ELECTRON GUNS FOR TECHNOLOGICAL LINEAR ACCELERATORS

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INTRODUCTION

The modern technologies based on linear electron accelerator require intensive beams with small particle losses during acceleration. The beam quality at an accelerator exit is mainly determined by an injector and, in particular, by electron gun. In technological accelerators with a high beam intensity the vacuum accidents are over of danger that can cause the cathode poisoning. In these conditions electron gun designs which let in an operational cathode replacement are preferable. Such an approach was selected for providing the technological accelerators created and developed at the R&D "Accelerator" NSC KIPT with electron guns. The calculations of gun optics and beam characteristics have been carried out both analytically and numerically with using the «EGUN» code [1]. Results of development of three guns are below. The hexaboride lanthanum (LaB_6), dispensive tungsten emitter impregnated with barium aluminate and covered by an Os-Ir-Al film, was used as cathodes. The gun tests were conducted at special test installations.

HIGH-VOLTAGE ELECTRON GUN

The diode-type electron gun creating an electron beam with energy 80-120 keV, current not less than 3 A and normalized emittance no more than 70 mm·mrad is developed. It allows getting the electron beam exit parameters established by specifications at the high-power accelerator [2]. The last one includes an injector accelerating system with a variable phase wave velocity. The calculations of the shape of the gun electrodes forming a convergent electron beam were carried out by Pierce´s theory [3].

The conic convergent beam can be formed between electrodes the form of which represents parts of concentric orbs. A part of the external orb is the cathode and the internal one is the anode. The potential distribution between two concentric orbs with taking into account the space charge is described by the Poisson equation. In spherical coordinates the equation solution for a full beam current I is given by:

$$I = \frac{16\pi\varepsilon_0}{9}\sqrt{2\eta}\,\frac{V^{3/2}}{\alpha^2} = 29.33\cdot 10^{-6}\,\frac{V^{3/2}}{\alpha^2},$$

where ε_0 is the permittivity of free space, η is the ratio of an electron charge to its mass, α is the function of the ratio of a curvature cathode radius r_k to an anode radius r_a, V is the anode voltage.

For a cone with the half-angle θ cut out from an orb the beam current I_θ makes the next value from a full current I:

$$I_\theta = \frac{1-\cos\theta}{2} I = 14.67\cdot 10^{-6}\,\frac{1-\cos\theta}{\alpha} V^{3/2}$$

The gap between orbs (r_k - r_a) is selected to supply the electric strength for a selected voltage and necessary beam current.

The electron gun parameters for r_k/r_a =2 were calculated on the PC with using the special «EGUN» code.

The current density on the cathode was selected 1.5 A/cm^2. The cathode square needs 2 cm^2 for beam current 3 A, and its diameter is 16 mm.

The simulated results are listed in Table 1 and the calculated trajectories of beam particles are shown in Fig. 1.

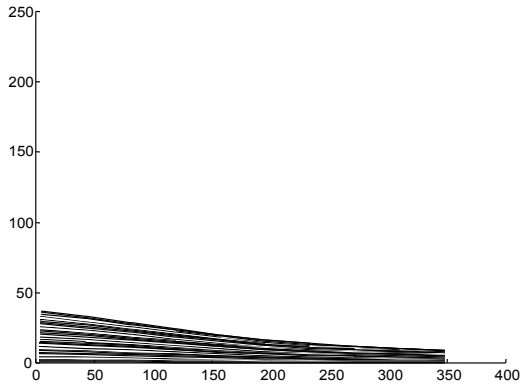

Fig. 1 – The gun geometry and particle traces

Table 1. Electron gun parameters for current 3 A.

Anode voltage, kV	80	120
Normalized emittance, π·mm·mrad	31.2	23.2
Beam radius on anode, mm	4	4
Beam radius in crossover, mm	1.7	1.72
Distance to crossover, mm	68	93
Beam perveance, $A/B^{3/2}\cdot 10^7$	1.3	0.72

For the gun under consideration we used the LaB_6 cathode which at the temperature about 1500 C provide the emission current density 2 A/cm^2, stable operation down to pressure 10^{-2} Pa, does not change the properties for a long storage in air, has the low velocity of evaporation. The durability of such a cathode exceeds several thousands hours.

Cathode heating up to the working temperature 1500 C (required power of the heater not less 200 W) was performed by a method of electronic bombardment [4]. A feature of the diode high-current gun with the LaB_6 cathode is the necessity to use a fixed construction design. The last one has to eliminate displacement with cathode heating up to 1500° C and ensure not complicated replacement of cathodes.

For this purpose the main and auxiliary guns are built up on rigid basic insulators installed on a steel plate. The gun construction allows one to change the anode-cathode distance and to choose the optimum geometry for different anode voltage values (80-120kV). At the setting-up the alignment of the anode, cathodes of the main and the heating guns is

ensured with the help of template with an accuracy not worse than ± 0.2 mm.

For gun feeding the high-voltage pulse modulator with the full discharge of the capacity accumulator was developed. As the switchboard the thyratron TGI-1-2500/35 was used. The equivalent load of the modulator is 12 kOhm. The characteristics of the modulator are listed in Table 2.

Table 2.

Parameters for working:	On load 12 kohm	On gun and ballast resistor 15 kohm
Amplitude (kV)	120	110
Pulse duration on level 0.9 (μs)	6.4	6.0
Pulse front duration (μs)	1.3	1.4
Pulse droop duration (μs)	1.2	1.6
Beam current (a)	--	1.1
Pulse top duration (μs) for inequality (%)	--	4.8 μS, 1.2
Pulses repetition (hz)	300	300

Fig. 2. Experimental and calculated volt-ampere characteristics.

The electrostatic deflector was applied for decreasing the current pulse front and droop duration [2], that allows one to decrease their duration up to 0.1 μs.

Tests of the gun and measurements of beam characteristics have shown a good coincidence of calculated results and experimental data (Fig.2).

The current-design gun has worked on the accelerator more than 2000 hours with characteristic parameters: a beam current - 1.1 A, electron energy - 110 keV.

LOW-VOLTAGE (25 kV) ELECTRON GUN

In an injector system of the technological accelerator KUT [5] the low-voltage injection is used. A feature of an injector is a flange junction of the cathode unit with the anode of a gun, which is a component of an injector. The cathode unit of a gun, which is now in use, does not allow making a cathode replacement. Therefore 'there was a problem in development of a new gun, which would allow to do it. Obviously that the developed gun and the beam characteristics on its exit should be entered in the existing injector scheme. The experience of an accelerator work and results of a detail numerical research of beam dynamics in an injector were taken into account for gun development. The input data for calculation of electrodes gun geometry are as follows: high voltage - 25 kV, an output current - about 2 A, geometry of the anode is former. Proceeding from the value of current take-off about 1.5 A/cm^2 we have stopped the choice on the flat cathode with a diameter 14 mm. The results of simulated beam particle traces with using of the «EGUN» code for selected gun geometry are represented in Fig. 3. The anode voltage is 25 kV and output current is 2.15 A, normalized emittance is 8 mm·mrad. The transverse beam structure at the gun exit in cartesian coordinates constructed by data processing of trajectories calculated is shown in Fig.4.

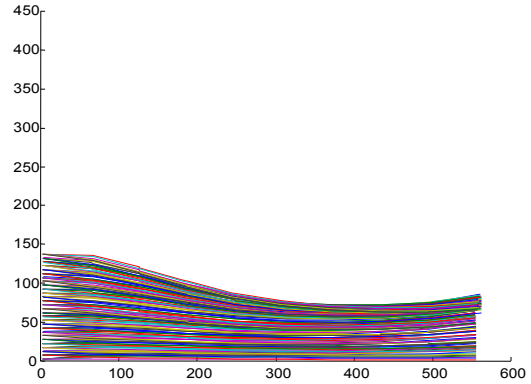

Fig. 3. Geometry of gun electrodes and particles traces.

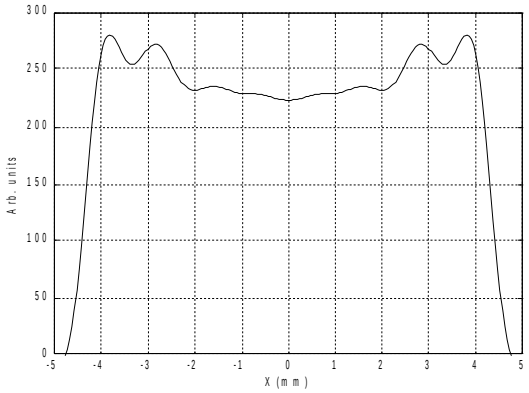

Fig. 4. Transverse beam profile.

The calculated results were used for designing the gun. The flat dispenser tungsten emitter by a diameter of 14 mm with barium aluminate impregnation and surface cover with Os-Ir-Al film is used as an emitter. The last allows to decrease cathode temperature that increases it service life. The gun structural feature is the flange cathode-heating unit junction with an insulator of a gun for maintenance of operating cathode unit replacement.

The special stand was created. to test the experimental gun sample. The gun was fed from the modulator with the partial discharge of a capacity accumulator. The modulator ensured a smooth control of high voltage and heating voltage within the limits of 11-25 kV and 1.5-8 V, respectively. The high-voltage pulse duration was regulated from 1 up to 4 μs. The modulator is supplied with a high-voltage potentiometer and induction current transducer for monitoring the high-voltage pulse amplitude and the cathode current.

For a measurement of transversal beam distribution and measurement of emittance the mobile multi-sectional monitor was developed. It consists of 32 copper foils with a thickness of 0.25 mm located vertically and isolated from each other by a layer of mica with a thickness 0.25 mm. Thus, the monitor makes it possible to measure a horizontal beam structure with a discretization of 0.5 mm.

Nowadays the gun is made and installed on the stand. The cathode activation is made and the preliminary tests of a gun are conducted. The calculated value of a gun current is obtained for the anode voltage amplitude 25 kV.

ELECTRON GUN for K-BAND LINAC

In connection with realization in R&D "Accelerator" works directed on creation of the accelerator of a centimetric wave range [6], there was a necessity in developing of an appropriate electron source. In conformity with results obtained after simulation of the injector [6], the following requests were presented to main gun characteristics: anode voltage - 25 kV, beam current - 50 - 100 mA, beam diameter at a gun exit - no more than 1 mm. Being based on these data, the geometry of gun electrodes was designed with using of the «EGUN» code. As the cathode we used the flat dispensive tungsten emitter of a 2 mm diameter with barium aluminate impregnation and surface cover with Os-Ir-Al film were used for The beam envelope constructed with using the calculation results on particle traces are shown in Fig. 5.

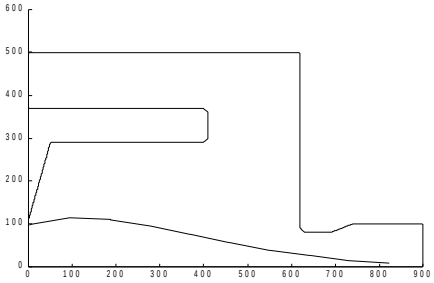

Fig. 5. Beam envelope.

For the anode voltage 25 kV the output gun current was 100 μA, beam diameter at the gun exit 160 μm, beam emittance- 1.2 mm·mrad. The results obtained completely satisfy the requests. Now, the gun construction is under development.

CONCLUSIONS

So, at NSC KIPT the electron guns for multipurpose linear electron accelerators are developed and constructed. Their parameters completely satisfy the requirements. The technique and experimental equipment for gun research are created. The results of an experimental research are well agreed with obtained calculated data.

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