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DESIGN AND CONSTRUCTION OF A THERMIONIC CATHODE RF ELECTRON GUN FOR IRANIAN LIGHT SOURCE FACILITY

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Abstract

We present a program for the design and construction of a thermionic cathode RF gun to produce bright electron beams, consisting in the first step toward the possible development of S band linac based pre-injector at Iranian Light Source Facility (ILSF). The program is aimed at the goal to attain a beam quality as requested by ILSF. As a first step within this mainstream, we are currently developing a thermionic cathode side coupling RF electron gun which is expected to deliver 100 pC bunches with emittances below 2 mm-mrad at 2.5 MeV. We report the performed simulation and design activity, as well as cold test results of first fabricated prototype, which are in good agreement with simulation results.

INTRODUCTION

Iranian Light Source Facility (ILSF), is a 3rd generation synchrotron radiation facility under development at Institute for Research in Fundamental Sciences (IPM) in Iran. The facility contains an electron storage ring with energy of 3 GeV and circumference of 528 m, a booster injector, and a pre-injector linac with energy of 150 MeV. Figure 1 shows the general layout of the ILSF pre-injector lattice.

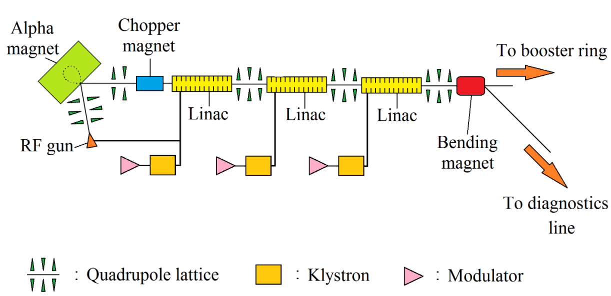

Figure 1: General Layout of ILSF pre-injector lattice.

An RF electron gun is chosen for generation of electrons in the pre-injector and is currently under development at ILSF. It contains a full and a half cell accelerating cavities operating in 2856 MHz, $^{\pi}/_{2}$ mode, with a side cavity for coupling the RF wave between them. The structure is powered by 4 MW of RF input power, producing a bunched beam of electrons with 300 mA peak current and 2.5 MeV energy. In order to inject the output beam to TW linac sections for further acceleration, an Alpha magnet is designed for longitudinal compression of bunches.

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RF ELECTRON GUN

The RF gun structure is designed using SUPERFISH [1] and CST Microwave Studio [2]. With the aim of decreasing back bombardment of electrons on cathode surface, electric field amplitude in first half cell cavity is selected to be 30% of that of the second full cell one.

In order to evaluate the simulation results, a copper prototype of the RF gun was manufactured and low power RF measurements were done utilizing an Agilent E5071C network analyser and an S band coaxial to waveguide transition attached to the upper flange of the waveguide. Bead pull measurements were also performed for on axis field evaluation. The results are in good agreement with initial design parameters, demonstrating -20 dB unloaded coupling with less than 1 MHz frequency shift. On axis field evaluations also showed less than 2% field error. The only drawback was the Q factor, which was decreased to half because of not using OFHC copper and not brazing the structure, both pointed to be resolved in the high power tests prototype. Figure 2 shows the design and drawing of the RF gun as well as the fabricated copper prototype, Figure 3 shows the simulated and measured on axis electrical fields inside the RF gun, and Table 1 shows the simulated and measured RF parameters of the gun.

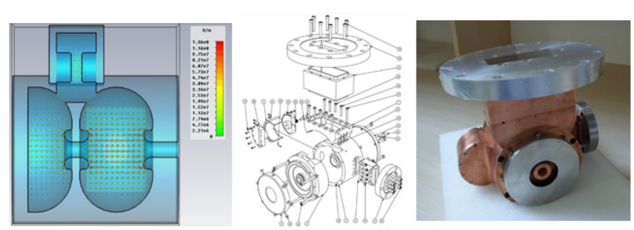

Figure 2: Design, drawing, and fabricated prototype of RF electron gun.

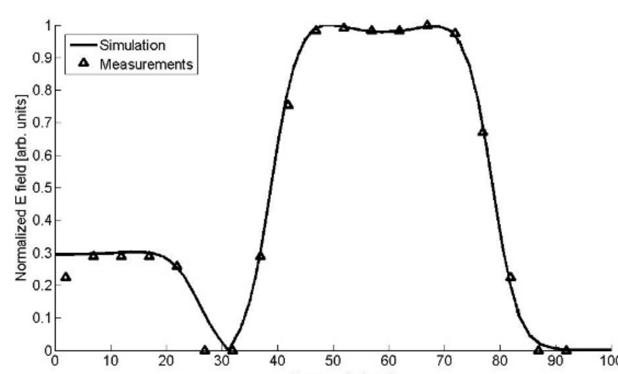

Figure 3: Simulated and measured on axis electrical fields inside the RF gun.

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Table 1: Simulated and Measured RF Parameters of the Gun

Parameter	Simulation	Measurement
Resonant frequency	2859.38 MHz	2859.57 MHz
Unloaded Q factor	13200	6150
Shunt impedance	86.2 MΩ/m	39.8 MΩ/m
S_{11}	-20 dB	-19.6 dB

ALPHA MAGNET

The alpha magnet is designed using POISSON [1] and RADIA [3]. The path length of central particle with 2.5 MeV energy is about 25.5 cm and scrapers are chosen to let pass of 10% energy spread of the bunch.

Mechanical drawings of the alpha magnet are prepared and the manufacturing will begin in the near future. Nevertheless, since the alpha magnet is not manufactured yet, it is not possible to evaluate the simulation results directly. Therefore, the simulations were calibrated by simulating the alpha magnet of SSRL [4] and benchmarking the results with their measurements. Figure 4 shows the design and drawing of the ILSF alpha magnet and Figure 5 shows the simulation and measurement of SSRL alpha magnet's depth gradient.

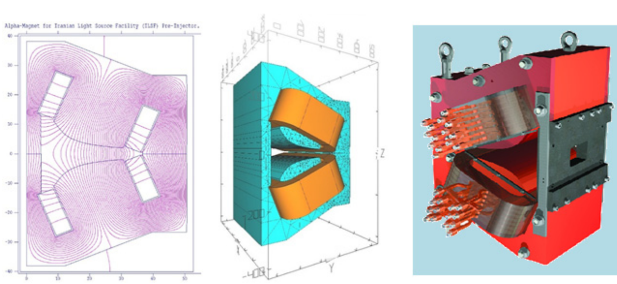

Figure 4: Design and drawing of the ILSF alpha magnet.

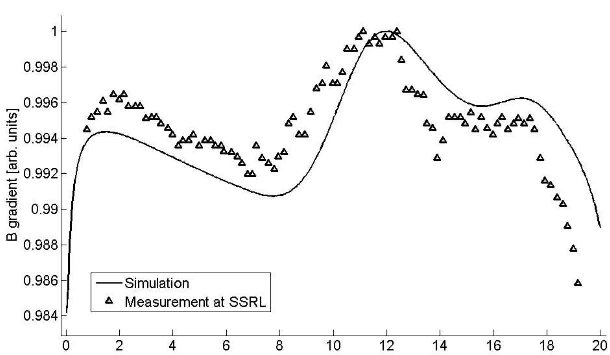

Figure 5: Simulation and measurement of SSRL alpha magnet's depth gradient.

BEAM DYNAMICS CALCULATIONS

Output bunch of the RF gun is simulated using SPIFFE [5] and compression of this bunch in the alpha magnet is simulated using ELEGANT [6]. The results show an initial acceleration of electrons to the energy of 2.5 MeV with normalized transverse emittance of 2 mm-mrad and longitudinal bunch length of 12 ps (RMS), which increases to 30 ps when the bunch reaches the Alpha magnet (1 m distance). The alpha magnet was placed after three quadrupole magnets and results show compression of bunches from 30 ps to 1.1 ps in 2 m distance after the alpha magnet (again two quadrupole magnets are placed for transverse beam focusing). Transverse normalized beam emittance also increases to 6 mm-mrad at that point. Figure 6 shows the longitudinal phase space of particles after the RF gun and Figure 7 shows the longitudinal phase space of particles after the alpha magnet.

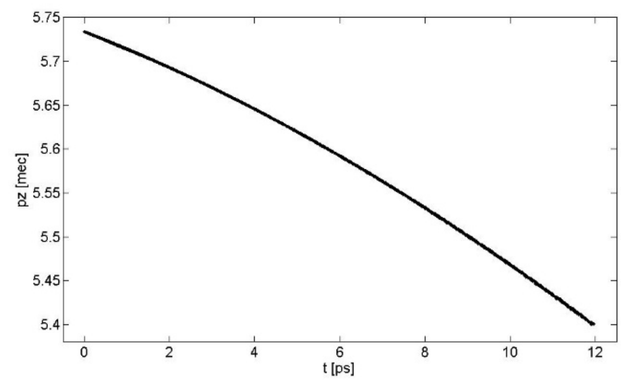

Figure 6: Longitudinal phase space of particles after RF gun.

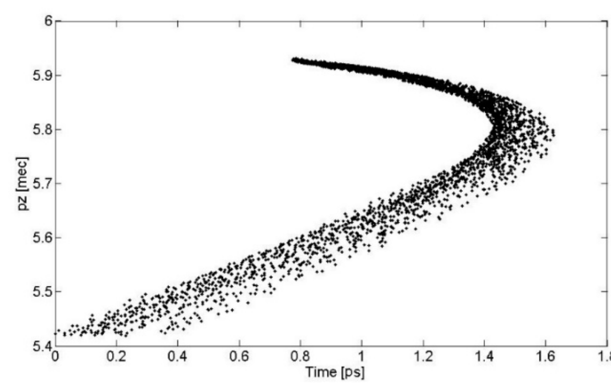

Figure 7: Longitudinal phase space of particles after alpha magnet.

Further beam dynamics calculations are done for the whole pre-injector lattice using ELEGANT. For ease of demonstration, ten different points were selected through the lattice as longitudinal positions and beam parameters were calculated at these points. These points are as follows:

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1. After electron gun
2. After filtering 50% of low energy particles which will be lost anyway by the alpha magnet scraper
3. Before the alpha magnet
4. After the alpha magnet
5. Before the first linac
6. After the first linac
7. After the quadrupole lattice between the first and second linacs
8. After the second linac
9. After the quadrupole lattice between the second and third linacs
10. After the third linac

Figure 8 shows the beam RMS energy spread. Although this parameter is considerably high after the RF gun, it starts to decrease by adiabatic damping in linac sections, especially in the first one, decreasing to 0.06% at the end tail of the pre-injector.

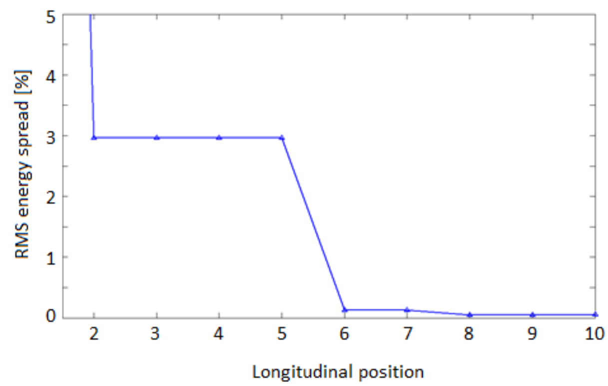

Figure 8: RMS beam energy spread for different longitudinal positions.

Figure 9 shows the normalized beam transverse emittance in both x and y directions. The reason for the growth of emittance in the GTL is the dependence of the quadrupoles focal force to the particles energy and large initial energy spread (~10%) of the particles.

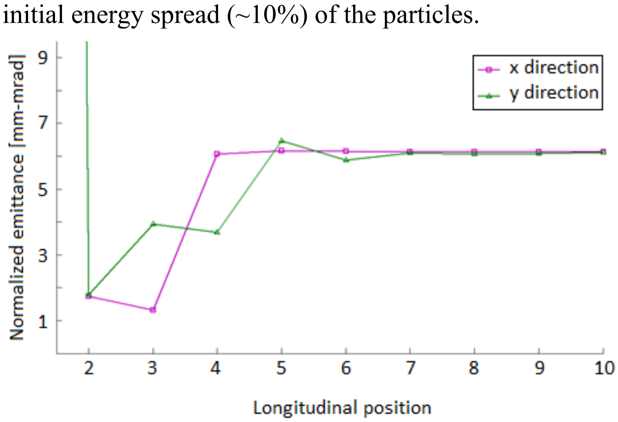

Figure 9: Normalized transverse emittance for different longitudinal positions.

CONCLUSION

The principle advantage of RF guns stems from the rapid acceleration that can be achieved with the strong electric fields possible in an RF cavity, which leads to high output energy, high brightness, and no need for further bunching sections. These advantages persuaded the selection of RF gun instead of conventional DC gun for ILSF. Simulations and low power RF measurements, discussed in this article, have proved the righteousness of the choice.

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