Recent Simulation Results of the Polarized Electron injector (SPIN) of the S-DALINAC

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RECENT SIMULATION RESULTS OF THE POLARIZED ELECTRON INJECTOR (SPIN) OF THE S-DALINAC *

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Abstract

Recent research and development for a polarized electron source (SPIN) for the recirculating superconducting electron linear accelerator S-DALINAC will be presented. The polarized electron beam will be produced by photoemission from an InAlGaAs/GaAs superlattice cathode and will be accelerated to 100 kV electrostatically. The results of the beam dynamics simulation will be shown in detail. The start phase space of the electron bunch at the gun exit has been approximated. The transverse focusing system consists of very short quadrupoles. Further main components of the new injector are a Wien filter, a Mott polarimeter, a chopper-prebuncher system (based on devices used at the Mainz Mikrotron MAMI), and diverse beam diagnostic tools. For the approximation of the start phase space MAFIA and for the beam dynamic simulation V-Code is used.

INTRODUCTION

Polarized electron beams have been widely used for various spin physics experiments at many electron accelerators. Recent polarized electron sources reach a degree of polarization of about 80 $\%$ by using strained or super-lattice structures of GaAs and a quantum efficiency of 0.x $\%$ by using negative electron affinity (NEA).

The S-DALINAC [1] is the only electron accelerator to analyze electric and magnetic excitations of nuclei with low momentum transfer world wide. Planned experiments focus on the investigation of violation of parity in the nuclei, breakup reactions of light nucleus and determination of low-energy constants in effective field theory. Therefore the new S-DALINAC Polarized injector (SPIN) is being designed where the new 100 keV polarized electron source feeds the S-DALINAC in addition to the existing 250 kV thermionic electron gun. The design requirements of the new gun are a polarization degree of at least 80 $\%$, a mean current intensity of 60 μA and a 3 GHz cw time structure. The concept of the MAMI Gun [2, 3] was used as a starting point for SPIN.

APPROXIMATION OF START PHASE SPACE

The results of the optimization of the source are described in [4]. The final design is shown in Fig. 1. The cathode is similar to the Pierce gun design supplemented by a nose to reduce the problem of field emission and voltage breakdown. In the idealized case where all electrons are emitted perpendicular to the cathode surface the beam is nearly divergence free.

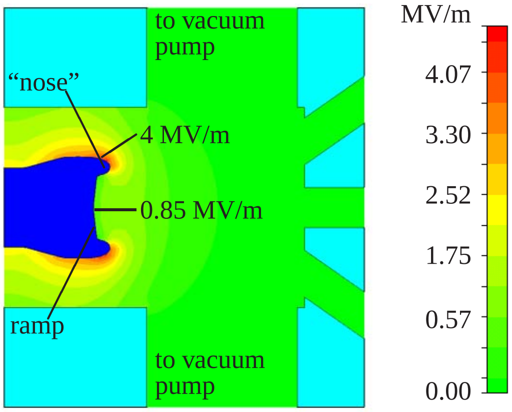

Figure 1: $|\vec{E}|$ in the source yz plane (CST EM Studio^{TM}).

For more realistic simulations, a full 3D PIC simulation of the gun was done in MAFIA [5] to approximate the phase space of the bunch parameter at the gun exit. For the transverse and longitudinal beam dynamics simulation the V-Code [6] was used. The V-Code is based on the VLASOV equation. Therefore the beam has to be described by the phase space distribution function of particle density in the full six dimensional phase space. The latter is approximated by the first and second order moments which are calculated directly from the real particle distribution from the MAFIA PIC simulation. The moments calculated that way define the start ensemble of the beam dynamics simulation in V-Code. V-Code uses the normalized momentum $\vec{p}$ and energy γ

$$\begin{aligned} \vec{p} &= \frac{\vec{P}}{m_0 c_0}, \\ \gamma &= \frac{\vec{E}}{m_0 c_0^2} = \sqrt{1+\vec{p}\cdot\vec{p}}. \end{aligned}$$

The normalized 1σ emittance is given by

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σ_x	$\sqrt{M_{xx}}$	0.3459 mm
σ_y	$\sqrt{M_{yy}}$	0.3458 mm
σ_{p_x}	$\sqrt{M_{p_xp_x}}$	$7.251 \cdot 10^{-4}$
σ_{p_y}	$\sqrt{M_{p_yp_y}}$	$7.242 \cdot 10^{-4}$
$\epsilon_{n,x}$	$\sqrt{M_{xx}M_{p_xp_x} - M_{xp_x}^2}$	$0.0331\ \pi$ mm mrad
$\epsilon_{n,y}$	$\sqrt{M_{yy}M_{p_yp_y} - M_{yp_y}^2}$	$0.0330\ \pi$ mm mrad

Table 1: Ensemble Parameter [6] at the end of the polarized 100 keV gun.

$$\begin{aligned}\epsilon_{n,i} &= \sqrt{\sigma_i^2\sigma_{p_i}^2 - < ip_i >_{ave}^2} \\ &= \sqrt{M_{ii}M_{p_ip_i} - M_{ip_i}^2} \quad ,i = x, y, z.\end{aligned}$$

In MAFIA the following bunch parameters are chosen to get a realistic approximation of the phase space behind the gun. The whole charge is set to 20 fC which is equivalent to a mean current of 60 μA. The time structure is given by a 50 ps flat pulse. The radius of the beam is 0.15 mm (1σ) and the maximum angle of beam spread is 60° (1σ). The important transverse bunch parameters at the end of the gun are compiled in Table 1 and the transverse phase spaces are shown in Fig. 2. The transverse mean values are equal to zero.

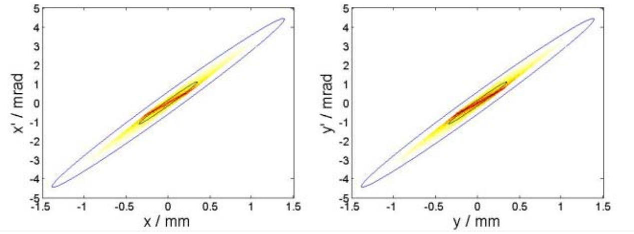

Figure 2: Transverse phase space. The darker the colour the higher the charge density: transverse normalized emittance 1σ (black) and 2σ (blue).

This ensemble provides the start values for the transverse beam dynamics simulation in V-Code.

SHORT QUADRUPOLES

Because of space problems, especially in the vertical beam line the focussing system has to be very short and compact. The triplet was simulated in CST EM STUDIO^{TM}. Fig. 3 shows the final design of a compact triplet and the magnetic field at a cross-section of one quadrupole. One quadrupole is 12 mm thick and the distance between each quadrupole is 18 mm. Therefore the whole triplet is 72 mm long. The disadvantage of this compact triplet is that the fringing fields of the quadrupoles interfere with theirs neighbors. Therefore a higher current is needed, but this disadvantage can be disregarded in the case of a 100 keV slow electron bunch.

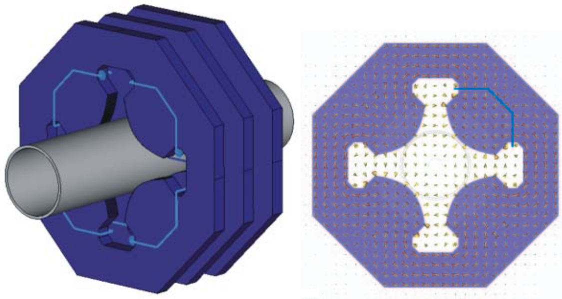

Figure 3: Compact triplet (left), Field distribution at a cross-section of one quadrupole (CST EM STUDIO^{TM}).

For the correct field description of such short triplets, V-Code was extended [7]. The advantage of this extension is that overlapping fields can be simulated such that even in a compact triplet every quadrupole can be tuned individually.

TRANSVERSE BEAM DYNAMICS SIMULATION

Fig. 4 shows the offline test stand of the polarized injector in detail. There are several design requirements which must be strictly adhered to get a good transmission through the injector because of a few small apertures. These critical parts are the aperture of the differential pumping stage, the Wien filter, two Chopper slits, the target wheel of the Mott polarimeter and the final focus on a Faraday cup. In a first step, the Alpha magnet and the Wien filter are treated idealized meaning that the components are handled as drift spaces. Also the effect of the 90°-dipole at the test stand is neglected in a first step in the V-Code simulation. Two different setups are simulated. The first setup is a conservative variant and the second one is to make the whole injector shorter. Both concepts are discussed in the following.

As one can see in Fig. 5, the conservative setup uses four triplets for focussing the beam. Thus, there is one triplet for focussing the beam on nearly every on critical apertures. The simulation shows that one gets a nearly perfect transmission of 99.999 % through the test stand with this design. Therefore this variant is ideal to check the new source and to measure all bunch parameters and compare them with the simulation results.

In a next step the focusing system is reduced to two triplets, the two triplets in the middle are omitted. Therefore the vertical first triplet has to be tuned to a long focus point as one can see in Fig. 5. Therefore a compromise for a good transmission through all critical positions has to be found. The last triplet is installed to have a good focus point for the measurement at the Faraday cup at the test stand or later a good transverse focus point at the capture cavity at the injector. The transmission is also very high as it amounts to 99.947 % through the whole teststand. This design can also be checked by the offline test stand because the two triplets are still on the same position as in variant 1. One only has to switch off the two triplets in the middle of Fig. 4.

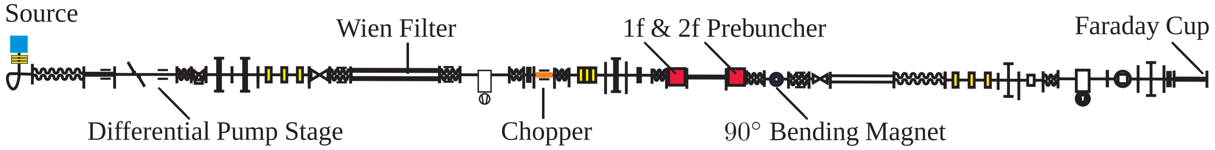

Figure 4: Offline Test stand of the Polarized Injector.

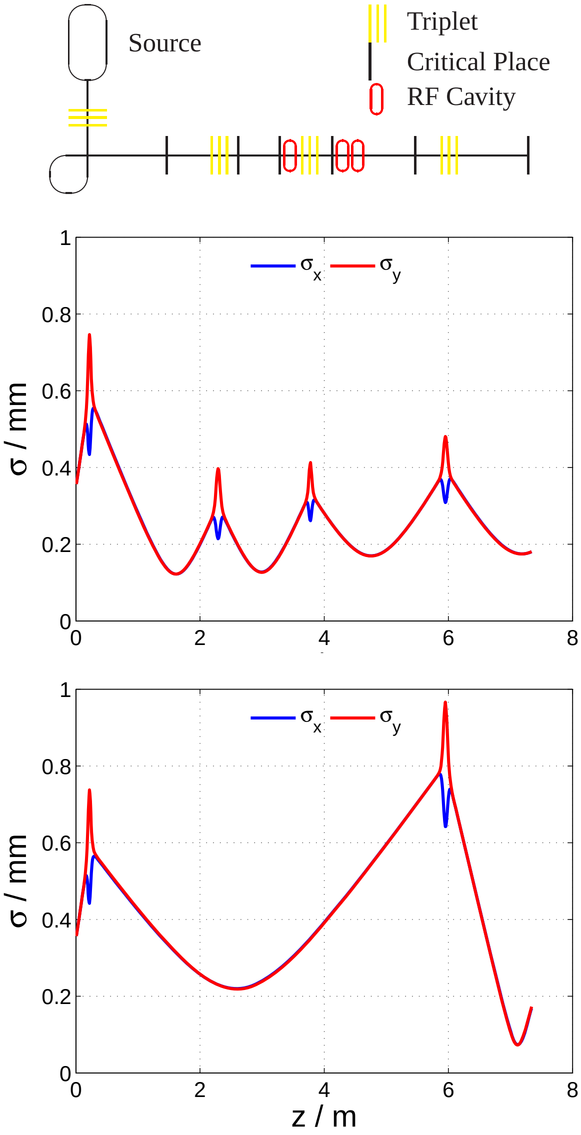

Figure 5: Schematic set-up of the beam dynamics relevent elements at the test stand (upper). Transverse Beam Characteristic of variant 1 (middle) and variant 2 (lower).

CONCLUSION

The advantage of the first set up is that one has more then enough degree of freedoms to focus the beam. Therefore a nearly perfect transmission through the test stand and a high quality is expected for the measurements. One can see the final design of the offline test stand in Fig. 4. The problem is that the beam line with four triplets is too long for the installation at the accelerator. The second variant shows a first step to shorten the beam line. The injector has to be as compact as possible for the installation at the accelerator because of limited space in the accelerator hall. Further simulations will concentrate on finding more possibilities to shorten the 100 keV beam line without loosing any diagnostic tool or getting less transmission.

The longitudinal beam dynamics calculation is currently being carried out. The design of the chopper and prebuncher cavities are finished [8]. Next steps will be to simulate the injector for the test stand with the correct fields of the Alpha magnet and the dipole. Another point will be the simulation of the whole injector to find the best overall solution for both electron sources.

ACKNOWLEDGEMENTS

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