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# 200 keV ELECTRON MINI-ACCELERATORS FOR SCIENTIFIC AND APPLIED PURPOSES

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Created at BINP 200 keV electron mini-accelerators with high-voltage generators of different types are described: cascade generator with serial capacitance connection; generator with high voltage step-up transformer and voltage-doubling circuit of rectification; generators on the base of pulse and Tesla step-up transformers. Their circuit design performance peculiarities and fields of application are described.

Описываются построенные в ИЯФ им. Г. И. Будкера СО РАН мини-ускорители на энергию 200 кэВ с генераторами высокого напряжения различных типов: каскадный генератор с последовательным соединением сопротивлений; генератор с высоковольтным пошаговым преобразователем и дублирующим выпрямительным кольцом; генератор на базе тесла- и импульсного преобразователей. Даны специфика их работы и области применения.

## INTRODUCTION

In recent years the 200 keV electron beam sources have wide application due to:

— energy losses do not overcome 20–30 keV on beam output to atmosphere;

— the volume charge influence on this energy is insignificant and permits one to use these beams for injection to large accelerators;

— it is comparatively simple to realize these sources in small sizes.

At BINP there was worked out some models of 200 keV electron mini-accelerators for different purposes.

## 1. ELECTRON SOURCE ON THE BASE OF SERIES CAPACITANCE COUPLING CASCADE GENERATOR (CCCG)

A small-size 200 keV electron source with current 1–3 mA and turn-on time of about 3–5 min was required for electron processing investigations. The CCCG was selected as high-voltage generator for source due to the absence of:

— moved parts take place in Van-de-Graaff generator:

— closed core with coils with additional process design problem taking into account high-voltage assembling.

Electron source scheme is shown in Fig. 1 [1]. Its design features are:

• Monophase full-wave cyclic rectification circuit;

• Step-up Tr1 is used for column power supply and step-down Tr2 — for cathode heating and levelling gradient along the column. The magnetization inductance Tr1 and Tr2 may be

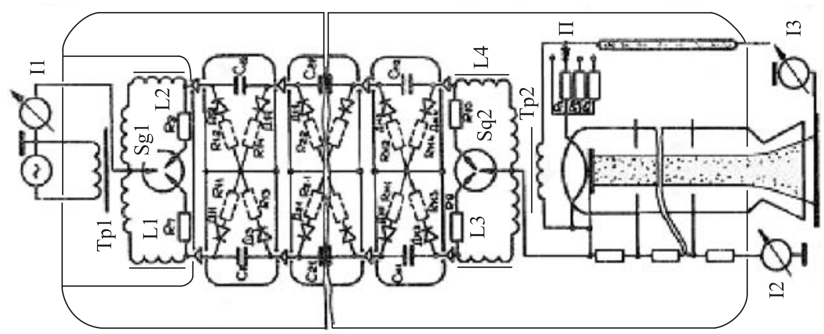


Fig. 1. Electron source scheme with cascade generator

varied by core gap changing. For their protection on breakdown spark gaps Sg1–Sg2 and chokes L1–L4 are used.

• The cathode heater power may be varied by using switch S1 from ground through Plexiglass rod.

There are 12 cascades in the column. The capacitors K15-10 3300 pF (two — in the first modification and 1 — in the second) are used as capacitance and KC-106G — as diodes. The first column model has 145 mm in diameter, the second one — 110 mm. Its length — 230 mm. Both models had been commissioned, tested, and had permitted one to perform needed science experiments on voltage up to 200 kV, currrent 1–3 mA and switch time near 5 min.

## 2. SOURCE OF ELECTRON BEAM WITH ENERGY OF 200 keV AND AVERAGE POWER OF 2 kW

In a number of cases the pulse electron beams proved to be more preferred in comparison with the continuous ones. Sometimes there is a need of compact sources of electron beam. A compact pulse electron source to be created for the radiation technology is described below [2].

Technical characteristics of the source:

| | |
|---|---|
| Average electron energy in the beam, keV | 200 |
| Pulse beam current, A | 10 |
| Average beam power, kW | 2 |
| Beam window dimensions, mm | 180 × 60 |
| Energy spread in the beam, % | + 10/–30 |

Sort of insulation — gas, $SF_6$ under pressure of 0.8 MPa.

Foil cooling — by air, cooling of supporting tubes — by water–alcohol mixture from an independent source.

The pulse duration may be varied but average beam power cannot overcome 2 kW.

The design of high-voltage generator (HVG) and electron beam source is shown in Fig. 2. High-voltage generator converts the alternating voltage with a frequency of 1 kHz into a direct

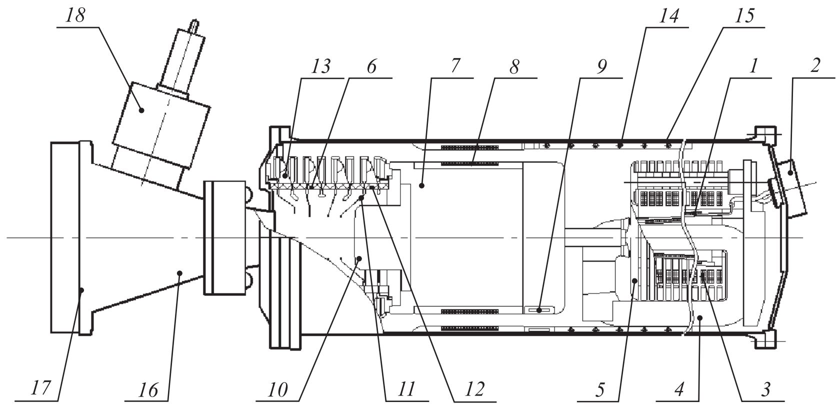


Fig. 2. Electron accelerator. *1* — primary winding; *2* — input of primary winding; *3* — section of a secondary winding; *4* — magnetic circuit; *5* — high-voltage electrode; *6* — accelerating tube; *7* — electron gun power supply and control unit; *8* — isolating transformer for power transfer; *9* — loop couplers; *10* — cathode-grid unit; *11* — focusing electrode; *12* — insulator; *13* — potential divider; *14* — water-cooled jacket; *15* — high-pressure vessel; *16* — scanning horn; *17* — beam window; *18* — ion pump

voltage using the full-wave rectifier and the single-phase transformer *1*. The feeding voltage is supplied to the transformer through input *2*. The HVG rectifier comprises 30 rectifying sections connected in series. The primary winding and a column formed by rectifying sections are installed coaxially in the core *4*. The primary winding is made cone-shaped to reduce leakage inductance. The core and the primary winding are covered by the shield to protect the primary winding in case of possible breakdowns of high-voltage insulation. The high-voltage part of a secondary winding is ended by a high-voltage electrode *5* with the radius of curvature providing rather low working gradients of electric field tension. The high-voltage electrode is connected to the accelerating tube (AT) *6* through the electron gun power supply and control unit (GCU) *7*. The GCU is fed through the isolating transformer *8*. The control voltage pulse is transmitted through the loop coupler *9* or fiber bundle. The potential divider *13* is placed on the outer side of the accelerating tube. It provides the uniform voltage distribution along the accelerating tube and takes away the charge of the electrons that hits the focusing electrodes *11*. The protective spark gaps are connected to the rings of the divider protecting accelerating tube from energy liberation at breakdowns. The water cooling jacket *14* removes heat from the transformer and other components. All units of the source are placed inside high-pressure vessel *15*.

The electron beam has an elongated form at the output of the accelerator due to focusing by quadruple lens. This beam is directed into the scanning horn *16* having beam window *17* made of aluminium–berillium alloy. The foil is cooled by air. It is supported from vacuum side by the tubes (cooled by independent water–alcohol mixture cooling system) which reduce the operating temperature in it. The chosen width of tubes provides transparency for beam passage not worse than 90%. The pumping of the accelerating tube and scanning horn is carried out by ion pump *18*. Figure 3 shows HVG assembling and Fig. 4 — the beam current

Fig. 3. High-voltage generator assembly

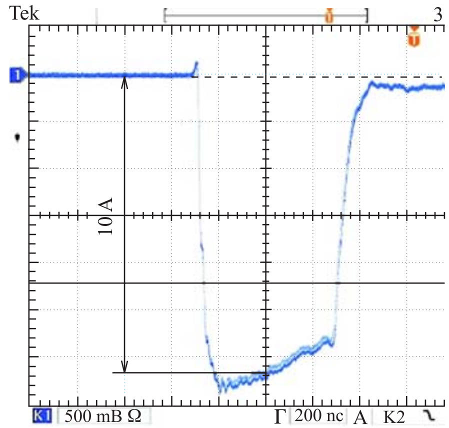


Fig. 4. The beam current pulse oscillogram

pulse. The electron beam source was repeatedly successfully tested on voltage up to 220 kV, current up to 10 A, pulse duration $0.2 \div 2$ $\mu$s, average power in beam up to 2 kW and test duration over the range of one hour. The system of the next breakdown protection operated safely.

## 3. THE 200 keV PULSED ELECTRON BEAM SOURCE FOR THE VEPP-5 INJECTION COMPLEX

At the Budker Institute of Nuclear Physics SB RAS a construction of the VEPP-5 injection complex is continued. To provide the complex project parameters, electron gun with parameters listed below was designed.

| | |
|---|---|
| Electron energy, keV | 200 |
| Pulse repetition rate, Hz | 50 |
| Bunch current amplitude, A | 10 |
| Beam emittance less than, $\pi \cdot$ cm $\cdot$ rad | 0.01 |
| Pulse duration (at half height), ns | 2–3 |

The electron source design is shown in Fig. 5 [3]. Accelerating tube (*11*) with gun control unit (GCU) (*12*) installed in it, pulse transformer (PT) (*3*) and modulator parts (IGBT module (*1*) and primary storage unit (*13*)) are placed in common SF6 filled tank (*2*) under pressure 0.17 MPa. All modulator pulse elements are shielded by metal tank, therefore electromagnetic striking is reduced to minimum. High-voltage pulser is based on the resonant charge of secondary capacitance through the step-up pulse transformer and subsequent discharge to the primary storage capacitance back. Cathode-grid unit with focusing electrode is manufactured on the flange as one spear unit (*5*). To decrease the breakdown influence on the GCU reliability the scheme with «grounded» grid is utilized. A dispenser spherical cathode unit 20 mm in diameter produced in «Thorium», Moscow, is used as an electron emitter. The cathode allows 4–5 disassemblies of the gun and exposures on the air without its emission degradation. The control grid has spherical radius 100 mm, cell size $0.4 \times 0.4$ mm,

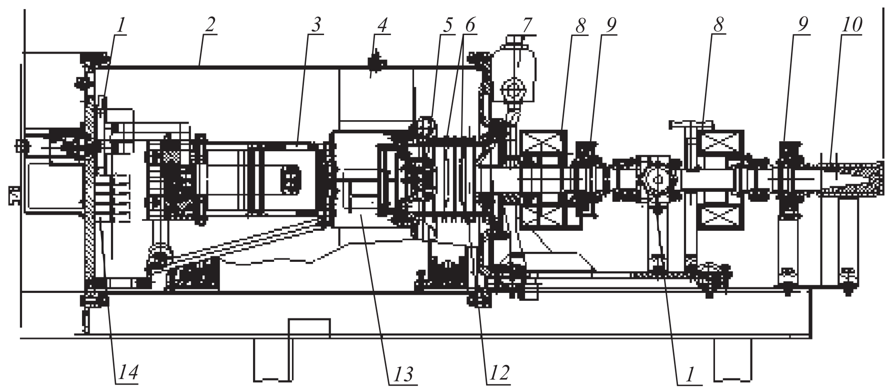


Fig. 5. 200 keV gun- and pulse-modulator design. *1* — IGBT module; *2* — SF6 filled tank; *3* — PT; *4* — capacitive divider; *5* — cathode-grid unit with focusing electrode; *6* — electrodes; *7* — ion pump; *8* — magnetic lenses; *9* — beam current resistive monitors; *10* — collector; *11* — gate; *12* — accelerating tube; *13* — gun control unit; *14* — primary circuit capacitive storage unit

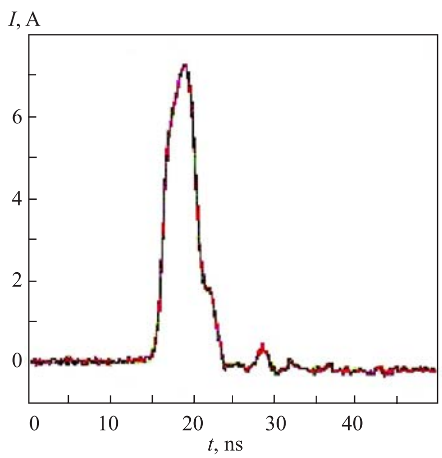


Fig. 6. The shade of beam current on first monitor cathode in a range 10–200 V. The same unit supplies the cathode filament. Pulse former triggering is realized using plastic optic

width of crosspieces 0.06 mm and is made of 100 $\mu$m molybdenum. The distance between the grid and the cathode is equal to 0.5 mm and is decreased down to 0.4 mm when the unit is heated. The measured grid transparency is 0.685. The accelerating tube consists of 6 welded alumino–oxide ceramic 22HS rings with outer and inner diameters 150 and 135 mm, respectively. The beam transportation and its matching to the linear accelerator input is performed by means of two magnetic lenses (*7*, *9*). Nanosecond resistive wall current monitors (*8*) allow measuring an amplitude and a shape of the current pulses with required precision. Vacuum gate (*10*) installed between the gun and the linear accelerator permits one to fix on the preinjector the operational gun previously prepared and tested on the separated facility.

The primary storage capacitance is charged from special charging unit which allows one to stabilize output voltage with precision better than $\pm 0.25\%$.

The specially designed compact gun pulser generates voltage pulses of up to 290 V amplitude and pulse duration at half-height $\sim$ 3 ns. To disable current and to regulate extraction voltage the unit forms constant bias voltage on the fiber cables. The shade of beam current on first monitor is shown in Fig. 6.

## 4. PULSE ELECTRON SOURCE ON THE BASE OF TESLA TRANSFORMER FOR THE BEAM OF CHARGED PARTICLES NONDESTRUCTIVE TESTINGS

This source will be used for the beam of charging particles nondestructive testing. Its parameters are: operating voltage — 120–200 kV, pulse current — a few mA on pulse duration about 1 $\mu$s and repetition rate — a few Hz. The ideal Tesla transformers particularity is absolute power delivery from primary circuit to secondary if circuits are tuned in resonance on coupling coefficient 0.6 [4]. The design of the source with Tesla transformer generator is shown in Fig. 7.

The source is placed in vessel *1*. It is performed coaxial with primary *2*, secondary *4* windings and accelerating tube *6*. Impregnated cathode *7* with control electrode is supplied from ferrite isolating transformer *8*.

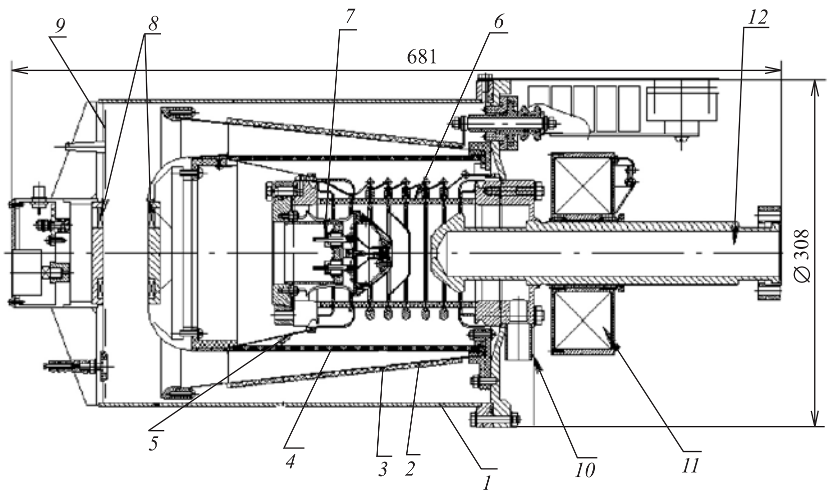


Fig. 7. The design of pulse test electron beam source

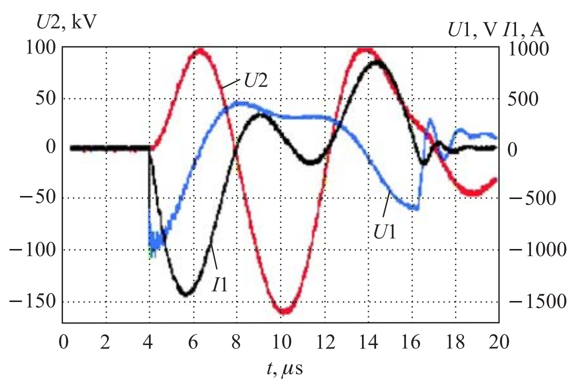


Fig. 8. Tesla transformer curve high-voltage $U2$, primary voltage $U1$ and primary current $I1$

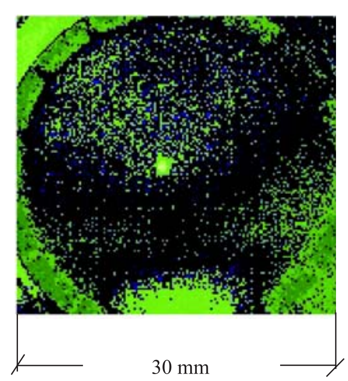


Fig. 9. The beam autograph with a size less than 1 mm

The Tesla transformer pulser is performed at one IGBT. Its using had permitted one to realize the power recuperation after pulse ending.

As the result of the beam calculations there was found the decision where the beam has a size not more than 0.3 mm at the distance 1 m from cathode.

The Tesla transformer curve (high voltage $U2$, primary voltage $U1$ and primary current $I1$) is shown in Fig. 8, the beam autograph — in Fig. 9.

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