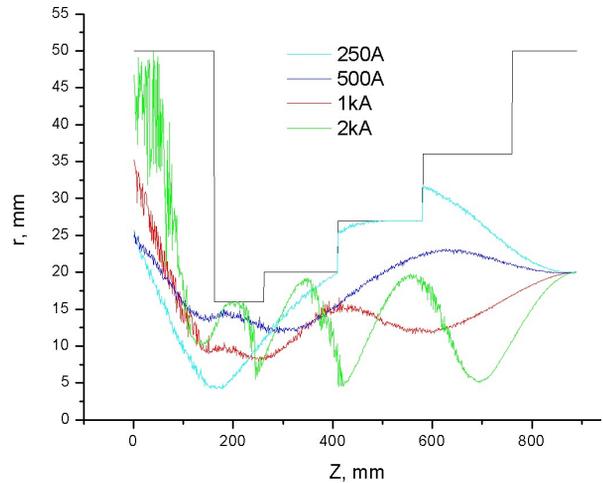


Figure 6: The electron beam envelopes for different amplitudes of current in APL.

The calculation results are given in Figs. 7 and 8 for a beam current of 10 A. The concentration of imaging dots corresponds to the product of the beam density $n_e(r)$ and the coordinate r .

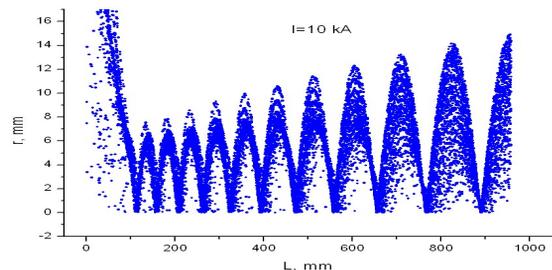


Figure 7. Results of calculation of beam propagation through APL with $I = 10$ kA.

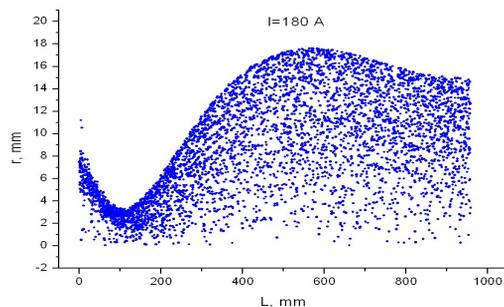


Figure 8. Results of calculation of beam propagation through APL with $I = 180$ A.

The first variant corresponds to the real adiabatic mode of lens operation, described at the beginning of this section, when the lens length is substantially larger than the wavelength of oscillations of the focused particles. In the second (nonadiabatic) variant, a quarter-wavelength of particle oscillations is placed on the lens length. This variant may be more preferable for use during the Z-pinch creation.

EXPERIMENTAL RESULTS

The stable discharge occurs in the APL at a pressure of ~ 0.1 Torr. The APL tests were conducted on the electron beam with energy of 250 keV and a current of 50 A. Figure 9 shows a luminosity of scintillators at the APL entrance and exit, as well as in the middle of the discharge tube of Z-pinch formation. The total size of the beam at the APL entrance is ~ 40 mm, while at the APL exit and in the discharge tube it amounts to ~ 10 mm.

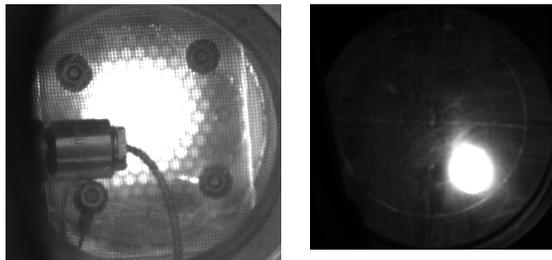


Figure 9. Glow of scintillators at the entrance and exit of APL and in the discharge tube.

The first observations of plasma luminosity in the discharge tube were conducted (Fig. 10) under the following conditions. Discharge current was ~ 50 kV; discharge time was ~ 5 μ s; and beam parameters were as follows: diameter of ~ 1 cm, current of ~ 10 A, and duration of 100 ns. The discharge tube was located directly behind the APL. The gas was atmospheric in composition, residual, and pressure was 0.1 Torr.

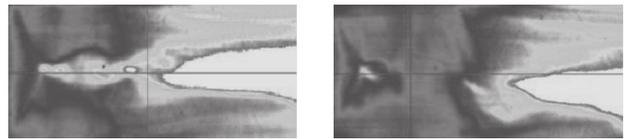


Figure 10. Plasma luminosity in the discharge tube without (on the left) and with (on the right) the beam at the first 2 μ s.

CONCLUSIONS

Numerical and experimental studies of the developed system for forming an electron beam with 250-keV energy make it possible to start systematic investigation of Z-pinch creation by means of relativistic electrons. The offered method for the discharge excitation is nontraditional, which evokes interest in the search for physical distinctions of this discharges type from the traditional ones excited along the surface of the insulator. The calculations [6] show that the current distributions at the initial time instant the discharge qualitatively differ from the traditional. This leads to the smoother distribution of the current over the discharge and hence to the smaller compression ratios at the instant of maximum compression, as well as, consequently, to the lower temperatures on the discharge axis. This qualitatively corresponds to the experimental data available. Such differences will make it possible to carry out a more complete study of plasma compression in Z-pinchs, as well as to better understand the dynamics of the discharge current distribution under different conditions of the process. The issue of what discharge current distributions correspond to the definite types of focusing of charged particle beams was studied in detail in our work [7].

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