TWO-CELL RF GUN FOR A HIGH-BRIGHTNESS LINAC

N.I. Ayzatsky, E.Z. Biller, A.N. Dovbnya, V.A. Kushnir, V.V. Mitrochenko,
NSC KIPT, 1, Akademicheskaya str., Kharkov, 310108, Ukraine

Abstract

We present the design and results of experimental study of the multipurpose two-cell RF gun. The RF gun can be used with both thermionic and photoemission cathodes. The main peculiarity of the gun is change by special tools the distribution of RF electric field along axis of the cavities. This feature gives possibility to choose the optimal conditions for obtaining requisite beam characteristics in both modes of operation. The RF gun has been installed and tested at Laser Injector Complex (LIC) facility. In particular, pulse current of 2A at the gun exit was obtained under using the thermionic cathode.

1 INTRODUCTION

The state-of-the-art experimental R&D, that need electron linear accelerator (linac) beams, put forward very stringent requirements for beam intensity and emittance, i.e. for beam brightness. In the light of this fact a prominent emphasis has been given of late to R&D in the area of injector systems, including RF electron sources, namely, RF guns [1.2].

As the analysis of particle dynamics in a RF gun indicates, the beam characteristics, and its emittance, above all, determined by the shape of electron field distribution along the resonance system axis. Considering the above - said, it is of interest to construct such an RF gun in which field distribution along the cavity axis could be varied at will. This would allow to arrange the dynamics very near optimum and form the necessary phase - energy particle distribution, while using one and the same resonance system with different cathode types. It is exactly this objective that we had in mind while developing a new multipurpose double-cavity RF gun for LIC - accelerator [3,4] with following baseline design specifications: operation frequency - 2797.15 MHz, electron energy - 0.7 - 1.0 MeV, rms normalized emittance $\varepsilon_{n\ rms}$- bellow 30 π·mm·mrad, bunch phase width - well within 60°. Depending on the cathode type used, the gun should provide for research beam production across a wide range of current pulse duration and amplitude. For example, with thermionic cathode pulsed current up to 2 A, the typical pulse duration will be 0.5 - 5.0 μs. In the case of photocathode the pulsed current duration and amplitude is determined by cathode and incident laser beam characteristics. A prominent feature of the gun is possibility to change field distribution along the cavity axis.

2 CALCULATIONS

In order to optimize the gun cavity shapes and determine the beam characteristics a set of calculations was performed of its RF characteristics as well as particle dynamics simulations. From the calculations it follows that the gun can be used efficiently in both modes: photo- and thermionic emission. In the case of photoemission operation mode (τ=10 ns) at 2 MW - power input ($E_{z\ max}$=40 MV/m) one would have according to the calculations: maximum electron energy 1.4 MeV, energy spread 14%, bunch phase width (70% particles) 45°, $\varepsilon_{n\ rms}$=10 π·mm·mrad, and pulsed output current would take 49% of the cathode current. In the thermionic emission mode (τ>0.5 μs) at the gun output current 1 A the maximum field strength along the axis 40 MV/m which corresponds to the power input about 3 MW. Concurrently, $\varepsilon_{n\ rms}$=13 π·mm·mrad, energy spread 18%, bunch phase width 57°, maximum electron energy 1.4 MeV. In detail the results of calculation described in [5].

3 DESIGN OF THE GUN

Fig. 1 shows a simplified schematic of the RF gun. The resonance system consists of two E_{010} cavities, coupled via the central beam-hole, the diameter of which (25 mm) and disk thickness (16 mm) determine the coupling coefficient (in our case 2.4·10^{-3}). The operation

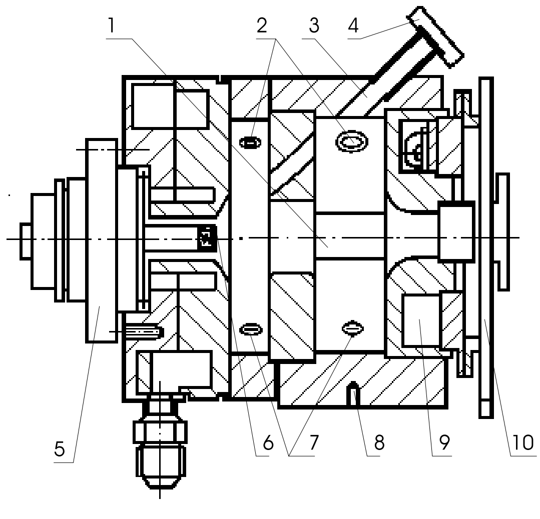

Fig. 1

mode is π. RF power is put into the gun using the waveguide through the coupling window 1. The coupling coefficient between cavity and waveguide depends on the electric field strength ratio in the first and second cavities η (at η=1, the coupling coefficient is 1.15). The RF gun arrangement allows, care of special plungers 2, to re-adjust the each cavity within ± 3 MHz, leaving the resonance frequency of the gun resonator system, on the whole, unchanged. This allows to vary the accelerating field distribution along the axis of the gun (η = 0.53...2.34). The frequency re-tuners contain half-wave chokes which ensure the electric durability at field strengths along the cavity axis being 40 MV/m and more. We have taken care to admit laser light into the cavity in order to irradiate the cathode in the wavelength range 1064 - 240 nm. Two diametrically opposite ducts 3 serve this purpose that have optical windows 4, vacuum sealed and made from sapphire (the second duct is not shown in the figure). One duct is in operation serving to pass the laser light in. The second duct can be used, for instance, for an auxiliary cathode irradiation by another laser, pyrametrical measurements or precision adjustment of the laser spot relative to the cathode center. As breadboard RF measurements indicate, the presence of a second duct allows for a considerable reduction of the undesirable field asymmetry. Arrangement of the cathode-holder 5 permits to study various cathode types with the diameter up to 8 mm. Besides, there is a possibility to move the cathode within ± 1 mm which is very important for gun operation mode optimization. Each cavity holds inductive probes 7 (attenuation - 70 ± 0.25 dB) that are used with the diodes for electric field evaluation inside the cavity. The gun mainframe has internal ducts 9 for cooling and heat exchanging purposes with distilled water. Thermoelectric couple 8 is used for temperature monitoring. Gun cavities are made of OFHC - copper with the internal surfaces turning with diamond tools. Immediately at the gun exit there is a wide - band beam current monitor 10.

4 RESULTS OF MEASUREMENTS

Upon construction of the gun, its RF characteristics were taken very carefully showing a good agreement between the calculations and experimental results. Thus, in particular, Fig. 2 shows, for case η = 0.8, the electric field distribution along the cavity axis as calculated and measured using the small perturbation technique. The method of adjusting the RF gun cavity has been studied experimentally. Fig. 3 show the measured dependencies on plungers position vs. needed ratio of maximum electric field strength along the first cavity axis to this value in the second cavity η with constant resonance frequency 2797.15 MHz

After adjusting and obtaining of the necessary vacuum 10^{-7} Torr, the gun was RF-tested at LIC accelerator by way of a sequential increase of the power input and RF-pulse length up to 2 MW and 2.5 µs,

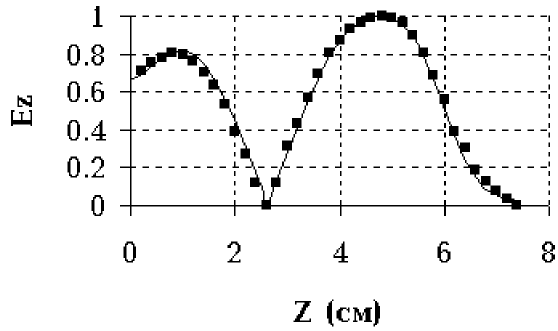

Fig. 2

respectively. During the testing the cathode was replaced by a metallic simulator whose shape fully matched that of the cathode. Upon reaching the maximum power level (2 MW), which is limited by the minimum attenuation of the waveguaide directional coupler, a study was made of field - emission (dark) currents off the cavity surfaces. In particular, the dark current intensity vs. field strength relationship was measured. Using the Fowler - Nordheim relationship, this technique allowed to determine the coefficient of electrical field increasing on microasperities. From the experiments it can deduced that mean value of this coefficient is 90 for on -- surface

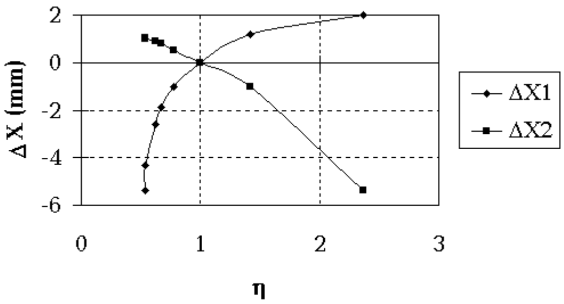

Fig. 3

electric field strength 48 - 56 MV/m. From comparison of the above results with published data, one can safely say that the cavity condition meets all modern requirements. The dark current pulse amplitude was no more than 0.6 mA at the maximum field value.

Initially, the output beam characteristics were studied from a thermionic pressed BaNi cathode, 5 mm in diameter [6], operating in the regime of current pulse microsecond duration. In the experiments was observed a ramp in pulse current and a drop of field strength in the cavities on account of the back bombardment that is characteristic of thermionic-emotion RF gun [7,8]. This phenomena was studied during the experiments. We used the optical pyrometer for measurements of surface temperature of the cathode. It was found that at a pulse repetition rate exceeding 6.25 pps the overall average cathode surface temperature went up above 90° C which called for a decrease of the heating, leading under certain RF-power input conditions to an unstable gun operation.

In stable gun operation regimes (pulse repetition rate ≤6.25 pps, current pulse duration 2 μs, RF-power input ~1.8 MW) the typical current pulse amplitude at the exit was 1.5 - 2.0 A. Acting on the premise of an analysis of the capture coefficient, while going into accelerating section with $v_{ph}=c$ (up to 70%) and beam emittance at the exit, we can conclude that in this mode of operation the particle energy at the exit is at least 700 keV, with the rms normalized emittance being well within 20 π·mm·mrad.

We have also pilot-tested the gun in the photoemission mode. As photocathode we used the thermionic cathode operating at temperatures that would, preclude thermionic emission. During irradiation of the BaNi cathode by laser light at 355 nm we obtained pulsed current 2.5 A at pulse duration 7 ns. The calculated quantum efficiency of the cathode in the experiments was 10^{-4}. This value is different from the value to be obtained early for similar type of cathodes in low laser energy operation mode [9]. Now causes of this difference are studied.

5 CONCLUSIONS

Thus, the universal RF gun for a high-brightness accelerator has been designed and put in to operation. At present the described RF gun is being employed as part of LIC accelerator for research activities in the aria of plasma physics. However the work on study and improvement the RF gun characteristics is in progress. In particular, we plan to widen the pulse length up to 8 μs for FEL purpose and to test different type of cathodes.

6 ACKNOWLEDGMENTS

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