Compact pulsed electron beam source ELIS

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Abstract: New compact pulsed electron accelerator ELIS is described. In ELIS electron gun is connected to the main unit by cable, therefore it is easy to arrange an electron beam in any place and very compact radiation shield is required. Technical features of the accelerator: electron energy – 100 keV, electron beam current – 50 A, pulse duration – 1 ns. ELIS can be used in the high energy chemistry, radiation biology and emission spectroscopy.

Keywords: pulsed electron beam, compact electron accelerator

1. Introduction

Electron beams are traditionally used in radiation chemistry for changing the properties of substances and creation of plasma medium. The linear accelerators of electrons of the direct action (pulsed and DC) are mainstream devices. In those accelerators the high voltage is applied to the cathode, acceleration of electrons occurs in the anode-cathode gap and the electron beam is derived through the grounded output window, which consists usually of the supporting lattice and the thin metal foil. The accelerators, utilized in technology, have large power, sufficiently large overall dimensions; they require special accommodations for the work. At the same time, for scientific studies the compact accelerators of electrons are sufficient frequently, they make it possible to carry out experiments in the usual laboratory rooms with the use of local radiation shielding only.

Successful examples of such instruments are the pulse electron accelerator RADAN [1], and also installations on its base: electronic sterilizer, pulsed microwave generators, spectroscope CLAVI [2], intended for investigating the luminescence of minerals under the action of electron beam (cathode luminescence). Mentioned instruments have small overall sizes and weight, they are placed on the laboratory bench easily. Parameters of the electron beam, formed by accelerator RADAN, are as follow [3]: energy of electrons - 150÷200 keV; the amplitude of the beam current pulse - 200÷500 A; the pulse duration - 2 ns, the maximum pulse repetition rate - 10 Hz. The pulsed electron tube IMA3-150E with the cold explosive-emission cathode is used as the tube diode in accelerator RARAN. The general views of accelerator RADAN and spectroscope CLAVI are shown in Fig.1 and Fig.2. The special feature of the generation of the high voltage pulses in the accelerator RADAN is the use of gas-filled spark gap as the switch, which does not make it possible to ensure the accuracy of the pulse triggering of electron beam better than 1 µs usually. In addition, the accelerator was developed for the work with the pulse repetition rate not more than 25 Hz.

In recent years pulsed high-voltage sources with the completely solid-state switching system are created in the Institute of Electrophysics (Russian Academy of Sciences), which ensure the nanosecond pulse triggering and pulse repetition rate up to several kHz. The new pulsed electron beam source ELIS is made on the base of one of such generators; its main features are small-size electron gun, separated from the HV power supply, and also, the
improved time stability of the electron beam pulse generation.

2. Design

ELIS consists of the high-voltage pulsed generator Proto-1M and electron gun (vacuum diode), connected to the generator by the one-meter high-voltage cable. Overall view of electron source ELIS is shown in Fig.3. In the high-voltage generator completely solid-state switching system of high-voltage chains is accepted [4], it ensures the nanosecond stability of the generation of output pulses.

The circuit diagram of Proto-1M is represented in Fig.4. Proto-1M is supplied with the single-phase network of ~220V, 50 Hz. Circuit with the sub nanosecond SOS-diode is charge for the diode peaker circuit. The energy, accumulated in the thyristor charger (TCU), enters the magnetic compressor (MC). Further MC compresses energy in the time to tens of nanoseconds for the realization of pumping sub nanosecond SOS-diode. The output power amplifier, which consists of the MC output component (peak transformer PT2, capacitor $C_p1$) and the circuit elements of reverse pumping (peak transformer PT3, capacitor $C_p2$, intermediate inductive accumulator $L_1$), realizes the two-circuit pumping of sub nanosecond SOS breaker. The break of return current with SOS breaker in time of approximately 1 ns leads to the generation of the charging pulse for the output driver circuit with the diode peaker (DP). The forming line is charged from the feeding generator through the blocking diode D and the separating inductor $L_s$. Diode peaking circuit generates on the load $R$ short (~1 ns) high-voltage pulse with the amplitude of ~100 kV.

The generator Proto-1M is fabricated as the table movable device in the rectangular housing with the sizes of 450x400x200 mm. Low-voltage elements of TCU, and also the part of the elements of magnetic compressor with the working level of voltage is not more than ~15 kV (peak transformer PT1, capacitors $C_p$, magnetic key MS') are located in the air part inside the housing.

Elements MC with the operating voltage of ~40 kV, power amplifier with the sub nanosecond SOS-diode, and also forming line with the diode peaker circuit are located in the metallic tank, filled with transformer oil. Wide-band capacitor voltage divider $U_c$ of the umbellate type is used as the sensor for the voltage pulses registration. The generator Proto-1M is designed for the long running (up to 8 h) with repetition rate of 100 Hz. Generator has an automatic unit with the remote panel, which makes it possible to control the mode of operation - to give and to remove the feeding voltage, to solve or to block triggering pulses.
Electron gun (tube diode) is connected to the pulse generator Proto-1M by the coaxial high-voltage cable with diameter of 10 mm and length of 1 m. Two types of electron guns are used.

First type gun is made on the base of tube IMA3-150E (it is shown in Fig.3), another type gun is developed especially for the accelerator ELIS, it has the smaller overall dimensions (Fig.5). Explosive-emission cathode being made of the tantalic foil is used as electron source in both electron guns. Electron guns have split output window, electrons leave the guns through the replaceable titanium foil with a thickness of 8 μm. During the work of ELIS the vacuum diode is pumped out by the fore pump (pressure in the gun - 10^-2 Torr).

Due to the use of the electron gun separated from main unit in ELIS it is possible to place electron beam into any position and to irradiate target from any direction (from above, from below, at any angle) easily. Furthermore, because of the small dimensions of electron gun very compact radiation shield is required, since it’s necessary to cover only object and gun, but not entire instrument.

3. Technical specifications

The electron beam current was measured by the faraday cylinder, mounted on the output flange of tube diode after the output foil. The pulses of beam current and voltage (from the capacity divider of the generator Proto-1M) were recorded by the oscilloscope Tektronix TDS5054 with the bandwidth 500 MHz. An example of waveforms is shown in Fig.6. The time shift of the current pulse relative to the voltage pulse is connected with different lengths of the measuring circuit cables.

The radiation-monitoring film TSDP2-F2 was used for obtaining the image of electron beam and determination of the distribution of the beam current density; it was placed on different distances from the output foil. The images of beam and the distribution of current density immediately after the output foil and at a distance 2 cm from the foil are shown in Fig.7.

The distribution of the beam current density at the diode exit has dip on the axis of the beam, which is connected with the annular form of explosive-emission cathode. At a distance 1-2 cm from the foil the dip disappears, the distribution of current density has one maximum on the axis of the beam.

The following main characteristics of the electron beam and accelerator ELIS are determined: electron energy – 100 keV, electron beam current – 50 A, the cross-section diameter of exit beam - 0.7 cm, electron beam current
density ~ $10^2$ A/cm$^2$; pulse duration – 1 ns, maximum repetition rate – 100 Hz; accuracy of the triggering of electron beam pulse – 30 ns; external dimensions, main unit - 530×400×220 mm, electron gun - Ø26×90 mm; weight (without the vacuum pump) – 16 kg.

Resource with continuous operation is determined by the destruction of output foil and exceeds $10^5$ pulses for the frequency of 10 Hz. If necessary the replacement of output foil is carried out easily during several minutes.

The small size of electron gun makes it possible to carry out action on the target of several electron beams easily – Fig.8.

In such experiments the use of ELIS will ensure precise synchronization and controlled delay between the pulses of electron beams; it will simplify radiation shielding to the decrease in sizes of protection and reduction in the energy of electrons; it will lower expenditures for conducting the experiments.

4. Conclusions

The developed compact pulsed electron beam source (electron accelerator) ELIS has:
- completely solid-state switching system;
- possibility of the detachment of the power source and electron tube;
- lowered requirements for the radiation shielding;
- improved time stability of electron beam pulse generation;
- high pulse repetition rate;
- small overall sizes and weight.

Pulsed electron beam source ELIS is intended for the investigations in the high energy chemistry, radiation biology and emission spectroscopy.

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References