SIMULATION OF BEAM PERFORMANCES OF THE TWO-CELL RF GUN.

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Abstract

The two-cell microwave gun has been installed to inject the beam directly to the backward wave accelerating structure at the LIC facility. Design of the gun allows to change widely the ratio of maximum on-axis electric field amplitudes in the cavities (η). Simulated dependencies of beam performances at the structure entrance as a function of both η and the maximum amplitude of on-axis electric field are presented. It was shown that the optimal formation of the bunches can be reached both for the thermoemission and the continuous photoemission regimes of the gun by choosing the needed η value. The normalized rms emittance of the beam equal to 9 π·mm·mrad and pulse power of the back bombarding two times less then that for a single cell RF gun with the same output energy and current were predicted for the thermoemission case. The nearly linear phase-energy distribution of the electrons can be obtained under the certain conditions so that a α-magnet can be used to increase the micropulse current. Beam performances for the picosecond photoemission case are discussed.

1 INTRODUCTION

RF-gun based electron injectors have been of considerable interest of late. Photocathodes in such injectors guarantee a high-brightness beam production. However, high-efficiency cathodes have limited lifetimes and driver lasers emitting mode locked picosecond light pulses of sufficient intensity to match the RF-gun resonator system are sophisticated and costly to implement. An emission, continuous during the RF-field accelerating half-period, from a thermionic emission- or photo-cathode can considerably simplify the injector layout. A difficulty to cope with, while at this, is a considerable range of phase and energy spreads of electrons at the RF-gun output for operation in this regime. Magnetic bunchers at the entrance into the accelerating sections are employed in order to decrease the bunch phase length and limit the energy spread, yet, as a result, the output beam loses particles and the emittance degrades due to magnetic system aberrations and action of space charge forces. With this in mind, such a layout of the RF-gun would be of interest that would provide for the acceptable values of particle phase and energy spread before being injected into the accelerating section. This report gives results of the simulation of RF characteristics, data of "cold" test and the simulation of particle motions for RF gun that would meet above requirements.

2 RF CHARACTERISTICS

The RF-gun resonator system consists of two cavities that are coupled through a central hole used for beam passing [1]. RF power is fed to the second cavity. The RF gun layout permits to vary across a wide range the on-axis field balance η by way of variation of cavity eigen frequencies using adjustment plungers, while maintaining the constant frequency of π-mode oscillations. Such a set-up allows for optimum conditions of bunch-forming under different gun operation modes.

Fig. 1 presents the cavity geometry employed for electric field distribution calculations along the gun axis, as performed with the SUPERFISH code [2]. The plunger actions were simulated during the calculation by way of cavity diameter variations.

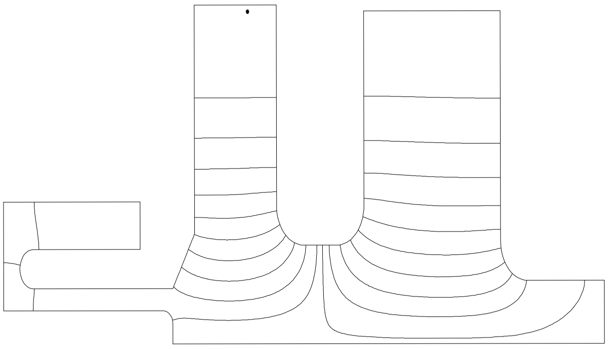

Fig. 1

Fig. 2 shows the relationship of the waveguide coupling coefficient β, unloaded - Q_0 and waveguide-loaded Q_l quality factors vs. η. The calculated and measured performances of the RF gun resonator system are given in Table 1. As simulations indicate, dependence of the radial electric field component on radius is mostly linear owing to a large diameter of the

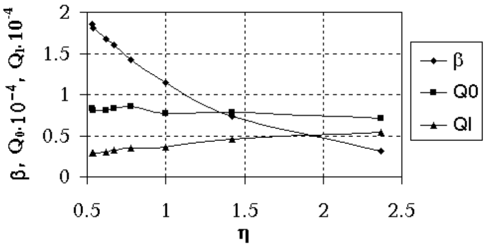

Fig. 2

beam passing holes. Although such a layout reduces the cavity shunt impedance, yet one should hope for a good stability, while in the thermionic emission mode, and for a lower level of wake-fields.

3 BEAM DYNAMICS

Table 1

Parameter	Experim.	Simulation
f (π-mode) MHz	2797.15	2797.15
Δf (0, π mode) MHz	7.34	6.8
$\frac{E_{z\ \max}}{\sqrt{P\cdot Q_0}}\left(\frac{\mathrm{V}}{\mathrm{mW}^{1/2}}\right)$ (η=1)	388	342
Q_0 (η=1)	10300	7600
β (η=1)	--	1.15
$E_{surface}/E_{z\ max}$ (η=1)	1.31	--
$E_{cathode}/E_{z\ max}$ (η=1)	0.8	0.8
η	--	0.53--2.34
β	--	1.85--0.3
Inter-cavity coupling	$2.6\cdot10^{-3}$	$2.4\cdot10^{-3}$

The calculated field distributions for different η values were used to simulate the particle dynamics. In case when space charge was negligible the simulations were performed using the EDINT code developed by us. For a more detailed study, the PARMELA [3] code was employed. Considered were three cases: thermionic emission, continuous photo-emission and picosecond photo-emission. While simulating the particle dynamics using the PARMELA code, an addition code was written, forming a file on the macroparticle input coordinate array in order to take into account changes in the cathode thermoemission capacity, due to the Shottky effect, and photo-current limitations by the space charge, as mandated by the Child low. Macroparticles were emitted with a homogeneous distribution on the cathode radius the diameter of which was 5 mm. In case of thermionic emission the cathode temperature was taken to be 1150° K with the work function 1.7 eV which corresponds to the pressed oxide BaNi cathode. Note, however, that the real cathode working temperature, observable during the experiments, was lower than the above given one. We suppose that emission from the cathode in RF guns deviates from the Richardson-Dashman low considering the Shottky barrier effect owing to the skin effect, but this assumption needs to be study carefully. Simulations were performed for different η values and various E_{max} - maximum field strength along the axis, since those values can be most accurately measured during experiment. The calculations are true for a certain temporal point within the limits of RF pulse, since the accelerating field characteristics can change during the pulse on account of cavity beam loading and back bombardment. Values of the bunch charge emitted from the photo- and thermionic emission cathode were chosen to be appropriately equal: - $q\approx1$ nC during photoemission and $q=0.5$ - 1.3 nC during thermionic emission.

Fig. 3 and 4 show the PARMELA code calculated relationships of the rms. (*1*σ) normalized emittance of a beam, emitted from a photo- and thermionic emission cathodes, vs. the value η at different E_{max} values, respectively. These performances represent the coordinate of the accelerating section entrance. In the mode of continuous photo-emission the current pulse duration is about 10 ns, and, for this reason, the electron acceleration should take place in the storage energy mode, with E_{max} being in excess of 40 MV/m. In this case, at η=0.5 the beam emittance will be minimum. If the RF-gun operates with a thermionic emission cathode, then, the accelerating field will be drastically reduced due to the effect of beam loading. Estimates, done on the power balance basis, indicate that at the exit current 1.3 A and η=1.5 the value E_{max} should be on the order 25 MV/m for the incident RF-power being 2 MW. As the figure indicates, this setup helps achieve the minimum emittance. However, such an operation mode is not desirable on account of a low value of the cavity-waveguide coupling coefficient under beam loading. From this standpoint, the η=0.8 mode is more advantageous. At the gun exit current 1.1 A and incident RF power 2 MW, E_{max}=30 MV/m becomes achievable, with the normalized emittance being $\varepsilon_{n\ rms}$ =10 π mm mrad.

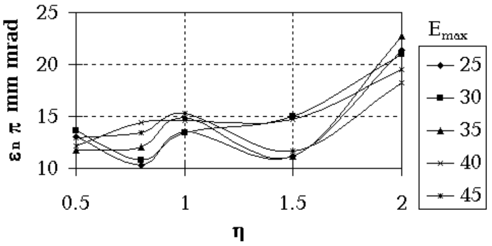

Fig. 3

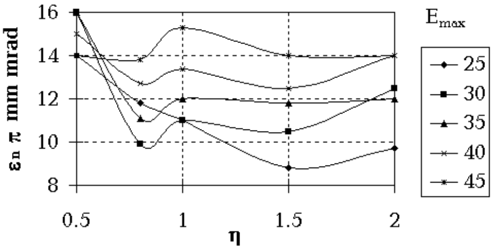

Fig. 4

Fig. 5 shows the beam energy spectrum at the accelerating structure entrance for this case. One can clearly see that a considerable amount of particles is concentrated in the high-energy portion of spectrum (mean energy 776 keV, energy spread for 70% of particles being 290 keV). Changing in both E_{max} and η changes the form of phase-energy particle relationship. The latter for the above case is, practically, linear, with the bunch phase length for 70% of the particles being 65°, and that is why, in principle, α-magnet can be used to compress the bunch and limit the energy spectrum.

During the simulation, attention was also paid to the effect of back bombardment, with the calculations showing that the power of back bombardment electrons in this particular kind of the gun is two times less than that in the single-cavity one [4], the output current and maximum energy being equal in both cases. The major contribution in emittance forming, according to the calculations, is made by particles emitted at phases, exceeding 70°. Output beam emittance is getting worse taking into account the non-optimality of the transverse dynamics of such particles. Especially emittance- and bunch phase length increasing are particles that perform the longitudinal oscillations and come out through the gun exit in subsequent RF-field periods.

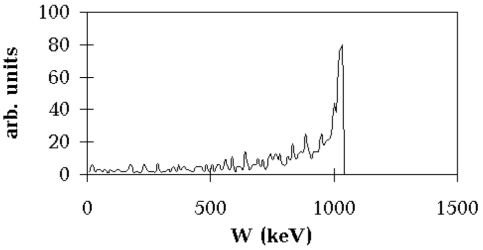

Fig. 5

With this in mind, it was interesting to simulate emission for the case of picosecond electron bunch. The spatial and temporal profiles of produced particles was taken to be Gaussian with σ_r=1.5 mm and σ_ϕ=10°. Fig. 6 shows the dependence of beam emittance at the gun exit on E_{max}, for various η at bunch charge 1 nC (injection phase 27°). As far as one can see, at η=1 one can obtain $\varepsilon_{n\,rms}$=2.6 π mm mrad. With increasing of bunch charge $\varepsilon_{n\,rms}$ increases almost linearly up to the value $\varepsilon_{n\,rms}$=20 π mm mrad at q=10 nC. The bunch phase spread analysis indicated that there is a particle compression and at the gun exit σ_ϕ=3.9° (q=1nC), with the phase spectrum having the shape very close to a rectangular one.

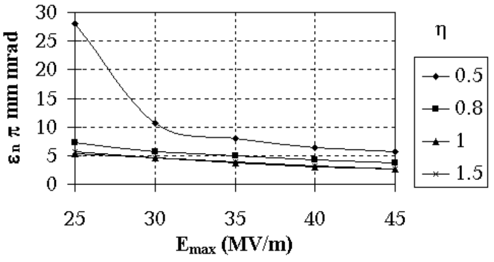

Fig. 6

4 CONCLUSION

From the above simulations it is follows that the presented RF-gun can be successfully used both the thermionic- and photo-emission modes, including the case of picosecond bunch acceleration. By selecting E_{max} and η one can obtain different phase-energy relationship, in particular, those closely resembling the linear one, and, also, vary across a wide range the output beam parameters, depending on experimental requirements. The majority of particles at the gun exit is concentrated in the high-energy spectrum region, making it possible to inject the beam immediately into the accelerating section with the phase velocity being equal to the speed of light. The power of back bombardment electrons being two times less than that in a single-cavity RF gun allows to operate with a lower duty factor of current pulses. Beam performance at the exit of LIC-accelerator [5] after the above gun has been installed for operation there confirm the high-quality beam generation at its exit.

5 ACKNOWLEDGMENTS

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