Multidimensional search program for photo injectors optimization

Olexiy Lazarevych
Moscow Institute of Physics and Technology (State University)
Institutskiy per. 9, Dolgoprudny, Moscow reg., Russian Federation
Email: olexiy.lazarevych@desy.de

Production of electron beam of high quality is a key issue of photo injector design. Theoretical study and computer simulations are of great importance for producing high quality beam. ASTRA is a powerful computer tool for beam dynamic simulations and for investigating beam properties dependence on a number of machine and laser parameters, but a multidimensional direct scan is rather time consuming. To increase the efficiency of computer simulations a new program has been developed. It is based on the method of deforming polyhedron (Nelder-Mead's method) and uses ASTRA solver. Results of 3-parameter search using this program for minimum transverse emittance at 1 nC beam charge for various laser longitudinal profiles are presented in the paper.

1 Introduction

A Free Electron Laser[1] generates tunable, coherent, high power radiation, currently spanning wavelengths from millimeter to visible and potentially ultraviolet to x-ray. It can have the optical properties characteristic of conventional lasers such as high spatial coherence and a near diffraction limited radiation beam. It differs from conventional lasers in using a relativistic electron beam as its lasing medium, as opposed to bound atomic or molecular states, hence the term free-electron.

A Free Electron Laser for wavelengths down to 6 nm in the vacuum- ultraviolet and soft X-ray regime (VUV FEL) is under construction at the TESLA Test Facility (TTF) at DESY[2]. It is operated in the "self-amplified spontaneous emission" (SASE) mode and delivers sub-picosecond radiation pulses, with gigawatt peak powers.

Due to the short pulse length and their high peak brilliance these FELs will open up exciting new paths for basic research and application-oriented studies, giving scientists, for example, insight into hitherto unknown properties of materials.

SASE FEL sources can provide extremely brilliant beams of VUV-to X-ray radiation. They require electron beams of high quality in terms of bunch charge, pulse length and emittance.

Fig. 1: *The PITZ tunnel*

The Photo Injector Test facility at DESY Zeuthen (PITZ)[3,4] was built to develop electron sources for the TESLA Test Facility Free Electron Laser (TTF-FEL) and future linear colliders. The facility includes a 1.5 cell L-band cavity with coaxial rf coupler, a solenoid for space charge compensation, a laser capable to generate long pulse trains, an UHV photo cathode exchange system, and different diagnostics tools. The main goal is to study the production of small (1 π mm mrad) transverse emittance beams with short bunch length at medium charge (1nC). This task is rather difficult to fulfill, as transverse emittance is a function of number of different parameters.

A Space Charge Tracking Algorithm (ASTRA)[5] was developed as a computer tool to investigate dependence of the beam characteristics on different parameters of photo injectors. ASTRA offers different options for doing parameter scan, but opportunities are rather confined and calculations could take too much time and computer resources.

A new program "Auto" for parameters scan and optimization was developed as an application to ASTRA. It organizes multi-parameter search using ASTRA and its output files. Optimizing algorithm is based on Nelder-Mead's method[6] for searching for minimum of n-variable function.

In this method an initial simplex – a configuration of (N+1) ponts in N-dimensional space – is placed around initial point. Then transference of the simplex by reflection of the apex with the greatest value of the function take place relatively to center of mass of the opposite base of the simplex. Here some special operations are used. They are concerned with expanding of the simplex in the direction of function decrease and contraction of the simplex if an unsuccessful transference has occurred. The realization of the method uses four constant parameters: parameters of reflection (a<0), expanding (b<1), contraction to the base (0<c<1) and contraction to the best apex (0<d<1).

"Auto" makes it possible to perform scanning of a number of parameters that is limited only by computer resources and practical sense. Using of Nelder-Mead's algorithm guarantees a considerable saving of time, especially in comparison with direct scanning implemented in ASTRA.

2 Simulation experiment

Calculations with the help of "Auto" were applied for one of the most important tasks – optimization of facility parameters for obtaining electron bunches with minimum possible transverse emittance. One of the important conditions was charge conservation along the beam line.

2.1 Setup conditions for simulation

- RF gun

  The cavity field has been applied (See Fig.2)

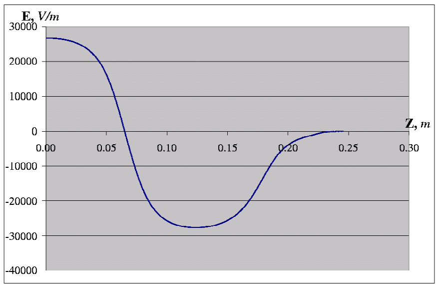

Fig. 2: *Cavity field*

- Solenoid

  The solenoid field has been applied.(See Fig. 3) Position of the solenoid has been set to 0.28 m. The buck coil has not been applied, so there is a small magnetic field at the cathode.

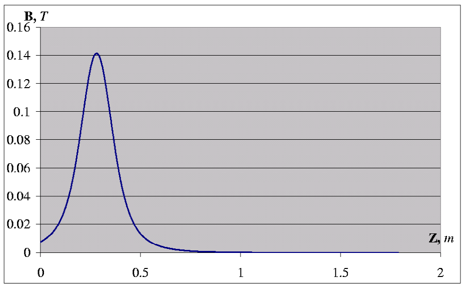

Fig. 3: *Main solenoid field*

- Initial electron beam

  The initial transverse particle distribution has been radial, the longitudinal particle distribution has been flat top. Thermal emittance has not been applied. The number of particle have been considered is 2000. The values of the rise time of the bunch has been considered are 2, 4, 5 and 6 ps; the values of the full width at the half of

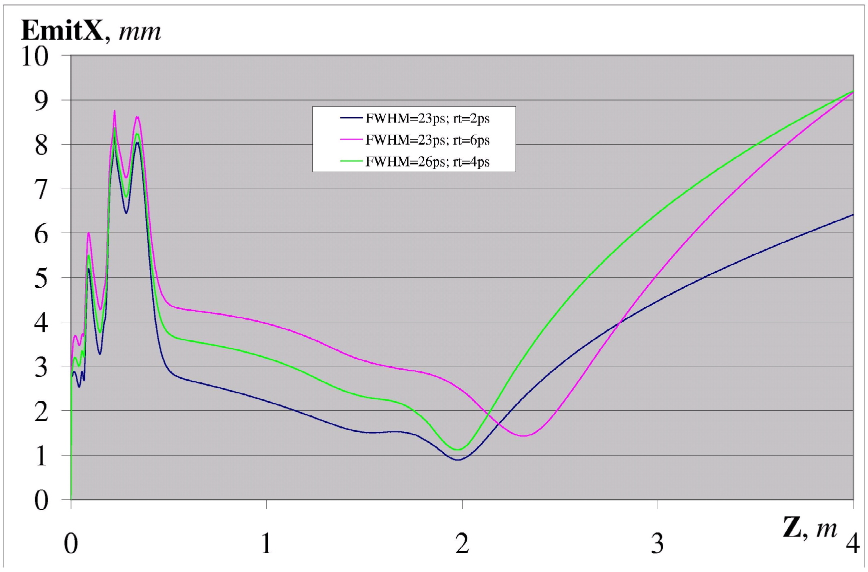

Fig. 4: *Transverse emittance for simulation experiments with 50000 particles*

maximum of the bunch are 20, 23 and 26 ps.

- Parameters that have been optimized

  Parameters and their range pf values are listed in Table 1.

Tab. 1: *Variable parameters*

Horizontal rms beam size (XYrms), mm	0.3 – 1.0
Phase of the rf field (Phi(1)), degree	10 – 40
Maximum field value of the solenoid field (MaxB(1)), T	0 – 0.25

The results has been obtained are listed in the Table 2.

The best results has been confirmed by the ASTRA simulations with 50000 particles.

Simulations show value of the transverse emittance in case of present laser parameters (FWHW≈26 ps, τ≈4 ps) and in case of project parameters (FWHW=20 ps, τ=2 ps).

The coordinate of the minimum of the transverse emittance is an important value which will help to define the best position of the next facility device – booster cavity. It is important for PITZ-2, as one of the its main objectives is the proof of the emittance compensation technique and experimental optimization, since many future FEL proposals rely on this technique.

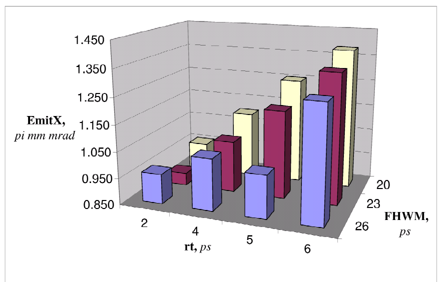

Fig. 5: *Dependence of the transverse emittance on rise time and FWHM*

3 Conclusions

The application for ASTRA simulation "Auto" has been developed for optimizing photo in-

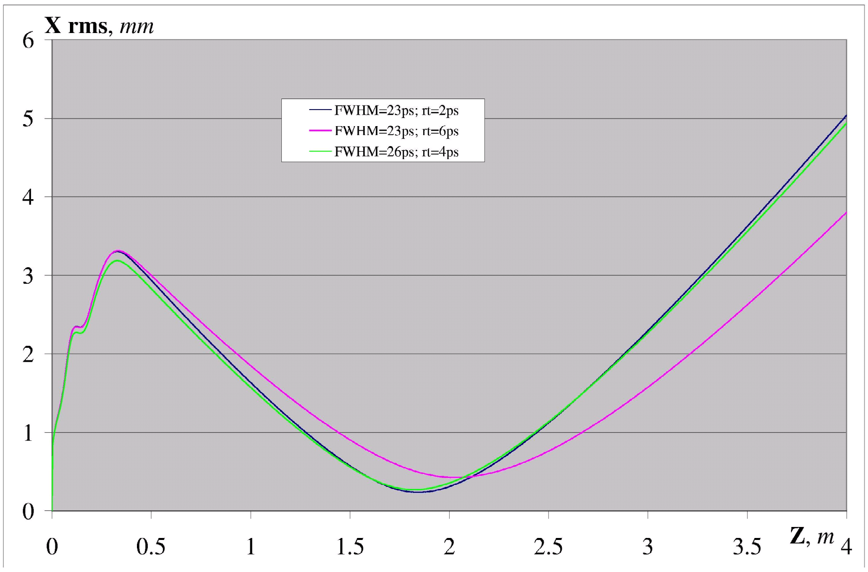

Fig. 6: *Horizontal rms beam size for simulation experiments with 50000 particles*

jector parameters to obtain desirable electron beam properties needed for FEL. As shown by the calculations has been performed, the program is a realy powerful tool for doing search for optimal parameters. Moreover "Auto" could be applied for other purposes, for example, for simulations of measurements for actual facility parameters using measured beam properties. Thus possibilities of "Auto" are not restricted by the calculations described above, its extension could provide a lot of other simulation experiments.

References

[1] Free Electron Laser, http://www-hasylab.desy.de/facility/fel/

[2] *M.Ferrario et al.*,Conceptual Design of the XFEL Photoinjector, TESLA FEL Report, 2001–2003

[3] *J.Baehr et al.*, First Beam Measurements at the Photo Injector Test Facility at DESY Zeuthen, FEL 2002.

[4] *F. Stephan et. al.*, Photo Injector Test Facility under construction at DESY Zeuthen, Proc. FEL2000, Durham, August 2000.

[5] ASTRA, A Space Charge Tracking Algorithm, http://www.desy.de/m̃pyflo/ Astra_dokumentation/, 2000.

[6] Nelder-Mead's method, http://baclanout.abitu.ru/ims/mpor/ j_e7zhr/l_6gzhr/p_gj0ir.esp, http://ssu.sumy.ua/cources/mo/rus/ m_n_mida.html

Tab. 2: *Simulation experiment results*

Full width at the half of maximum (FWHM), ps	Rise time (τ), ps	2000 particles				50000 particles	
		Transverse x-emittance, π mm mrad	Maximum field value of the solenoid field, T	RF Phase, degree	Horizontal rms beam size, mm	Transverse x-emittance, π mm mrad	Coordinate of minimum x-emittance, m
20	2	0.956	0.167	34.136	0.752	0.971	1.994
20	4	1.103	0.167	33.042	0.753		
20	5	1.245	0.166	33.215	0.753		
20	6	1.384	0.165	32.787	0.756		
23	2	0.897	0.167	33.042	0.753	0.892	1.978
23	4	1.046	0.165	32.820	0.692		
23	5	1.184	0.167	33.000	0.767		
23	6	1.139	0.165	32.787	0.765	1.428	2.314
26	2	0.962	0.169	33.333	0.658		
26	4	1.046	0.167	33.000	0.767	1.120	1.978
26	5	1.011	0.164	34.615	0.661		
26	6	1.283	0.164	32.783	0.755		