DESIGN OF AN L-BAND RF PHOTOINJECTOR FOR THE IDAHO ACCELERATOR CENTER 44 MeV LINAC

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Abstract

At the Idaho Accelerator Center (IAC) of Idaho State University, we have been operating a 44 MeV L-band RF (1300 MHz) linear accelerator (LINAC) for various user applications such as medical isotope production, Laser Compton Scattering (LCS), positron annihilation energy spectroscopy, and photo fission [1]. But the LINAC is not optimized properly to supply high quality electron beam for those experiments due to limitations of an existing 85 kV thermionic DC gun. In the near future, we are planning to use the L-band LINAC for new user applications such as Accelerator Driven subcritical nuclear reactor System (ADS), photon tagging facility, Ultrafast Electron Diffraction (UED) facility [2], and high power coherent Terahertz light source facility. Therefore, recently, we have been studying a future upgrade of the L-band LINAC with an RF photoinjector using ASTRA code [3]. In this paper, we describe ASTRA simulation results and a new layout of the L-band LINAC, which is based on an L-band 1.5 cell RF photoinjector. Then, we describe its expected performance for two different single bunch charges (1 nC and 5 nC).

INTRODUCTION

Laser driven RF electron guns are potential sources to supply high quality electron beam with a high peak current, a low emittance, and a short bunch length [4]. The main advantages of an RF photoinjector are; the time structure and the bunch length of the electron beam can be controlled by a gun driving laser, no additional bunchers are needed [4]. In addition, a photoinjector provides a higher energy gradient compare to a thermionic DC gun, which is helpful to reduce space-charge effects before the entrance of the accelerating structures, therefore the emittance growth due to the space-charge effects can be minimized.
According to Ref. [7], following conditions should be satisfied at the end of a high performance injector:

- High peak current I_{peak}.
- Small normalized projected emittance ε_n.
- Small normalized slice emittance ε_{ns}.
- Uniform and symmetric current profile.
- Small Twiss parameters $\beta_{x,y} < 40$ m, $|\alpha_{x,y}| < 0.2$.
- Low slice mismatching parameter $\zeta_i \approx 1$.

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In this paper, we present the current layout of the IAC 44 MeV LINAC and its parameters. Then we describe the new layout of the LINAC with an RF photoinjector, which is similar to the DESY 1.5 cell L-band RF gun for the FLASH facility. Finally, we present the ASTRA simulation results to estimate the performance of the new injector [3] and summarize the final optimized parameters for two different single bunch charges.

CURRENT LAYOUT OF 44 MeV LINAC

At the IAC, the 44 MeV L-band normal conducting LINAC is used for various experiments [1]. Electrons are generated from the 85 kV thermionic DC gun. At the downstream of the gun, there are two 108 MHz subharmonic bunchers and an L-band tapered buncher for additional bunching of the electron beam. After the bunchers, there are two L-band LINAC structures. The first L-band structure accelerates the beam from 2 MeV to 20 MeV, and the second one accelerates from 20 MeV to 44 MeV. Fourteen 8 cm long solenoids are used to compensate transverse emittance due to the space-charge force and to focus the beam inside the LINAC structures. The detailed current layout of the LINAC can be found in Ref. [5], and its parameters are summarized in Table 1.

Table 1: Parameters of Current 44 MeV LINAC [5]

Parameter	Unit	Value
RF frequency of the LINAC structure	GHz	1.3
Energy at gun exit	keV	85
Energy after 1st LINAC structure	MeV	20
Energy after 2nd LINAC structure	MeV	44
Bunch length during short pulse mode	ps	~ 50
Bunch length during long pulse mode	μs	~ 4
Repetition rate of a macropulse	Hz	1-300
Normalized projected emittance ε_{nx}	μm	14.9
Normalized projected emittance ε_{ny}	μm	10.0

NEW LAYOUT WITH PHOTOINJECTOR

As we already mentioned, we are planning to adopt a similar photoinjector, used at the DESY FLASH facility [6]. The photoinjector consists of a 1.5 cell normal conducting L-band RF gun with a maximum gradient of 40 MV/m. The gun driving laser consists of the Nd:YLF oscillator, which will be operated in the UV regime, $\lambda = 266$ nm. The Cesium Telluride cathode (Cs_2Te) with a

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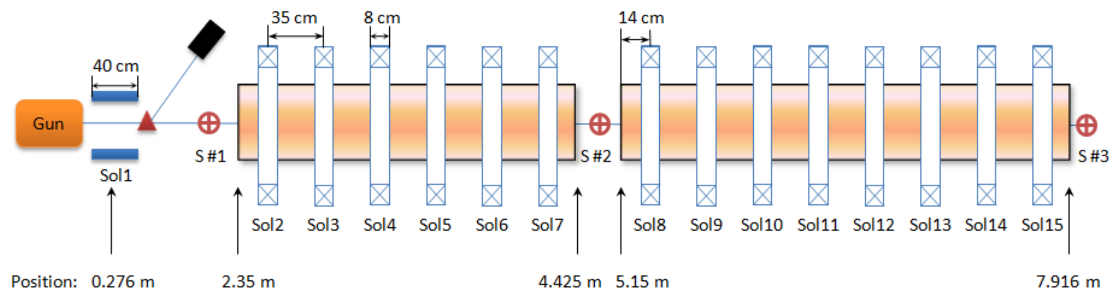

Figure 1: The layout of new injection system for 44 MeV LINAC at the IAC.

high quantum efficiency (Q.E.) will be used. As shown in Fig. 1, we will remove or relocate all components from the DC gun up to the tapered buncher, though two existing LINAC structures and fourteen solenoids will be remained in the new layout. The main solenoid will be added to compensate the emittance growth due to the space-charge effects [7].

NEW INJECTOR OPTIMIZATION

Concepts of Optimization

In general, the performance of an RF photoinjector strongly depends on following parameters; the magnetic field of the gun main solenoid, the gradient and RF phase of the gun, the gradient and RF phase of the LINAC structures, the rms spot size, pulse length, and 3-dimensional uniformity of the gun driving laser on the cathode, the solenoid strength of LINAC structures, and surface roughness of the cathode [7]. To optimize these parameters, we used scanning function of ASTRA code [3]. First of all, we scanned the strength of the gun main solenoid and the laser spot size on cathode, which are the most critical parameters to get a reasonably small emittance. Then, by scanning other parameters repeatedly, we could find invariant envelope matching conditions, which provide the emittance damping along the LINAC structures and the minimum emittance at the end of LINAC [6, 7].
During the optics matching at the downstream of the LINAC, the beam emittance can be increased due to the chromatic effects [7]. To avoid the chromatic effects, Twiss parameters at the end of the injector should be optimized to satisfy two following conditions; $\beta_{x,y} < 40$ m and $|\alpha_{x,y}| < 0.2$. To achieve these conditions, we had to optimize fourteen solenoids around the LINAC structures.

ASTRA Simulation Results for 1 nC

After scanning, the optimized parameters for 1 nC are summarized in Table 2. We used these optimized parameters to perform ASTRA tracking from the cathode to the end of the LINAC with 0.2×10^6 macro particles. We were able to minimize the chromatic effects by reducing the β-function and α-function at the exit of the injector as shown in Fig. 2 and summarized in Table 3. The transverse normalized emittance was reduced by one order of magnitude compare to the measured values from current LINAC layout. The peak current and the energy spread are dramatically improved as well, which are critical for the applications described earlier. The tracking results for 1 nC are summarized in Table 3.

Table 2: Scanning Results for 1 nC Operation

Parameter	Unit	Value
Magnetic field of main solenoid	T	0.1585
Gun gradient	MV/m	40
Gun RF phase from zero crossing	deg.	34.09
Gradient of 1st LINAC structure	MV/m	10.4
Gradient of 2nd LINAC structure	MV/m	15.0
RF phase of 1st LINAC structure	deg.	0.87
RF phase of 2nd LINAC structure	deg.	0.0
Laser beam spot size (rms) $\sigma_{x,y}$	mm	0.69
Laser pulse length (FWHM) ΔT	ps	20
Laser rising/falling time	ps	1.5
Laser radial profile	·	uniform
Laser longitudinal profile	·	flat top
Solenoid strength around LINAC	T	0.005-0.1

Table 3: Tracking Results for 1 nC Operation

Parameter	Unit	Value
Single bunch charge Q	nC	1
Maximum electron beam energy	MeV	48
Normalized emittance $\varepsilon_{nx,ny}$	μm	1.3
Normalized thermal emittance ε_{th}	μm	0.6
rms beam spot size $\sigma_{x,y}$	mm	0.47
rms bunch length σ_z	ps	7.3
Relative energy spread σ_δ	%	0.03
Peak current	A	42
Twiss parameter $\beta_{x,y}$	m	~ 20
Twiss parameter $|\alpha_{x,y}|$	·	~ 0

Figures 2 and 3 show the evolution of β-function as well as transverse normalized emittance along the LINAC. Since β-function is about 20 m and has zero slope, i.e.,

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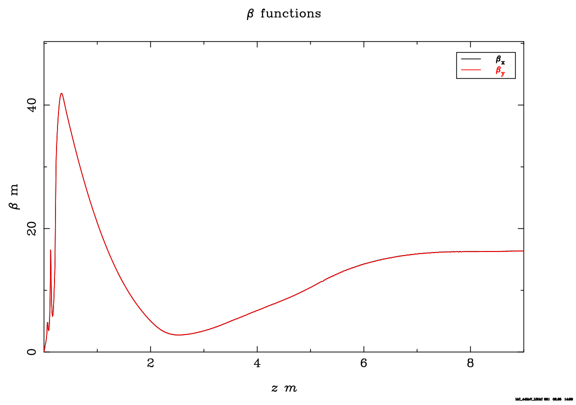

Figure 2: β-function along the injector for 1 nC.

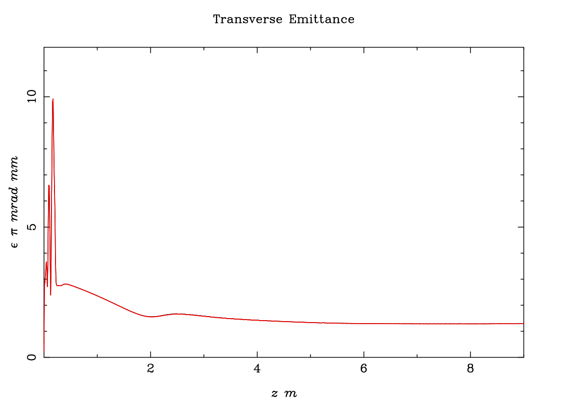

Figure 3: Normalized emittance along the injector for 1 nC.

α-function ~ 0 at the end of the LINAC, the chromatic effects can be negligible. In addition, as shown in Fig. 3, the strong damping of the normalized emittance was successfully achieved along the L-band LINAC structures. Therefore, the new RF photoinjector was optimized properly to satisfy the invariant envelope matching conditions [7]. As shown in Fig. 4, we got well symmetrized current profile.

ASTRA Simulation Results for 5 nC

In general, the total normalized projected emittance can be written as [7, 9],

$$\varepsilon_n = \sqrt{\varepsilon_{th}^2 + \varepsilon_{others}^2}, \qquad (1)$$

where the thermal emittance ε_{th} scales with the single bunch charge Q as: $\varepsilon_{th} \propto \sigma_{x,y} \propto Q^{1/3}$, while the emittance due to other effects ε_{others} scales as $\varepsilon_{others} \propto Q^{2/3}$. After scaling based on results obtained from 1 nC, we got $\varepsilon_n = 3.6$ μm for 5 nC single bunch. To cross check this result, we updated the values of the laser spotsize and pulse length by using a scaling method described in Ref. [7]. Then we performed an ASTRA tracking along the LINAC. As summarized in Table 4, the emittance obtained by two different methods are in a good agreement.

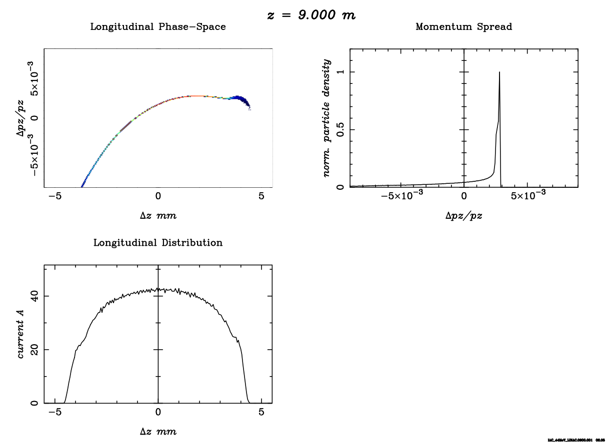

Figure 4: Longitudinal phase space at the end of the LINAC for 1 nC; top-left: phase space, top-right: momentum spread, bottom-left: longitudinal distribution and peak current.

Table 4: Tracking Results for 5 nC Operation

Parameter	Unit	Value
Single bunch charge Q	nC	5
Maximum electron beam energy	MeV	48
Normalized emittance $\varepsilon_{nx,ny}$	μm	3.5
Normalized thermal emittance ε_{th}	μm	1
rms beam spot size $\sigma_{x,y}$	mm	4.8
rms bunch length σ_z	ps	10.2
Relative energy spread σ_δ	%	0.09
Peak current	A	146

SUMMARY

We were able to optimize all important parameters to satisfy conditions required for a high performance injector for two different single bunch charges. ASTRA simulation results showed that, the transverse normalized emittance can be improved by one order of magnitude if we use an RF photoinjector instead of the current thermionic DC gun. In addition, a higher peak current and a lower energy spread can be achieved by the new RF photoinjector.

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