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THE BEAM DYNAMICS SIMULATION OF AN L-BAND ELECTRON GUN USING GENETIC ALGORITHM

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Abstract

The China Academy of Engineering Physics (CAEP) plans to build XFEL light source. In the beam dynamics simulation there are many parameters to be considered, so we need a high efficient method to find the optimal parameters. Genetic algorithm (GA) [1] is wildly used as one kind of evolutionary algorithm and it can help us to find the optimal parameters in a shorter time. In this paper, we will use genetic algorithm to do the beam dynamics simulation of an L-band electron gun used for the XFEL. We put emphasis on the optimization of the transverse normalized projected emittance and the relevant result will be given and discussed.

INTRODUCTION

The China Academy of Engineering Physics (CAEP) plans to build XFEL light source. A normal conducting L-band photocathode electron gun will be used to produce high quality electron beam and its working frequency is 1.3 GHz. One of the most important parameters that influence the FEL process is the normalized transverse projected emittance, hereafter called emittance. There are many parameters to be considered in the beam dynamics simulation of the electron gun in order to get an optimized result. We need one efficient way to find these optimal parameters. Genetic algorithm is wildly used as one kind of evolutionary algorithm and it can help us to find the optimal parameters in a shorter time. In this paper, we will use genetic algorithm to do the beam dynamics simulation.

THE BEAM LINE AND GA

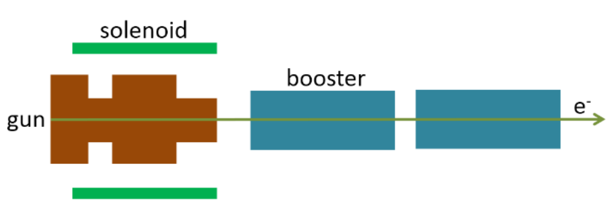

Figure 1: The simplified schematic of the beam line.

The electron source used for the XFEL is one normal conducting 1.6-cell L-band RF gun and its working frequency is 1.3 GHz (the field is shown in Fig. 2). The photocathode will use Cs_2Te or Cu, and they will be illuminated by UV laser pulses to produce high quality electron beams. The produced beams will be focused with solenoid installed around the gun. The beam will be further accelerated by the superconducting TESLA booster (9-cell). The simplified schematic of the beam line is shown in Fig. 1.

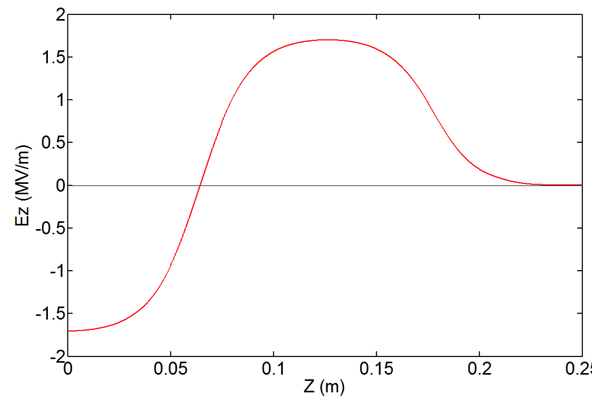

Figure 2: The electric field of the L-band gun.

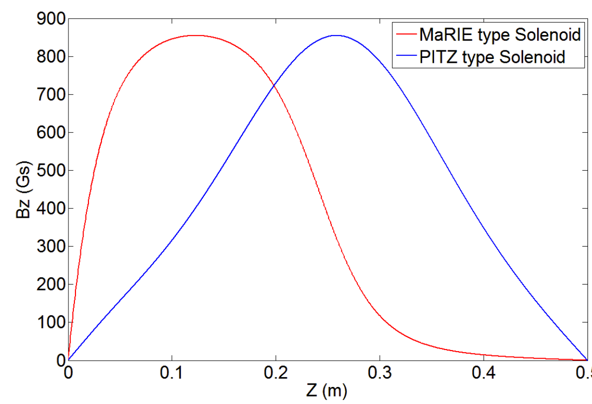

Figure 3: The magnetic field of solenoids.

In the simulation we compared the MaRIE [2] type solenoid, hereafter called M type, and the PITZ [3] type solenoid (P type). The magnetic field of the solenoids is shown in Fig. 3. We use ASTRA code [4] to do the beam dynamics simulation.

The initial condition is FWHM pulse length Lt = 20ps and the rise time rt = 2ps. The laser pulse longitudinal shape is plateau distribution, and the transverse distribution is 2D uniform distribution. The E_{acc} of the booster is 20 MV/m and the gain energy is about 20 MeV for each 9-cell superconducting cavity.

Genetic algorithm solver is in the optimization tool of MATLAB. The GUI interface of the GA solver in MATLAB is shown in Fig. 4. We need to write the fitness function and set constrains. The population type is double vector and the population size is 50 ~ 100 for 4 variables. In the stop criteria option, *Generations* specifies the maximum number of iterations the genetic algorithm performs. In the plot function option, *Best fitness* plots the best function value in each generation versus iteration number.

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Table 1: Results from the GA Simulation for the L-band Electron Gun

Solenoid type	Photo-cathode	Bunch charge (pC)	E_{cath} (MV/m)	Sig_x (mm)	Phase (degree)	MaxB (Gs)	[b]Pos(2) (m)	Emittance (mm-mrad)
M	[a]Cs_2Te	200	55	0.163	7.0	1892	2.05	0.241
M	Cs_2Te	200	60	0.147	7.2	2030	2.15	0.226
M	Cs_2Te	200	65	0.142	7.5	2167	2.29	0.214
M	Cs_2Te	100	55	0.106	7.9	1875	2.56	0.161
M	Cs_2Te	100	60	0.097	7.8	2018	2.49	0.148
M	[a]Cu	100	60	0.112	8.1	2031	2.09	0.074
M	Cu	200	60	0.156	7.3	2035	1.95	0.114
P	Cs_2Te	100	60	0.113	3.3	2102	2.86	0.190
P	Cs_2Te	200	60	0.157	2.3	2093	3.14	0.259

[a] LE of the Cs_2Te is 1.2 eV and 0.132 eV for Cu. [b] Pos(2) is the distance from the cathode to the first booster cavity.

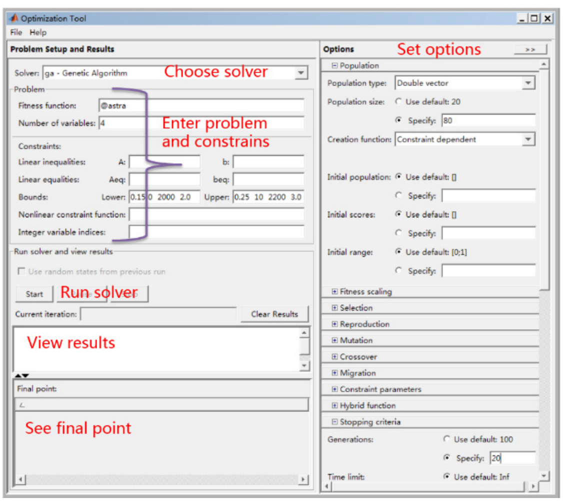

Figure 4: Genetic algorithm solver in MATLAB.

THE SIMULATION RESULT

Figure 5 shows one optimization result from the GA solver, we can see that the minimum emittance decreases gradually with the increase of generation. The average emittance of each generation has the same trend as the minimum emittance. Eventually, the average emittance coincides with the minimum emittance, it means that the result is converged.

Table 1 gives the results from the GA simulation for the L-band electron gun. From the result we can see that using M type solenoid gets lower emittance. With higher E_{cath} we can get better result. When the bunch charge changed, e.g from 100 pC to 200 pC, the phase of the cavity and the magnetic field of the solenoid have the similar value.

$$\frac{\rho_1}{\rho_2} = \frac{Q_1 / S_2}{Q_2 / S_1} = \frac{r_2^2 Q_1}{r_1^2 Q_2} . \qquad (1)$$

Actually, the charge density is basically constant for different bunch charge, the charge density relationship of between different bunch charge is shown in Eq. (1). Q is the bunch charge and r is the radius of the bunch.

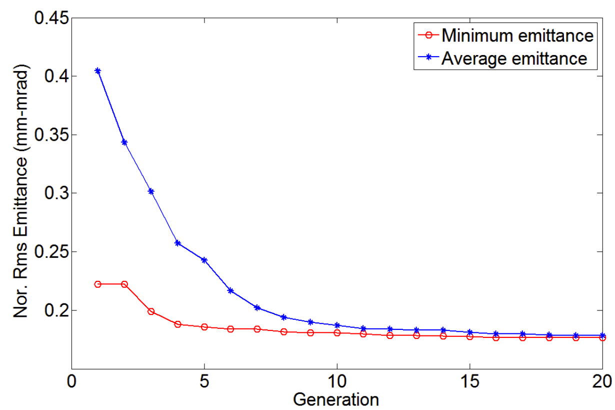

Figure 5: One optimization result from the GA solver.

For the P type solenoid and Cs_2Te photocathode case, $0.157^2/0.113^2/2= 0.97$, for the M type solenoid and Cs_2Te case, $0.147^2/0.097^2/2= 1.15$, and for the M type solenoid and Cu photocathode case, $0.156^2/0.112^2/2 = 0.97$.

SUMMARY

When there are many parameters to optimize we need one efficient way to find the optimal results. Here we choose genetic algorithm to realize this goal, and it proves that GA is very available. It help us save a lot of time. In the current optimization procedure we just have one objective function, in the future work we will use multi-objective genetic optimizer for the further optimization.

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