BEAM DYNAMIC SIMULATIONS OF THE NEW POLARIZED ELECTRON INJECTOR OF THE S-DALINAC*

B. Steiner [§],W. Ackermann, S. Franke, W.F.O. Müller, T. Weiland
Technische Universität Darmstadt, Institut für Theorie Elektromagnetischer Felder (TEMF)
Schlossgartenstrasse 8, 64289 Darmstadt, Germany
R. Barday, C. Eckard, R. Eichhorn, J. Enders, C. Heßler, Y. Poltoratska, A. Richter, M. Roth
Technische Universität Darmstadt, Institut für Kernphysik (IKP)
Schlossgartenstrasse 9, 64289 Darmstadt, Germany

Abstract

Aiming at an extension of the experimental possibilities at the superconducting Darmstadt electron linear accelerator S-DALINAC, a polarized gun is going to be constructed at the moment. The new injector will be able to supply polarized electrons with kinetic energy in the 100 keV range and should add to the present unpolarized thermionic 250 keV source. The design requirements include a polarization degree of at least 80 %, a mean current intensity of 60 A and a 3 GHz cw time structure. The gun part is simulated in MAFIA whereas subsequent beam dynamics simulations are performed in V-Code. Initial conditions for the V-Code's moment approach are extracted from CST MAFIA simulations. The injector consists of short triplets, an alpha magnet, a Wien filter, a Mott polarimeter, a chopper/prebuncher system and beam diagnostic elements. For the simulations, the 3D electromagnetic fields of the beam line elements are used by means of a Taylor series expansion of variable order. All components except the chopper and a collimator are represented in the simulations. Recent beam dynamic results will be presented.

INTRODUCTION

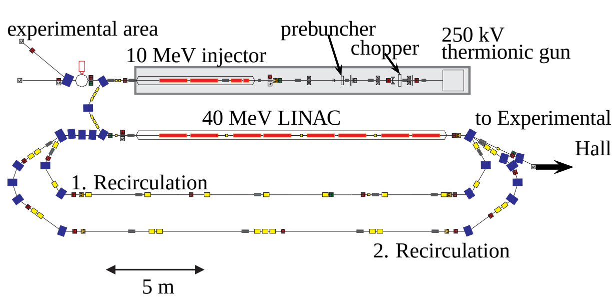

Figure 1: Accelerator hall of the S-DALINAC: The injector is underlayed with gray.

The superconducting recirculating electron accelerator S-DALINAC [1] is designed to deliver a continous wave (cw) electron beam for nuclear and radiation physics experiments and has commenced operations in 1991. It delivers an electron beam with average current of up to 60 μA at energies of 10 to 130 MeV. The current set-up of the S-DALINAC is shown in Fig. 1. For extending the experemential opportunities of the S-DALINAC, a polarized 100 kV source is under construction and has to be integrated into the injector. Therefore the new S-DALINAC Polarized INjector (SPIN) Fig. 2 is designed. The design requirements of the new source are a polarization degree of at least 80 %, a mean current of 60 μA and a 3 GHz time structure. The main components of the polarized injector are the 100 kV source [2], an α-magnet, a Wien filter [3], a Mott polarimeter, compact quadrupole-triplets and a chopper/prebuncher system [4].

For achieving complete beam dynamics simulations through the whole polarized injector, the source is calculated with the PIC-Code of MAFIA [5]. Behind the source a statistical analysis of the bunch is done and these statistical values are the start-ensemble of the V-Code simulations [6] where the beam dynamics of the beam line is calculated. The start values of the V-Code are $\sigma_x = 0.327$ mm, $\sigma_{p_x} = 6.289 \cdot 10^{-4}$ and a normalized transverse emittance of 0,066 mm mrad for a pessimistic estimated start parameters at the photocathode. The bunch length is 50 ps and the bunch energy is 100 keV with a relative energy spread of $0.4 \cdot 10^{-4}$.

TRANSVERSE BEAM DYNAMICS SIMULATION RESULTS

The nominal trajectory through the α-magnet is set for the middle of the working area at 450 Gauss. The V-Code simulations show that the α-magnet is working better at around 410 Gauss. Because the field is lower than the nominal the electrons fly deeper into the α-magnet which causes the offset of the bunch center in the α-magnet (Fig. 3). The fringe fields of the Wien filter produces an offset in y-direction. The electrons are defelected from the nomial trajectory and back to it. Steerers behind the α-magnet and Wien filter hold the bunch center on the nominal trajectory.

Four compact quadrupole-triplets provide to good focussing at the critical positions (Fig. 4). The first one fucusses in the α-magnet to minimize an emittance growth. Behind the α-magnet the beam is elliptic and goes with

* Work supported by DFG under contract SFB 634
§ steiner@temf.tu-darmstadt.de

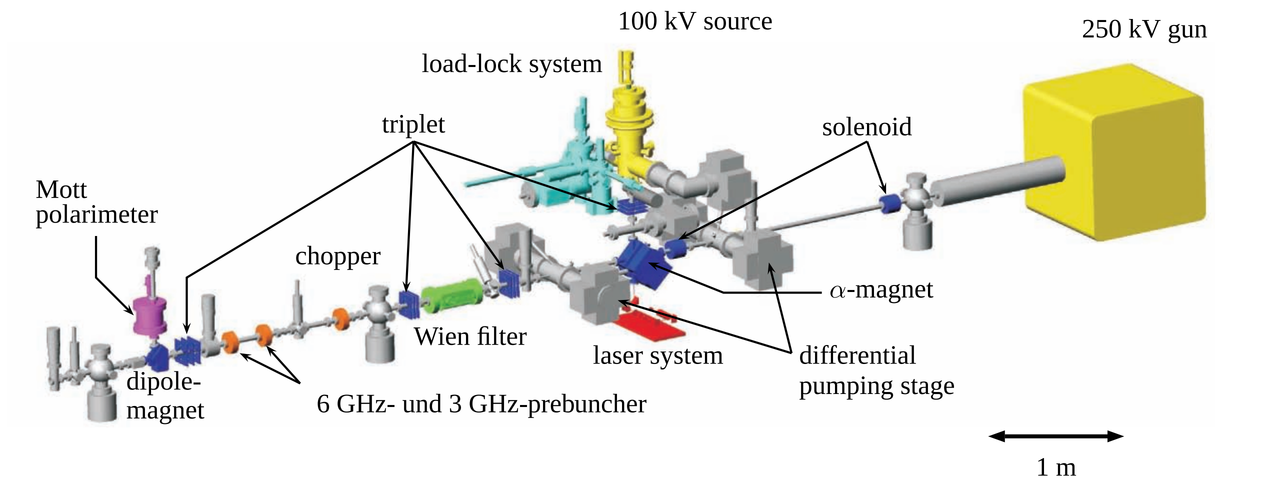

Figure 2: Layout of the new injector including the 250 kV thermionic gun and the 100 kV photoemission source. The supercondcting part of injector follows on the left hand side.

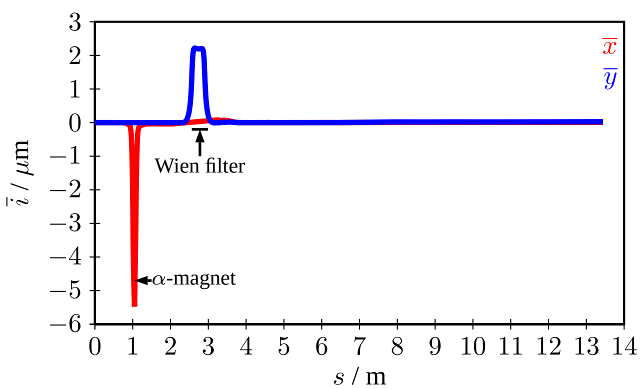

Figure 3: Horizontal and vertical offset of the bunch center over the whole injector of the 100 kV photoemission source. The Wien filter is set up for 90° spin rotation so that the maximun effects are shown.

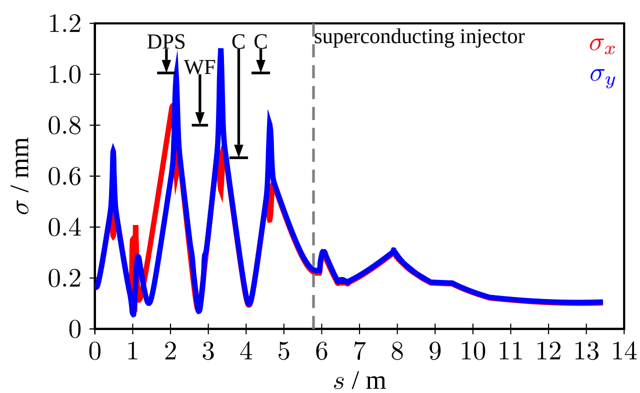

Figure 4: Horizontal and vertical 1σ bunch width over the whole injector of the 100 kV photoemission source. The Wien filter is set up for 90° spin rotation so that the maximun effects are shown. The arrows shows the maximum allowed 1σ beam width at the critical positions

high transmission (5σ) through the collimator which is in the middle of the differential pumping stage. The next triplet is focussing the beam into the middle of the Wien filter. The effects of the Wien filter is well reduced for this set up. That's why behind the Wien filter another triplet is needed to focus the beam through the chopper collimators. The last triplet focus into the 2-cell accelerator structure. In the following accelerating part the bunch width stays small.

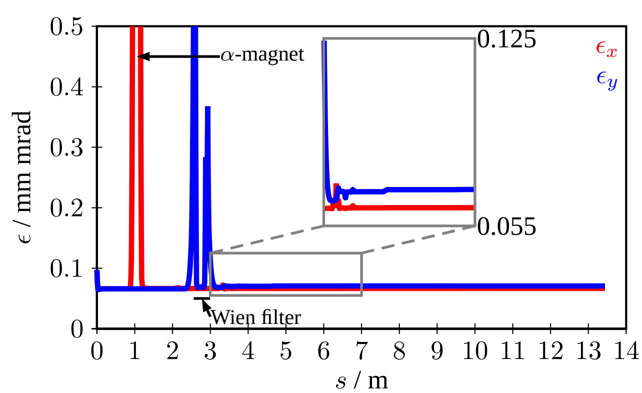

Figure 5: The normalized horizontal und vertical 1σ emittance over the whole injector of the 100 kV photoemission source. The Wien filter is set up for 90° spin rotation so that the maximun effects are shown.

The normalized transverse emittance growth is minimal (Fig. 5) because of the well focussed beam in the Wien filter. The normalized emittance starts at the source with $\epsilon_{x,n} = \epsilon_{y,n} = 0.066$ mm mrad and at the end of the injector with $\epsilon_{x,n}/\epsilon_{y,n} = 0.067/0.071$ mm mrad which fullfill the demanded emittance values of 1 mm mrad.

LONGITUDINAL BEAM DYNAMICS SIMULATION RESULTS

On the basis of de- and acceleration of the beam through the fringe fields of the Wien filter (Fig. 7) and the beam center moves from the nominal trajectory and back, the Wien filter causes a bunching of the beam, as you can see in Fig. 6. The prebuncher system consisting of a 3 GHz and a 6 GHz prebuncher bunches the beam down to 5 ps which is necessary to catch and accelerate the beam further through the S-DALINAC. The bunch length freezes by 5 ps. The simulations shows that the chopper is not needed for the photoemission gun.

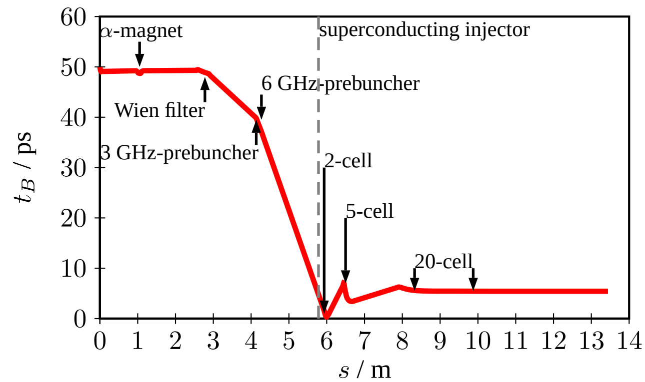

Figure 6: Bunchlength over the whole injector of the 100 kV photoemission source. The Wien filter is set up for 90° spin rotation so that the maximun effects are shown.

The electrons are accelerated in the gun electrostatically to 100 keV. Through the superconducting injector the beam energy rises to around 11.5 MeV (Fig. 7). Especially the 2-cell and 5-cell structure are tuned to deliver the maximum energy which minimizes the relative energy spread at the end of the injector.

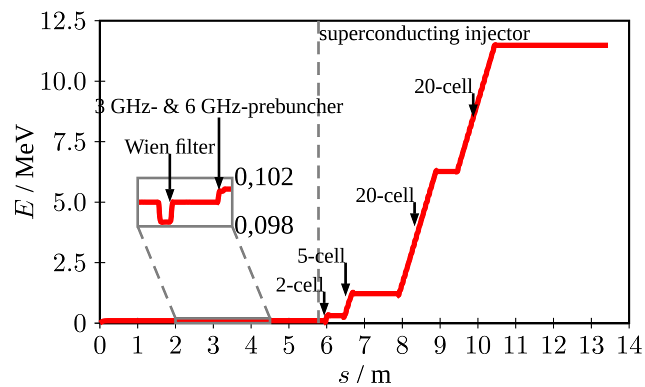

Figure 7: Bunch energy over the whole injector of the 100 kV photoemission source. The Wien filter is set up for 90° spin rotation so that the maximun effects are shown.

The relative energy spread (Fig. 8) is accumulated from the Wien filter and the prebuncher system. Because the 2-cell and 5-cell accelerating structure are optimized for 250 keV electrons from the current thermionic gun and not for the 100 keV electrons from the photoemission gun, the relative energy spread stays high in the range of 10^{-3}. As a result of the maximum energy given by these two cavities the two 20-cell structures ($\beta = 1$) can accelerate the bunch easier. These results in an optimal energy spread which is around $0.24 \cdot 10^{-4}$ which is about a factor 4 smaller than requested.

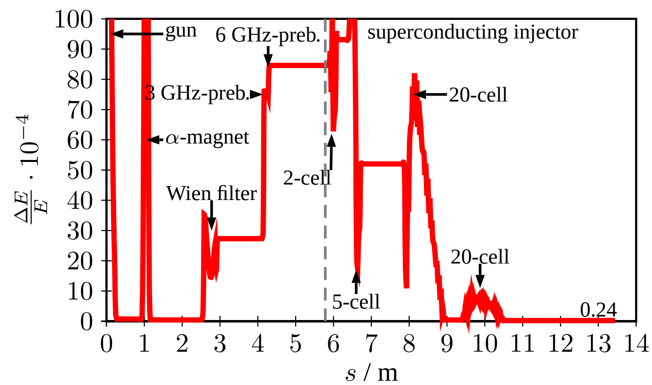

Figure 8: Relative energy spread over the whole injector of the 100 kV photoemission source. The Wien filter is set up for 90° spin rotation so that the maximun effects are shown.

CONCLUSION

One can achieve with the combination of the full 3D simulations of the gun in MAFIA and the following calculation of the beam line in the V-Code that the beam dynamics simulations of the whole injector is closed. Also one uses the real field datas with fringe fields which can come from a simulation with CST STUDIO SUITE™ or from a field measurement. The next step is to compare the V-Code simulations with the beam measurements at the accelerator. In future it is planned to use the V-Code because of the fast simulation time as an online simulation tool at the S-DALINAC.

REFERENCES

[1] A. Richter, *"Operational Experience at the S-DALINAC"*, EPAC'96.

[2] B. Steiner, et al., *Simulation for a New Polarized Electron Injector (SPIN) for the S-DALINAC*, 21th PAC'05.

[3] B. Steiner, et al., *Wien Filter as a Spin Rotator at Low Energy*, PAC'07.

[4] B. Steiner, et al., *Longitudinal Beam Dynamics Simulation of S-DALINAC Polarized Injector*, LINAC'06.

[5] CST - Computer Simulation Technology, Bad Nauheimer Str. 19, D-64289 Darmstadt, Germany, www.cst.com.

[6] A. Novokhatski, T. Weiland, *"Self-Consistent Model for the Beams in Accelerators"*, ICAP'98.

[7] B. Steiner, et al., *Recent Simulation Results of the Polarized Electron Injector (SPIN) of the S-DALINAC*, EPAC'06.