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SIMULATION OF THE ELBE SRF GUN II

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Abstract

By combining the code of ASTRA and elegant in a user-friendly interface, a simulation tool is developed for the ELBE SRF Gun II. The photoelectric emission and first acceleration to several MeV in the gun cavity are simulated by ASTRA with a 1D Model, where the space charge effect is considered. The dependence of the beam quality on key parameters is studied, and a compromised optimization for a 77 pC beam is used for further elegant simulation of the beam transport through a dogleg and ELBE Linacs. Proper settings of the magnets and RF phases are the main targets of improving the beam quality. Up to now the best simulation result is an electron bunch with the energy of 47 MeV, energy spread of 66 keV, bunch length of 0.35 ps and transverse emittance of 1.9 µm and 2.7 µm in the two perpendicular directions.

MOTIVATION

ELBE (Electron Linac with high Brilliance and low Emittance) SRF (Superconducting Radio Frequency) Gun II[1] is a new SRF photo injector which has been built up and in commission at Helmholtz-Zentrum Dresden-Rossendorf (HZDR) since May 2014. This SRF gun is an improvement of the ELBE SRF Gun I[2] with a fine grain 3½-cell Nb cavity for realizing higher gradient — up to 9 MeV — and a superconducting solenoid for the potential emittance compensation.

Electron bunches from ELBE SRF Gun II are supposed to transport through a dogleg and then into the Linac beam line of the ELBE, which is designed not for a SRF gun but for a thermal gun, and finally to conduct the Thomson backscattering experiment. Accordingly, a complete simulation is necessary to optimize the electron generation and the beam transport.

We aim to develop a flexible simulation tool to satisfy multiple operational modes during the commissioning and multi-purpose usages of ELBE SRF Gun II. Besides of precision of the simulation, relaxed requirements to users and a reliable optimization procedure are also important.

SIMULATION DESIGN

As shown in Figure 1, the whole simulation includes the electron bunch emission from a Cs_2Te Cathode and the transport in the gun and the beam line, composed of a dogleg, four 9-cell cavities and two chicanes. The superconducting solenoid at the exit of the gun cavity and quadrupoles along the beamline are also simulated but not indicated in Figure 1. The final focusing system will add into the simulation in short future.

Bunch Generation

The emission from the cathode can be completely described by the 6D phase space of the electron bunch. Following criterions are used to generate a proper bunch:

1. According to K. Flottmann[3], we simplify the kinetic energy of each electron to be a constant of 0.55 eV.
2. The electron density on the transverse plane is consistent with the laser spot distribution.
3. The longitudinal distribution of the bunch is coherent to the laser pulse time structure, which has the rms length of 1.3 ps and assumed to be Gaussian distributed.
4. Number of particles is a free parameter, which is normally set between 10k to 100k. And total bunch charge will be calibrated by the beam current intensity.

In-Gun Transport

In the gun cavity the bunch energy is gradually increased from quasi-zero to several MeV, Where the space charge effect is significant. The simulation is done by ASTRA, with RF and DC field distribution files as input. These files are calculated by Superfish for a defined DC Voltage applied on the cathode and a defined distance between the cathode and the cavity. A typical simulation time on PC is about 5 minutes.

High Energy Transport

After the electron bunch is accelerated to several MeV, emittance rather than space charge is dominating the transverse beam motion. Elegant[4] is further applied to simulate the beam transport ignoring transverse space charge effect. The matrix calculation is up to 3^{rd} order. The Coherent Synchrotron Radiation (CSR) effect[5] in the bending magnets and the Longitudinal Space Charge (LSC) effect[6] in drifts are considered. One run costs about 5 s on PC. This short time offers the possibility of manual optimization of the parameters.

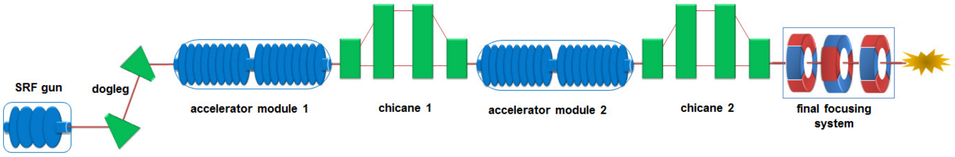


Figure 1: Beam line footprint of the simulation, the final focusing system will be included shortly.

Optimization Procedure

The simulation tool offers the possibility of scanning up to 2 parameters and plotting the results. This is functional to scan the RF phase and the chicane bending angle to optimize the longitudinal phase space. For the transverse phase space, a simplex optimization procedure is applied, suppporting the user to edit the optimization criterion. As there are more than 30 free parameters along our system, we do the optimization section by section. Within each section no more than 6 parameters are handled. This simplex procedure depends on the initial values, so manual optimization is better to be conducted at first.

All the above functions and considerations are realized in a Labview shell, with graphic controlling and automatic data-transaction between codes.

SIMULATION RESULTS

Gun Parameters Study

For ELBE SRF Gun II itself, we investigated the influences to the bunch performance after the gun cavity of important parameters, like laser phase, cathode position, the suppression DV voltage on the cathode and the laser spot size. In this section we only present the case that the laser spot size on the cathode plays an important role to the gun quality.

In Figure 2, the laser spot radius is scanned from 0.2 mm to 0.6 mm with different bunch charge from 1 pC to 100 pC. The bunch parameters at the exit of the gun cavity are presented. As expected, the transverse emittance increases with the laser spot size. However, both radius and divergence of the electron bunch are smaller after the gun cavity. Also for the term of bunch length, lager laser spot size shows superiority.

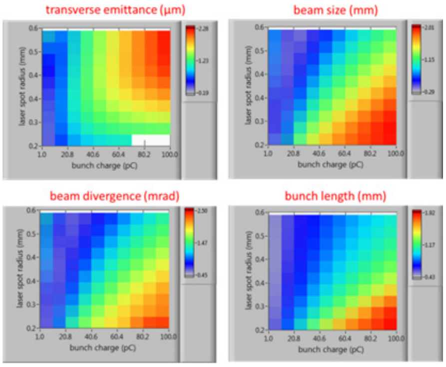
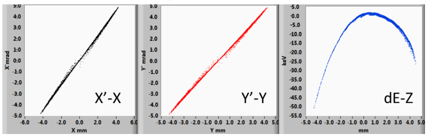


Figure 2: The influence of the laser spot size to the SRF gun beam quality.

In Figure 3, the phase spaces are compared between 0.3 mm and 0.6 mm of the laser spot size. It is shown that a lager laser spot size results in a fatter but shorter transverse phase space and a shorter, linear longitudinal phase space. The differences can be explained by the space charge effect which is relaxed when the original bunch size increases. In the further simulation with elegant, the electron bunch from a lager laser spot size can be optimized to better qualities.

laser spot radius = 0.3 mm



laser spot radius =0.6 mm

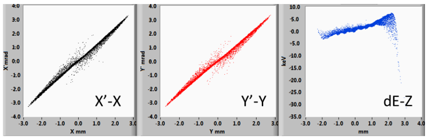


Figure 3: Phase space at the end of the gun cavity compared between 0.3 mm and 0.6 mm of the laser spot radius.

Beam Transport Optimization

In this section the optimization to the electron bunch shown in Figure 3 (laser spot radius = 0.6 mm) is presented. Optimized phase spaces are shown in Figure 4. The longitudinal phase space is optimized first by adjusting RF phases of the ELBE Linacs and the bending angle of the chicanes. Both modules are used for chirping and both chicanes compress the bunch. Any nonlinearity in the longitudinal phase space will lead to the crescent shape after the second chicane, when the bunch is the most compressed. Therefore a shorter bunch length at the entrance of both modules is important. At last, the LSC effect in the long drift after the second chicane will distort the longitudinal phase according to the longitudinal electron density distribution, which should also be considered when compressing the bunch.

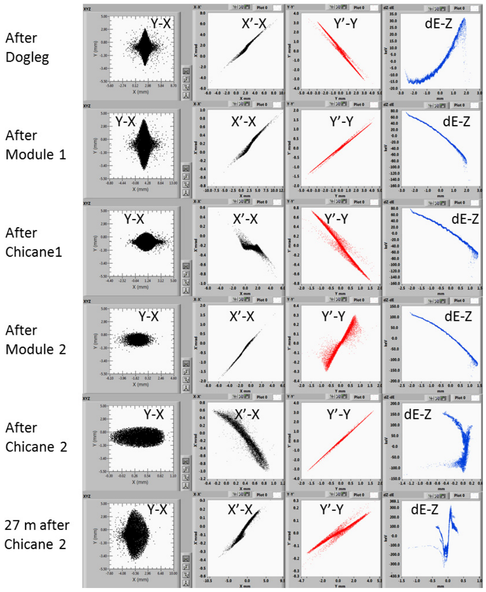


Figure 4: Bunch distribution and phase space evolving along the beamline for this optimized case.

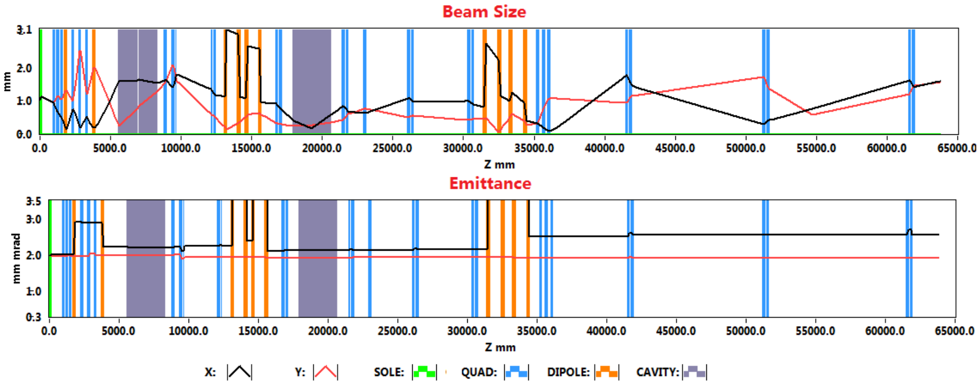


Figure 5: Beam size and transverse emittance evolving along the beamline. X is the bending direction in dipoles.

Table 1: Optimized Beam Qualities at the Exit of the Gun Cavity and the End of the Simulated Beamline

	E (MeV)	ΔE (keV)	X (mm)	Y (mm)	X' (mrad)	Y' (mrad)	ε_x (μm)	ε_y (μm)	Δt (ps)
Gun exit	7.6	2.3	1.2	1.2	1.39	1.39	1.22	1.22	3.48
Beamline	47.3	149.9	1.6	1.6	0.10	0.06	2.56	1.91	0.44

For the transverse optimization, the CSR effect contributes not only to the bunch energy, but also to the transverse emittance. If the CSR effect is ignored in the simulation, the transverse emittance keeps a constant before and after the chicanes. However, when taking account of the CSR effect, there might be an increase on the transverse emittance after chicanes, which can be minimized by properly adjusting the quadrupoles in front. The reason of this phenomenon will be further investigated, but now we apply the automatic simplex optimization with higher priority of emittance to solve this problem.

Figure 5 plots the rms beam size and transverse emittance of the whole system. Except for travelling inside the chicane, which is illustrated by four connecting dipoles, the beam rms size is always less than 2 mm. The emittance of the X direction increases through the dogleg although the η function in the dogleg is already compensated to be quasi-zero by the triplelet. The pure increase of emittance in two chicanes is minimized. Beam quality parameters after the gun and after the entire simulation are presented in Table 1. Each single parameter is not to its best but always has to compromise to others. Results listed are optimized with a certain demand, which is editable.

CONCLUSION

A simulation tool is developed for ELBE SRF Gun II. Gun parameters are studied and a setting for 77 pC beam has been chosen to conduct the further transport simulation. Simplex algorithm is applied to a single bunch to find the optimized beam quality in ELBE accelerators, with matrix calculation, CSR and LSC effect considered. In future the wall effect and wakes between bunches will be included step by step, and a more accurate optimization with a larger number of particles is planned to be carried out with the help of the Linux-clusters at HZDR.

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