High Current Electron Accelerators for Excimer Lasers

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Abstract – Designs of high-current electron accelerators developed at the IHCE for high-power excimer laser excitation are described. The accelerators have no intermediate storages of energy and operate in the microsecond beam current length regime. The high-voltage sources are Marx generators with vacuum insulation or linear transformers. Designs of high-current vacuum diodes have been developed; feed scheme of the sectioned diode consisting of six magnetically insulated diodes from two transformers has been realized.

Electron beams applied to excite high-power excimer lasers are characterized by the electron energy of up to ~500–600 keV, beam current up to hundreds of kiloamperes, cross-sectional area of 0.1–1 m^2, and electron beam energy up to tens of kilojoules. To obtain such beams, high-current electron accelerators with explosive-emission cathodes are used.

At development of high-current electron accelerators for excimer lasers there exist three groups of problems. They are as follow:

– creation of high-power pulse generators allowing realizing high power of active medium pumping in large gas volumes;

– development of explosive-emission cathodes with short turn-on time and high electron beam homogeneity;

– reduce of magnetic field influence on the electron beam formation in a diode and beam injection into gas volume.

Marx generators with forming lines are used usually as high-voltage sources in high-current accelerators. The forming lines are used to increase the output power of the generator. The forming lines usage complicates the accelerator design.

Pieces of velvet pasted on a metal cathode surface can be used as a material of the emitting cathode part. To increase the cathode emission properties, the velvet is saturated with CsI solution or else graphite fiber emitters are used. However, the fabrication and exploitation of these cathodes with a large-area emitting surface can be labour consuming.

The ways of reducing magnetic field influence on the beam formation are either superposition of the external guide magnetic field on the region of the diode and gas cell or spread of the current among several diodes magnetically insulated from one another with the current lower than the limiting one. The second way is simple but large number of generators equal to the number of diodes are required.

A new scheme of high-current accelerators based on high-power pulse Marx generators with vacuum insulation and linear transformers has been developed at the IHCE. In these accelerators, voltage is applied from generators directly to the vacuum diode operating in a microsecond pulse length regime, the forming lines being absent in the accelerator scheme.

The paper contains a short review of results of development and investigations of high-current accelerators without intermediate storages of energy. Description of accelerator designs and their elements as well as realized parameters are presented.

The Marx generator with vacuum insulation is developed in two modifications with rectangular and round columns [1, 2]. The generator consists of 8 or 9 stages with screens divided by means of polyethylene rings (Fig. 1). Each stage consists of three 0.18-μF, 100-kV capacitors. The capacitors have two 40-mm in diameter semispherical connectors that simultaneously serve as switch electrodes. One of the electrodes is connected through throttle providing capacitor charging and other electrode is connected to metal screen.

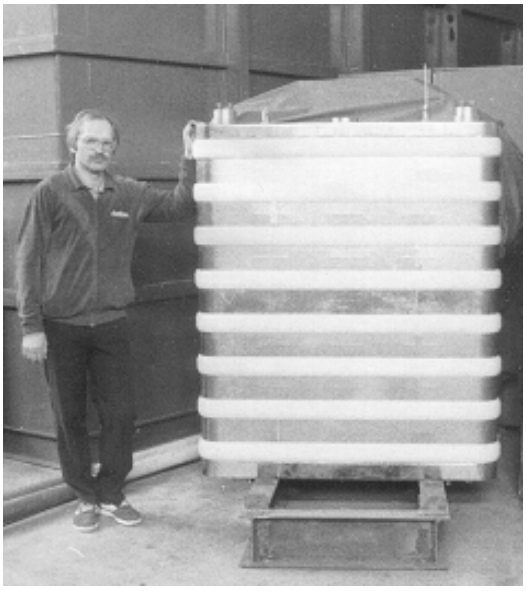

Fig. 1. The rectangular column of vacuum insolated Marx generator

The screens and polyethylene rings have vacuum-tight connection, the pressure in the column is 1.5 atm, the gas is the mixture of 30% SF_6 with air. The generator

operates in the regime of three parallel branches. Time scattering between operations of the branches is ± 10 ns. The output capacity of the 8-stage generator is 68 nF, self-inductance of the generator is 300 nH. At the charged voltage of 100 kV the stored energy is 22 kJ. The generator has the dimensions of 1500 × × 1200 × 200 mm and the mass of 500 kg.

A Module electron accelerator is assembled on the base of the 8-stage Marx generator with a rectangular column [1–3]. The generator, together with the cathode, is placed in a metal tank of dimensions 400×1480×1660 mm pumped out to the pressure of $(3–5)\times10^{-5}$ Torr. The cathode is mounted on the last stage of the generator; there is no bushing vacuum insulator in the design of the accelerator.

A configuration of the vacuum diode electrode gap in the Module accelerator is shown in Fig. 2. Herein, the trajectories and the corresponding distributions of the beam current density at the anode, calculated with the use of the Poisson-2 code, are presented. The cathode base is made of two stainless steel pipes of diameter 120 mm, connected by a plate of radius 600 mm. The distance between the axes of the pipes is 120 mm. The cathode emitting surface of the area 190×810 mm^2 was prepared from carbographite felt. The radius of curvature of the extraction window bearing grid is 528 mm. The cathode-anode distance in the plane of the diode symmetry is 60–65 mm. The calculated current density distributions in the direction along the anode surface in the absence of anode plasma are uniform enough.

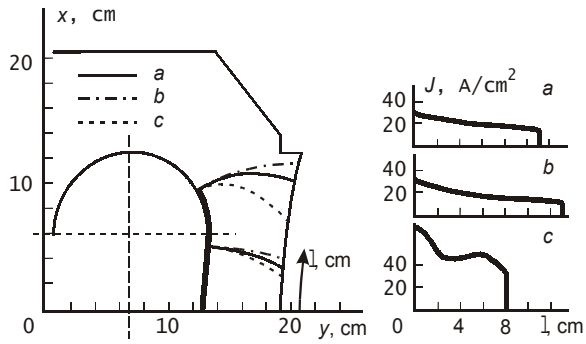

Fig. 2. Schematic of the diode of Module accelerator. Current density distribution at the anode for the voltage on the diode U = 500 (*a*) and 300 kV (*b*) and for U = 500 kV, the diode with anode plasma (*c*)

The experimental waveforms of the diode voltage and current, the time dependences of the electron beam power and energy, the diode perveance calculated from the waveforms, and the energy distribution for the extracted electron beam behind the anode foil, recorded in a pulse by means of 48 calorimeters TPI-2M are presented in Fig. 3. It can be seen that the voltage and current waveforms are similar to one another, and this fact testifies to efficient power transfer from the generator to the electron beam. The time of perveance establishment, which may be compared with the formative time of the plasma emission boundary is ~ 50 ns; the diode current appears there practically simultaneously with the appearance of voltage across the electrode gap. The diode perveance changes weekly during the pulse, testifying to the stability of the emission boundary position in the electrode gap during the most part of the voltage pulse. There is lack of agreement between the calculated beam current density distribution at the anode and the experimentally obtained beam energy distribution behind the anode foil. The lack of agreement can be explained by the presence in the electrode gap of the space charge of ions of the gas desorbed from the anode and not taken into account in the calculations.

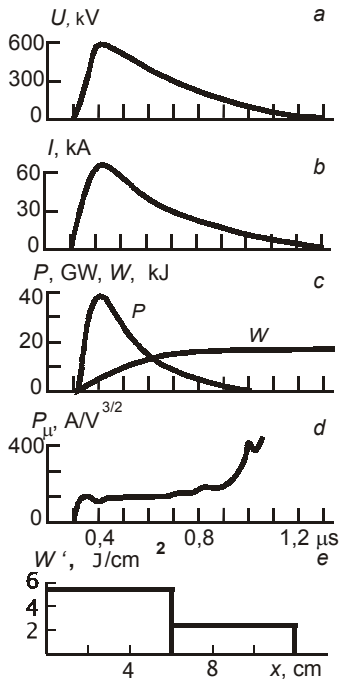

Fig. 3. Voltage (*a*) and current waveforms (*b*) for the Module accelerator diode. Time dependences of beam power and energy (*c*) and diode perveance (*d*). Beam energy distribution behind the foil (*e*). Electrode separation is 60 mm

At a 95-kV charging voltage, the diode voltage is 550–600 kV, the electron beam current is 55–60 kA, The current pulse length equals to ~ 1.5–2 μs and is limited by Marx generator discharge, the beam energy in the diode is 17 kJ, the beam cross-section is 25 × 100 cm^2. Electron beam extraction into gas was realized at the pressure up to 3 atm, the extracted energy value being of 10 kJ.

The power supply of the accelerator intended to excite an excimer laser with a 30 liters active volume is a round column 9-stage Marx generator [4]. The voltage from the generator is applied to the cathode forming a radially convergent electron beam (Fig. 4) The cathode is a stainless-steel cylinder of diameter 350 mm and length 830 mm with carbotextim PU or velvet strips pasted on its internal surface along the generating line. The external diameter of the cuvette

serving as the anode is 220 mm, the number of windows is four, and the window width is 130 mm. When using four velvet strips 130×800 mm in size, placed opposite the windows, the electron beams from individual strips enter the windows completely with almost uniform distribution of the current density over the window cross-section. The electron beam with the electron energy of 550 kV, beam current of ~ 60 kA, and duration of ~ 1.5 μs was obtained.

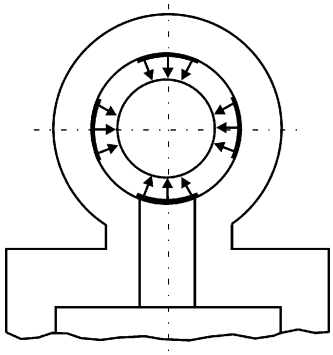

Fig. 4. Schematic of the diode for excitation of gas in the volume of 30 liters

The accelerator intended for excitation of a gas volume of 600 liters (620-mm in a diameter and 2000-mm long) is based on twelve vacuum-insulated Marx generators (Fig. 5–7) [5]. Each generator is furnished with a cathode. The generators are similar in design to those used in the Module accelerator. The generators are placed in pairs in six evacuated tanks, forming six accelerators with current and length of the beam being twice those realized on the Module accelerator. The accelerators are arranged on a radius round the cuvette so that the setup in plane has the form of a star. The cathodes bases are made of pipes of diameter 80 mm; the distances between the pipe axes are 180 mm. The emitting cathode parts of dimensions 210×950×20 mm are made of carbotextim PU and coated with velvet. The edges of the emitting parts are rounded to a radius of ~ 60 mm. The cathodes of the accelerators are placed opposite the foil windows in the cuvette; the total number of the windows is 24.

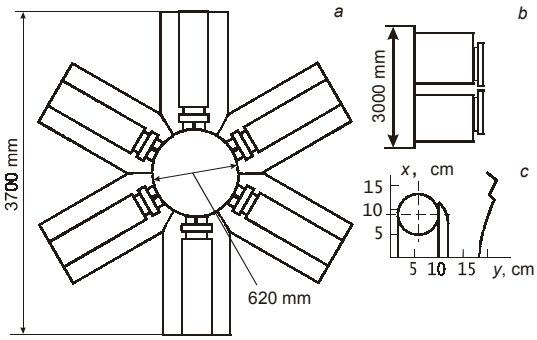

Fig. 5. Schematic of the accelerator for excitation of gas in the volume of 600 liters. *a* – accelerator cross section in plan, *b* – arrangement of modules, and *c* – cross section of the diode

With the charge voltage of the Marx generators of 95 kV an electron beam with the electron energy of 550–600 keV, the current up to 0.7 MA, and duration of 1.5 μs has been produced. For 230 kJ of energy stored in the Marx generators the energy of the electron beam in the diode was ~ 170 kJ and the energy of the electron beam deposited into the gas was ~ 70 kJ.

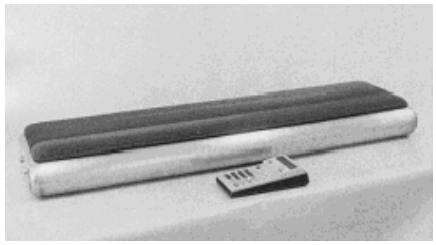

Fig. 6. One of 12 cathodes of the accelerator

Fig. 7. The view of accelerator for excitation of gas in the volume of 600 liters

At present, a new scheme of the accelerator has been developed, allowing decreasing the number of the generators while the diode magnetic insulation retains. Figs. 8, 9 present the view of the electron accelerator intended for the excimer laser excitation with the active volume of 200 liters (410 mm in diameter and 1500 mm length).

The power supplies are two linear transformers with vacuum insulation of a secondary coil. Both transformers are assembled from 10 stages, the energy of primary storages is 98 kJ.

The vacuum diode is assembled in the vacuum chamber of 1310 mm in diameter and 2100 mm length. A feature of the diode is availability of a large-

radius collector cylindrical electrode providing current supply from the transformers to the cathodes. The collector is suspended coaxially with the vacuum chamber by two springs that are located in tubes at the upper part of the chamber. The total inductance of the springs is 5.5 uH.

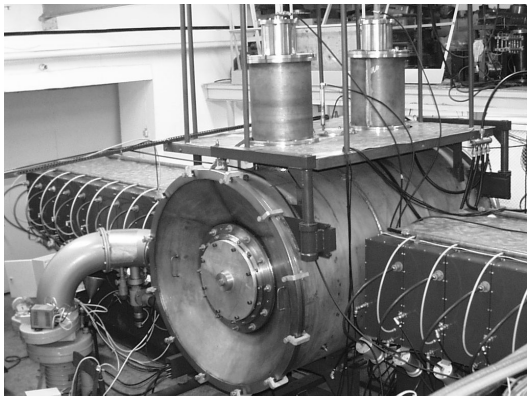

Fig. 8. The view of accelerator for excitation of gas in a volume of 200 liters

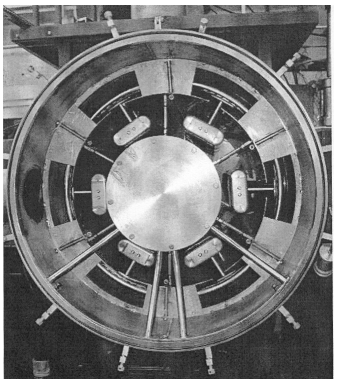

Fig. 9. The design of the vacuum diode of the linear transformer accelerator

The vacuum diode consists of 6 magnetically insulated diodes. Magnetic insulation is realized owing to application of the collector, a system of moving and fixed plates of reverse current. To eliminate the current flowing along the cuvette, the cathode of each magnetically insulated diode is divided into three parts. The total number of cathodes is 18. The cathode designs look like the design of 12-modules accelerator cathodes. The width of the emitting part of the cathode is 120 mm, the total emitting area is 0.95 m^2, the AC-gap is 60 mm. The inductance of the vacuum diode is ~ 40 nH.

The geometric transparency of the support frame is ~75%. A 40 um Ti foil is used to separate the gas cavity from the vacuum volume. The vacuum in the system is provided by two AVDM-250 pumps, the residual pressure is (3–4) 10^{-5} Torr.

At the diode voltage of 550 kV and diode current of 320 kA the radially convergent electron beams with the electron energy of 550 kV, beam current of 250 kA, beam energy in the diode of ~ 60 kJ, beam energy transported through the foil of 32 kJ, the energy deposited into gas up to 19 kJ have been obtained.

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