THERMIONIC TRIOD RF GUN SIMULATIONS FOR L-BAND FEL INJECTORS

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Abstract

The projected electron RF gun of L-band 10 MeV FEL injector employs a commercial thermionic cathode-grid assembly with 0.08 mm gap that conventionally used in metal-ceramic RF tubes. Computer simulations have been performed that use the mesh refinement capability of the both three-dimensional (3D) Microwave Studio (MWS) and 2D SAM codes to examine the whole region of the real cathode-grid assembly in static fields in order to illustrate the beam quality that can result from such a gridded structure. These simulations have been found to reproduce the beam current dependency on applied potentials. It is observed experimentally. Based on it ASTRA RF beam simulations predicts a complicated time-dependent response to the waveform applied to the grid during the current turn-on, calculates the dissipated power by electrons at the grid, and particle tracks before and downstream of the grid into RF gun cavity and further on. These simulations are representative in other sources, such as BINP Microtron-Recuperator 180 MHz injector [1,2], modernized ILU-12 for FEL requirements and for other industrial and scientific applications.

INTRODUCTION

The L-band injector was designed to produce a highly space-charge-dominated bunches of about 0.5 nC and 1.3 GHz repetition frequency in 10 μs macro pulses. Such an intense beam requires the use of numerical simulation for understanding the propagation characteristics.

The propagation of a beam is sensitive to the details of the initial beam distribution function [3]. In performing simulations of the initial distributions, it is conceptually advantageous to simulate the beam starting from the emitter surface.

Such simulations are complex. The RF gun employs a cathode (12 mm diameter) with fine parquet type grid (see Fig.1), having a rectangular cross section wires. Each cell has one narrow wire inside.

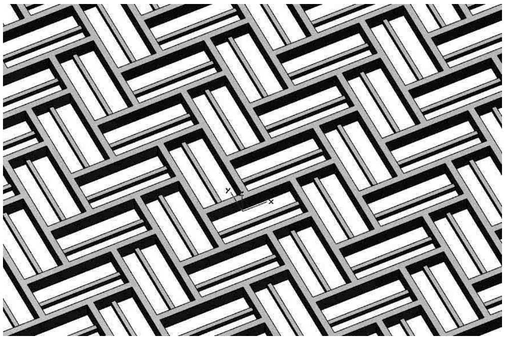

Figure 1: Layout of “parquet” type grid.

A particle tracking in the grid with its 350 cells is well calculated by 3D MWS code assuming static fields. The mesh subdivision was 20 μm. Nevertheless, a calculation in RF fields by ASTRA tracking code [4] employs axially symmetric grid geometry since ASTRA has the unique feature to take into account the aperture in view of a set of cylindrical plugs. So the equivalent axial-symmetric grid has been found for this with help of 2D SAM code [5].

Instead of a Child-Langmuir model for the cathode emission, as is commonly employed by the both MWS and SAM codes, ASTRA simply emits particles from the cathode surface, with a Gaussian velocity distribution. A thermal spread was assumed to be 0.1 eV. An emitted current exceeds the Child-Langmuir limit, therefore a virtual cathode appears at a distance of 2 μm from the cathode. The thermal emittance of the cathode, according to [6] formulas, is about 1 μm, that is observed by MWS numeric calculations also.

SIMULATION OF THE GRIDDED CATHODE

Each cell of the “parquet” grid (see Fig.1) has overall sizes of 420×840 μm, thickness of 135 μm, and wire width of 60 μm that are 80 μm from the cathode and 0.64 mm distance between grid and anode. The narrow wires have 40×45 μm in cross section. The light transparency is 70 %. The equivalent grid has a set of 27 cylindrical plugs alternated with two cross section sizes similarly to the “parquet” alternation of the normal and narrow wires as shown in Fig.2.

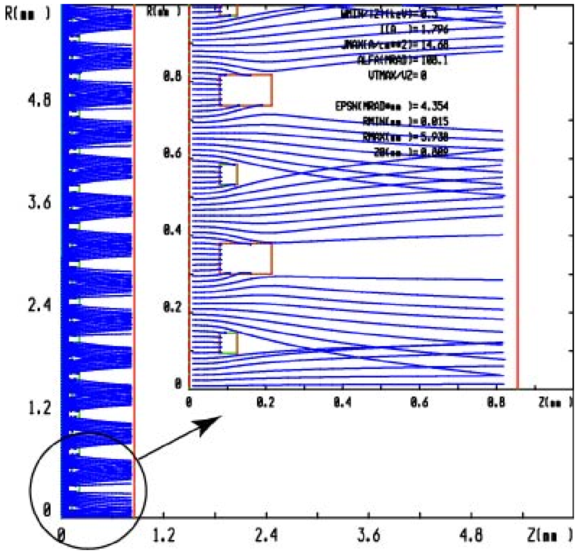

Figure 2: SAM calculations of the equivalent grid.

There are three criteria of the equivalence used: the light transparency (is 70 %), static electric field transparencies ($E_{cathode\text{-}grid}/E_{grid\text{-}anode}$), and emittances in the static field are equal for both cases of grids. In such a principle of the equivalency the last condition (emittance equaling) meets automatically with the accuracy of 10% as have been found in numeric calculations.

The numerically calculated behaviors of anode current and grid current versus of grid voltage for the stationary particle flow, observed experimentally with ±5% accuracy, are presented in Figs. 3, 4.

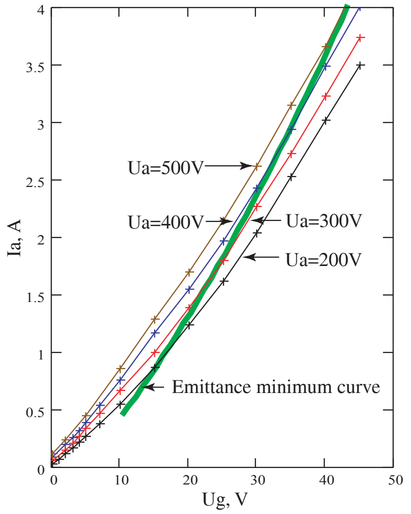

Figure 3: Anode current behaviour vs. grid/anode voltages.

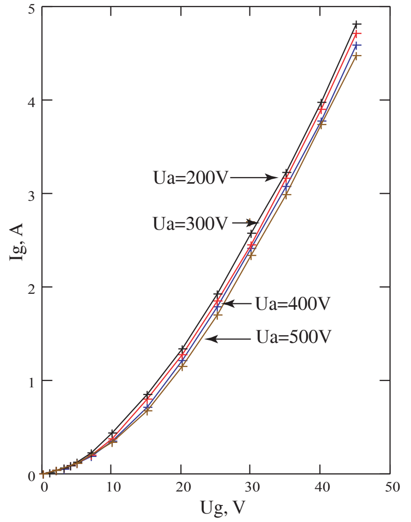

Figure 4: Grid current behaviour vs. grid/anode voltages.

Emittance of a Stationary Particle Flow

When the beam passes through the grid, it is divided into many beam lets. Due to the curved electrical lines around of each grid cell, the beam lets will feel a focusing or defocusing force causing its emittance growth. Theoretically, the emittance growth has a minimum when the electrical fields are equal at both sides of the grid. Our numeric calculations predict this fact; it is presented in Fig. 5. We have to note, as MWS calculations shown, the absence of narrow wires in each grid cell or all wire equaling thickness of 135 µm gives the emittance minimum close to the thermal one (of about 1 µm).

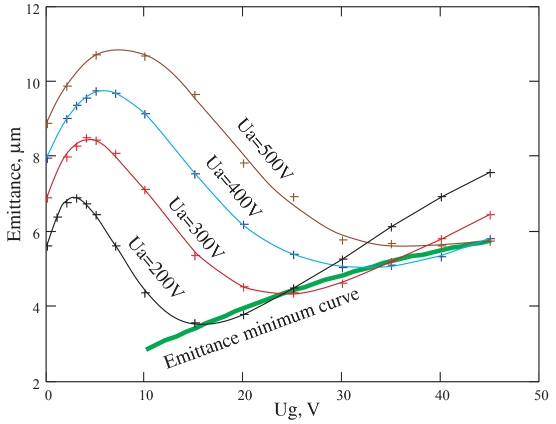

Figure 5: Emittance behaviour versus grid/anode voltages.

FULL RF GUN SIMULATIONS

The cathode-grid gap is actuated by 2.6 GHz RF power while the cathode is being under the bias potential.

There has been shown by MWS field's calculation at 1.3 and 2.6 GHz, all calculated static fields of cathode-grid assembly could be replaced by RF electric fields. These amplitudes were matched and extended to RF gun 1.3 GHz fields to employ in ASTRA. The temporal behavior of the cathode-grid controlling field (2.6 GHz) and RF gun field outside the grid (1.3 GHz) is presented in Fig. 6.

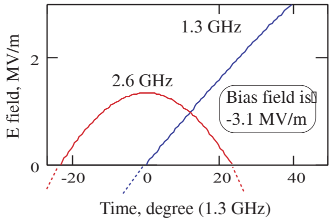

Figure 6: Temporal behaviour of RF gun electric fields.

The substantial numbers of numerical tests providing the best beam characteristics have been performed to find the details of this behavior, such as the launch 1.3 GHz phase of 0 degree, the field amplitude strength outside the grid of 4.8 MV/m, bias field of -3.1 MV/m. The average grid dissipated power by electrons is less then 3 W. The optimized bunch characteristics are presented in Table 1.

Table 1: Optimized bunch characteristics of the RF gun

Bunch charge	0.49 nC
Average particle energy	220 KeV
Normalized r.m.s. bunch emittance	14 µm
R.m.s. bunch length	5.6 mm
Average energy of grid captured electrons	88 eV
Average grid dissipated power/macro pulse	67 W

FULL INJECTOR SIMULATIONS

In the injector design (see Fig. 7) the beam propagation in RF gun cavity field at 0-degrees launch phase is applied to impart the initial bunch shortening (the tracking time is 13° in the cathode grid gap). Furthermore, the bunching 1.3 GHz cavity giving sufficient bunch compression in downstream drift space is used.

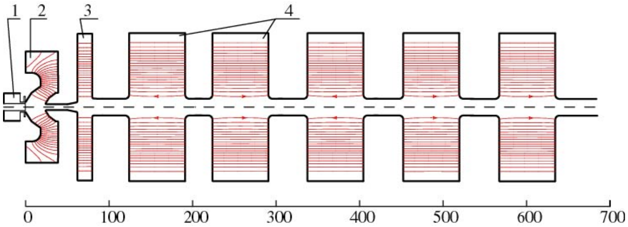

Figure 7: Layout of L-band injector. (1) 2.6 GHz cavity and cathode-grid assembly; (2) RF gun 1.3 GHz cavity; (3) buncher 1.3 GHz; (4) accelerating 1.3 GHz linac cavities.

Both bunch peak current and emittance depends on bunching and accelerating 1.3 GHz cavity dispositions, amplitudes and its off-crest RF phases. The substantial numbers of numerical tests have been performed to find these optimal values to provide the best beam quality.

The bunch size evolution while propagating the bunch through the injector and its portraits are presented in Figs. 8, 9. The optimized bunch characteristics and injector parameters are presented in Table 2.

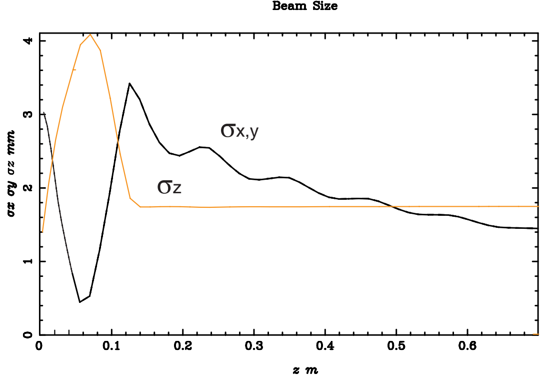

Figure 8: Bunch sizes evolution in the L-band injector.

Table 2: Injector-Bunch optimized characteristics

Rms transversal size	1.5 mm
Rms bunch length	1.7 mm
Normalized r.m.s. emittance, µm	22, $17_{95\%}$,$14_{\ 90\%}$
Peak current	170 A
R.m.s. energy spread	24 keV
Kinetic energy	10 MeV
Repetition frequency	1.3 GHz
Average beam current/macro pulse	0.38 A
RF power 1.3 GHz/macro pulse	12 MW
RF power 2.6 GHz/macro pulse	125 W

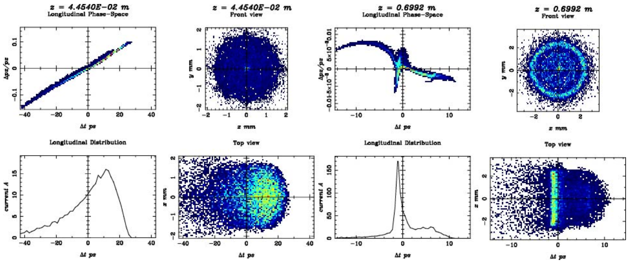

Figure 9: Bunch portraits evolution in the L-band injector.

CONCLUSION

The considered electrodynamics model of the cathode-grid unit is very helpful for the injector simulations. It gets a possibility to calculate objectively bunches with certain properties while the varying of the field amplitude and phase in the RF gun, the 2.6 GHz amplitude and bias voltages at the grid. It allow to calculate the cathode-grid emission at zero RF phase of the accelerating field giving shortened bunches with the greatest peak current and without of back travelling electrons.

Without of solenoid focusing, the beam is ideally matched with the linac, i.e. beam size is decreased monotonically without of emittance degradation while propagating the bunch through the linac (see fig.8).

The peak current is sufficiently large to excite any FEL of 100 µm wave length (see fig. 9).

Since the normalised emittance is small (20µm), such a beam could be used in scientific experiments.

Let list of main advantages of RF guns with such a thermionic cathode-grid unit:

- The ordinary and inexpensive system of thermionic cathode grid injection in comparison with laser driven photocathode one;
- Accessibility of cathode-grid circuits to a complete and safety operation due to the absence of static kilovolt tensions.
- Maximum cathode longevity, which is due to the actual sickness of back bombardment ions that could not gain appreciable energy in the RF field.

ACKNOWLEGMENTS

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