TRIODE RF GUN FOR LINEAR ELECTRON ACCELERATORS*

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Abstract

The paper describes a triode RF gun for electron internal injection into the accelerating cavity. An additional RF voltage is applied to the grid-cathode unit to optimize the bunch phase characteristics. The experimental results of the gun operation to a single-cavity pulsed accelerator ILU-10 with the energy of 5 MeV and average power of 50 kW at the frequency of 116.3 MHz are presented.

INTRODUCTION

An electron gun with appropriate injection system is a significant part of any RF linear electron accelerator [1,2]. Recently, triode RF gun based injection systems are frequently used [3,4]. In such guns, an alternate RF voltage applied to the grid-cathode gap is used together with constant voltages to form the electron bunches. As a rule, such a gun operates in class C regime.

The further simplification of this injection system is an installation of the grid-cathode unit directly at the accelerating gap entrance. The given internal injection system was used in pulsed RF electron accelerators of ILU type developed in INP SB RAS for various radiation industrial applications [5,6,7,8].

DESCRIPTION AND PRINCIPLE OF OPERATION

As mentioned above, use of the internal injection, when the cathode with the control grid is placed directly at the accelerating gap entrance, is the ILU-type accelerator's feature. The opposite electrode of the cavity acceleration gap is used as an anode.

Let us consider the internal injection system by the example of ILU-10 accelerator. In this accelerator, the 116.3 MHz single-gap cavity with 270 mm gap is used for electron acceleration up to the energy of 5 MeV. The accelerator operates in pulsed mode with an average beam pulsed current up to 500 mA, pulse duration of 500 s, and repetition rate up to 50 Hz.

The grid-cathode unit (5) is located on the upper electrode directly at the accelerating gap entrance (see Fig. 1). The triode gun consists of the cathode, control grid, and lower accelerating gap electrode in the role of the anode. The grid and upper electrode are the united peace made of copper. The cathode unit is installed on the insulator ahead of the grid. The 16 mm diameter cathode tablet is made of lanthanum hexaboride (LaB_6). 20 amperes current flows at a voltage of 12–15 V through the cathode heater which is a cone helix made of tungsten wire of 0.6 mm diameter. The anode hole has 30 mm diameter. A magnetic lens is installed inside the lower electrode allowing the beam transverse size at the output device entrance to be controlled.

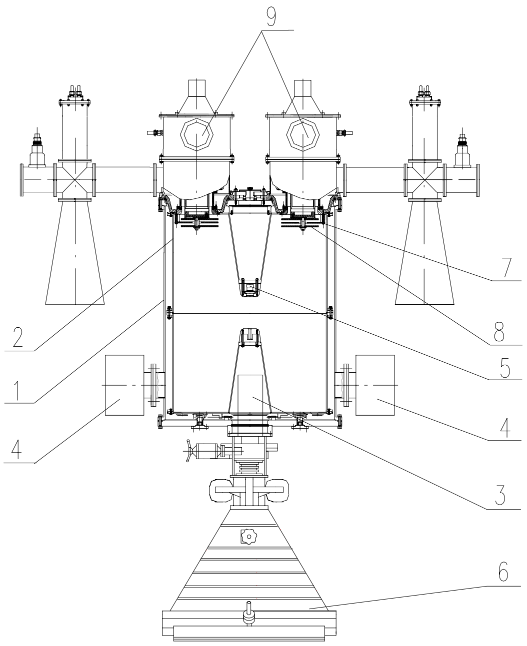

Figure 1: ILU-10 accelerator. 1 – vacuum tank, 2 – copper toroidal cavity, 3 – magnetic lens, 4 – ion pumps, 5 – grid-cathode unit, 6 –-outlet device, 7–-coupling loop support, 8 – vacuum capacitor, 9 – RF generators.

At this injection method, the current is formed by RF field penetrating into the grid-cathode gap from the accelerating gap and is determined by the grid penetration factor. The maximal current micropulse value is obtained practically at maximum of the accelerating voltage in the cavity gap. The injected current micropulse phase duration together with accelerated beam energy spread may be somewhat changed by varying the constant stopping potential on the grid. Here, there are no backing electrons.

The disadvantage of that scheme is the decreasing of accelerator efficiency because of considerable electron transit time within the accelerating gap, what is typical for single-cavity accelerators with relatively large accelerating gap to accelerating field wavelength ratio.

Figure 2 shows the calculated dependence between the electron energy at ILU-10 output [6] and arrival phase in the accelerating gap, as well as a single bunch current for various pulsed currents of 200 mA, 300 mA, 400 mA, and

500 mA. It may be seen, that th is about 70 degrees.

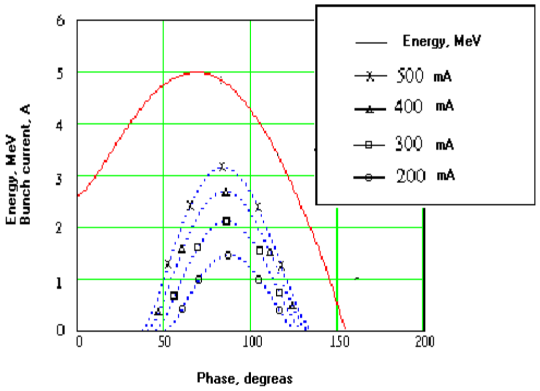

Figure 2: Electron energy at the ILU-10 cavity accelerating gap exit versus transit phase at the control grid plane.

The pulse of current should be shifted to the beginning of the RF voltage pulse to have the optimal phase injection.

To do so, an external voltage of the first, second, or third harmonic is applied to the electron gun grid-cathode gap in addition to RF field penetrating through the grid from the accelerating gap. Using the second or third harmonic assumes application of multiplying stages. Tuning the amplitude and phase of the external RF voltage, it is possible to choose the optimal phase of the injected current bunch center in relation to the accelerating field phase, what results in spectrum narrowing and accelerator efficiency increasing.

A test of the triode RF gun with the additional RF voltage first harmonic applying to the grid-cathode gap has been carried out at ILU-10 accelerator. The scheme of injection is presented in Fig. 3.

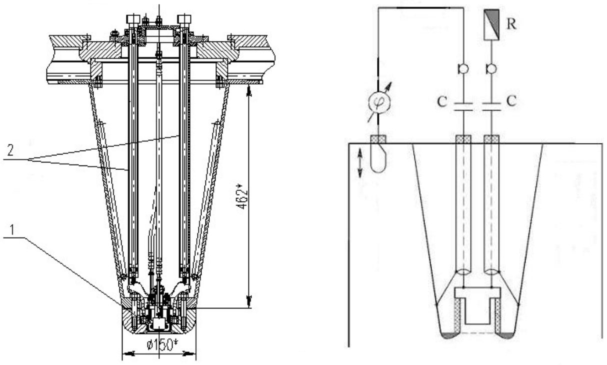

Figure 3: General view and scheme of applying the RF voltage first harmonic to the grid-cathode unit. 1-the grid-cathode unit, 2-the part of coaxial line.

An additional RF voltage is supplied from the accelerating cavity via the coupling loop, phase shifter, and coaxial line loaded on the 50 Ohm matched load. VSWR in the line subject to the grid-cathode unit impedance does not exceed 1.35. Capacitors C are blocking ones for the constant cathode bias relative to the grounded grid.

a coaxial cavity tuned at the third accelerating field harmonic frequency of 348.9 MHz was designed, manufactured, and tested at the operative accelerator ILU-10.

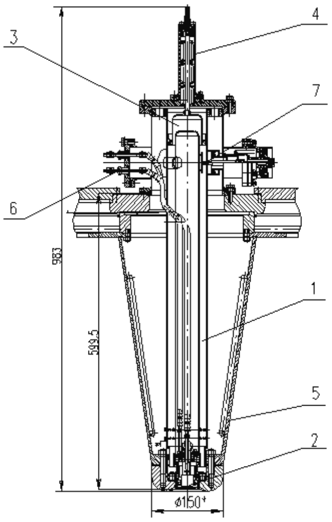

Figure 4: The grid-cathode unit with the 3-rd harmonic cavity.

Figure 4 presents a general view of the grid-cathode unit with the third harmonic cavity. The unit is installed into ILU-10 accelerator cavity as an injector. The gun coaxial cavity (1) of length is shortened on the one hand by the grid-cathode capacity (2) and on the other hand – by the structural capacitance capacity. The coaxial cavity resonant frequency may be tuned by moving the short-circuiting plunger (4). The cavity inner tube is insulated from the body and is under the constant positive potential of the cathode relative to the grounded grid. The grid-cathode unit together with the third harmonic cavity is placed inside the upper electrode chamber (5). The cathode heating voltage is applied through vacuum insulators (6) in the zero RF potential point. The cavity is excited by the tripler stage via controlled phase shifter. Coupling with the cavity has a capacitive nature and is adjusted by movable coupling unit (7).

EXPERIMENTAL RESULTS

Experimental data obtained from beam spectral characteristics measurements at ILU-10 output at the constant grid-cathode bias (1) and with the use of the first (2) and third (3) harmonics are presented in Fig. 5.

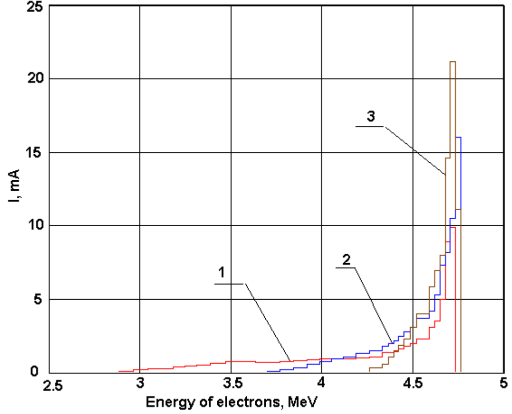

Figure 5: Experimental spectrum of beam electrons.

A magnetic spectrometer with not uniform magnetic field and electron beam rotation angle of 150° at 200 mm radius was used during measurements. 3 mm wide slots was installed at the spectrometer input and output for beam collimation.

For electron beam applications in various radiation processes and especially during beam conversion into deceleration radiation, it is important to have a grasp of what part of the total beam power lies within one or another energy spectrum range. Partial power P_{part} is determined from the following formula:

$$P_{part}(E) = \int_0^E \frac{\partial P}{\partial W} dW \ ,$$

where E is an electron energy, $\partial P / \partial W$ is beam power spectral density, $P_{tot}=P_{part}(E_{max})$ is the total beam power. Such experimental beam electron spectrum is shown in Fig. 6.

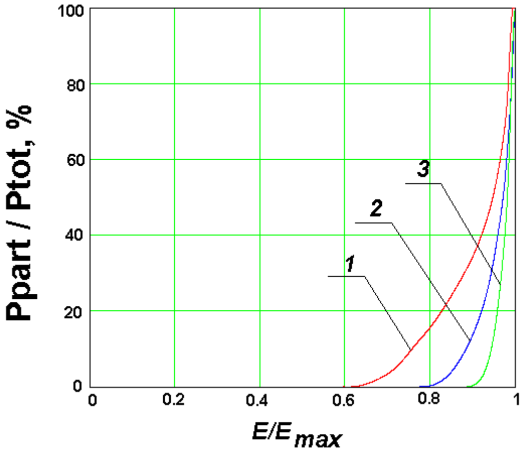

Figure 6: Experimental electron beam spectrum in terms of partial power units.

CONCLUSION

An improved internal injection system with RF adjustment of the bunch arrival phase designed for a linear accelerator has been introduced and experimentally tested. As a result, the electron energy spectrum was considerably narrowed, so the accelerator efficiency was increased. The decelerated radiation output from the beam energy conversion target is 20-25% higher relative to the case of injection with no additional RF voltage applied to the grid-cathode unit.

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