OPTIMIZATION OF INJECTOR SYSTEM FOR EARLY COMMISSIONING PHASE OF COMPACT-ERL

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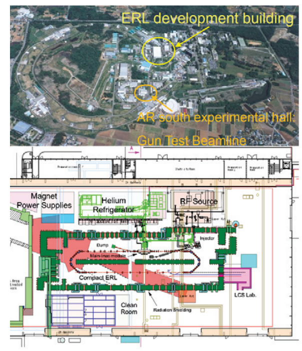
Abstract

Injector system of compact-Energy Recovery Linear accelerator, which is currently develping in Photon Factory of KEK at Japan, consists of the photo-cathode DC gun, two solenoids, a 1.3 GHz buncher ,three 1.3 GHz 2 cell injector cavities, 5 quadrupole magnet and merger section [1]. Target values of beam produced by the injector system are kinetic energy of 5 MeV, the normalized transverse emittance of under 0.1 mm-mrad and the bunch length of under 3 ps with the 7.7 pC charge per bunch and the repetition rate of 1.3 Ghz. In this low energy region, the effect of the space charge is dominated to cause the emittance growth [2]. The optimization is performed by using MOGA (Multi-Object Genetic Algorithm) with code GPT to consider the effect of space charge under optimization. The code General Particle Tracer (GPT) is a 3D Paricle-In-Cell(PIC) code based on multi-layer object-oriented design [3]. Using this method with code GPT, the target values were achieved at the exit of the merger section such as the normalized emittance of 0.1 mm-mrad with bunch length of 3 ps and kinetic energy of 5 MeV.

INTRODUCTION

Many users require a fourth generation light source that can produce high charge, short pulse, low transverse emittance and a high peak current electron beams [4]. The Energy Recovery Linac is one of the candidates for the fourth generation light sources that can meet these requirements. The compact-ERL at KEK, in the final stage, will provide a beam energy of around 125 MeV and a bunch charge of 77 pC, which is a prototype for the future 3 GeV ERL at KEK [5]. The c-ERL consists of an injector system, a merger section, a superconducting RF (SRF) section, two return loops and two straight sections. In the early comissioning phase, the injector produces electron beams with a bunch charge of 7.7 pC, beam energy of 5 MeV and bunch length of 2 $\sim$ 3 ps rms [6]. The beam energy is increased by 30 MeV with two 9 cell SRF cavities in the main ring. The information of the beam line specification and the location of the compact-ERL is shown in Fig. 1.



Parameters	Value
Beam energy (upgradability)	35 MeV 125 MeV (future) 245 MeV (future)
Injection energy	5MeV
Average current	10 mA (100 mA in future)
Acc. Gradient	15MV/m
Normalized emittance	0.1 mm-mrad (for 7.7pC) 1.0 mm-mrad (for 77 pC)
Bunch length	1~3 ps (usual) ~100 fs (for BC. mode)
RF frequency	1.3 GHz

Figure 1: Location and specification of compact-ERL.

INJECTOR SYSTEM

The electron injector system consists of a 500 kV photocathode DC gun,two solenoid magnets, a 1.3 GHz normal-conducting buncher cavity, three 1.3 GHz superconducting RF cavities, seven quadrupole magnets and a merger section. In the early commissioning phase for injector system, the injector system will be examined with beam diagnostic beam line which consist of the several screen monitor for measuring the emittance and beam size, TR cavity for measuring bunch length and beam dump. For this beam line, the electron beams has a bunch charge of 7.7 pC, a beam energy of 5 MeV and a bunch length of 2 $\sim$ 3 ps rms.

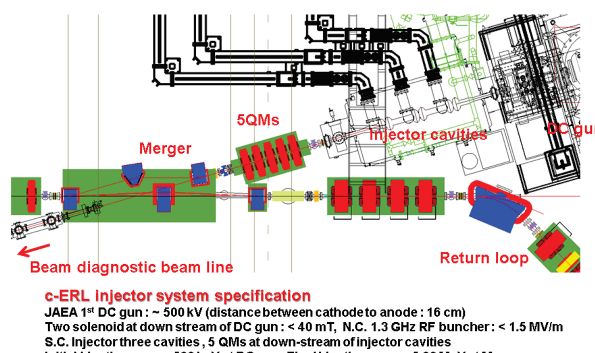


Figure 2: Schematic layout of the injector system.

In the early commissioning phase, the duration of the laser at the cathode surface will be advanced from 3 ps rms with Gaussian distribution to 16 ps with hard-edge distribution. Since the energy of the beam is low, 5 MeV, the effect of the space charge is dominated. Therefore, the effect of the space charge should be included in the optimization of the injector system. The MOGA(Multi-Objective Genetic Algorithm) method with GPT(General Particle Tracer) which can be included an external field map of RF cavities and magnet with PIC(Particle-In-Cell)

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simulation for the effect of space charge.

MOGA METHOD

A multi-objective optimization problem can be formulated as follows [7]:

$$f_m(x_1, x_2, \cdots, x_n), g_j(x_1, x_2, \cdots, x_n) \geq 0 \\ x_i^{(L)} \leq x_i \leq x_i^{(U)} \tag{1}$$

Objective functions $f(x) \equiv (f_1(x), f_2(x), \cdots, f_M(x))$ map n-dimensional decision variable space D of vector $x \equiv (x_1, x_2, \cdots, x_n)$, bounded with lower and upper limits $x^{(L)}$ and $x^{(U)}$, respectively, into M-dimensional objective space Z. The goal is to find all (or as many as possible) solutions x that maximize each objective function $f_m(x)$ subject to J inequality constraints $g_j(x) \geq 0$. Here we do not consider equality constraints, which are more difficult to deal with in practice. A solution x that satisfies all constraints and variable bounds is called feasible (as opposed to infeasible) and the set of all feasible solutions represents the feasible region S in the decision variable space D.

OPTIMIZATION RESULT

In the beginning of the operation of injector system, the laser pulse on the cathode has the duration of 2 ps rms with Gaussisan distribution. And It will be updated to 16 ps with uniform distribution. Therefore, the optimization study for the injector system was done with the laser duration of 2 ps rms and 16 ps, respectively. When we performed the optimization of the injector system, minimization of the emittance and the bunch length at the screen which was installed in the beam diagnostic beam line were set to the main goal.

Optimization with 3 ps Laser Pulse Duration

In the first operation of injector system, the laser which has the pulse duration of 3 ps with gaussian distribution will be used. The effect of the space charge due to the short pulse was dominated near the DC gun. The optimization to get the small emittance with short bunch length is performed using MOGA method. The result of the optimization is shown in Fig. 3.

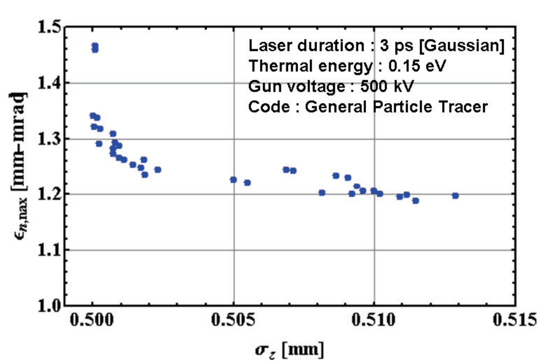

Figure 3: Optimization result by using MOGA method

Since the self field of the bunch relate with density of the particle in the bunch, the transverse emittance is depend on the bunch length at the screen. Therefore, the bunch length is one of the important parameter to get the small emittance. The minimum emittance of the beam is around 1.2 mm-mrad. The envelope of the normalized emittance, beam size and twiss parameter when the emittance was minimized are shown in Fig. 4.

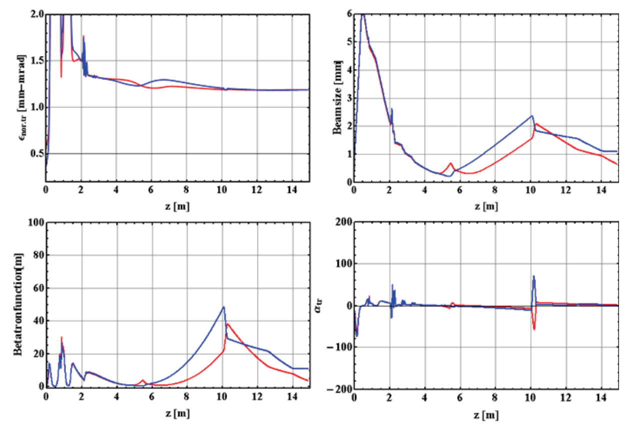

Figure 4: Envelope of the normalized emittance, beam size and twiss parameter.

The beam size was maximized near DC gun and solenoid magnet and it was well compensated by the solenoid magnet. The normalized emittance was also mainly increased near the DC gun due to the strong field strength of self field. The envelope of the energy, the energy spread and the bunch length of the beam are shown in Fig. 5.

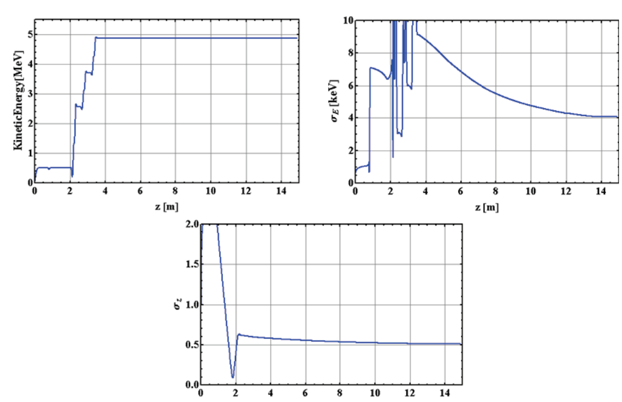

Figure 5: Envelope of the beam energy, energy spread and bunch length.

The beam energy was increased in the three injector SRF cavities to around 5 MeV. It is good for compensation of the effect of the space charge. The length of the bunch was compressed to 0.5 mm by using 1.3 GHz buncher and three injector cavities.

Optimization with 16 ps Laser Pulse Duration

In the second operation of injector system, the laser which has the pulse duration of 16 ps with uniform distribution will be used. The optimization to get the small emittance with short bunch length is performed using MOGA method. The result of the optimization is shown in Fig. 6.

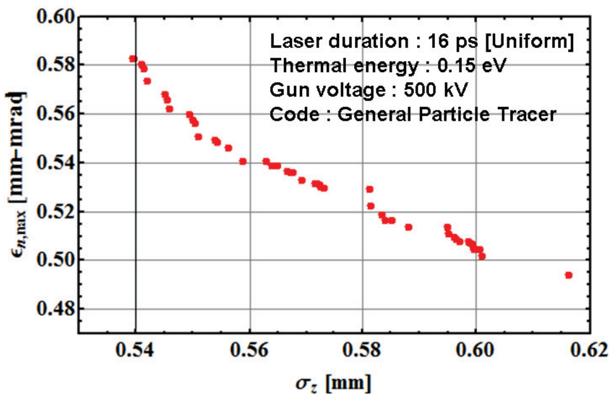

Figure 6: Optimization result by using MOGA method.

The normalized emittance at the screen was became more smaller than the case of the pulse duration of 3 ps due to a long pulse duration of the laser. The envelope of the energy, the energy spread and the bunch length of the beam are shown in Fig. 7.

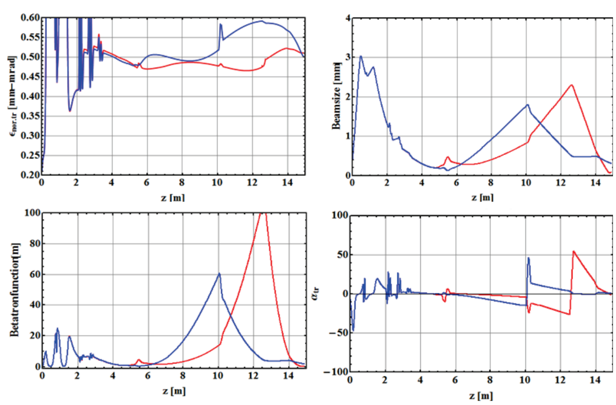

Figure 7: Envelope of the normalized emittance, beam size and twiss parameter.

As shown in Fig. 7, the growth of the beam size near the DC gun is more smaller than the case of the laser duration of 3 ps since the long pulse produced the long bunch length which has small amplitude of the self filed. The envelope of the energy, the energy spread and the bunch length of the beam are shown in Fig. 8. And the parameters of the elements after optimization is also listed in Tab. 1.

CONCLUSION

The optimization of the injector system with various pulse duration of the laser, 3 ps with Gaussian distribution and 16 ps with uniform distribution, is performed using MOGA method. In case of the 16 ps pulse duration, the effect of the space charge was minimized due to the relatively low intensity of the particle in the bunch. Hence, the laser which has the long pulse duration is required to achieve the small emittance of the beam. The injector system can provide the beam has the emittance smaller than 0.5 mm-mrad with the bunch length of 2 ps rms even through the duration of the laser pulse is 16 ps.

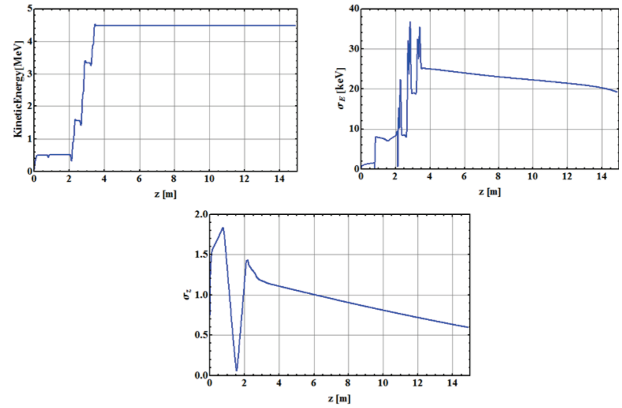

Figure 8: Envelope of the beam energy, energy spread and bunch length.

Table 1: Parameters of the elements after optimization with 16 ps laser pulse.

Parameter	Unit	Value
Laser diameter	mm	1.235
Laser duration	ps	16
Solenoid1	mT	33.81
Solenoid2	mT	22.17
E_{bun}, ϕ_{bun}	MV/m, deg	3.00, -90
E_{inj1}, ϕ_{inj1}	MV/m, deg	11.22, -30.00
E_{inj2}, ϕ_{inj2}	MV/m, deg	16.16, -9.98
E_{inj3}, ϕ_{inj3}	MV/m, deg	10.06, -10.00
k_{QM1}	$1/m^2$	-8.00
k_{QM2}	$1/m^2$	5.75
k_{QM3}	$1/m^2$	-32.35
k_{QM4}	$1/m^2$	40.00
k_{QM5}	$1/m^2$	-16.00

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