LONGITUDINAL BEAM DYNAMIC SIMULATION OF S-DALINAC POLARIZED INJECTOR *

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Abstract

In future, a polarized gun will extend the experimental possibilities of the superconducting recirculating linear electron accelerator S-DALINAC. Therefore a new injector is being designed where a new 100 keV polarized source SPIN will be addded to the present unpolarized thermionic source. A polarization degree of 80 %, a mean current of 60 μA and a 3 GHz cw structure are required. All features of the new source will be tested and measured at a seperate beam line.

The longitudinal beam dynamics of the injector are studied. The electron bunch length behind the gun is about 50 ps. The electrons have to be bunched to 5 ps for capturing the electrons to the main linac. Therefore a chopper/prebuncher system based on the devices used at MAMI (Mainz Microton) is being designed. The system consists of a harmonic chopper cavity, a collimator, a fundamental and a first harmonic prebuncher. Recent simulation results will be presented here.

INTRODUCTION

Polarized electron beams have been widely used for various spin physics experiments at many electron accelerators in medium and high-energy physics. 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 first 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 nuclei, breakup reactions of light nuclei 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 keV thermionic electron gun. The design requirements of the new source are a polarization degree of at least 80 %, a mean current intensity of 60 μA and a 3 GHz cw time structure. Moreover, the relative energy spread after the main accelerator has to be $1 \cdot 10^{-4}$.

* Work supported in part by DFG under contracts SFB 634 and GRK 410

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The concept of the MAMI gun [2, 3] was used as a starting point for the design of SPIN. The final cathode design [4] is a variation of the Pierce gun design. The Pierce angle is changed to 6.3°, and the edge ends with a nose to reduce the problem of field emission and voltage breakdown.

For beam dynamics simulation V-Code [5] is used. V-Code is based on the VLASOV equation, the beam has to be described by the phase space distribution functions of the particle density in the full six dimensional phase space. As a start ensemble the phase space distribution function is approximated by the real particle distribution from a full 3D PIC simulation in MAFIA [6]. The relevant parameters at the end of the gun are summarized in Table 1.

Table 1: Ensemble parameters [5] at the end of the polarized 100 keV gun

σ_x	$\sqrt{M_{xx}}$	0.346 mm
σ_{p_x}	$\sqrt{M_{p_x p_x}}$	$7.25 \cdot 10^{-4}$
$\epsilon_{n,x}$	$\sqrt{M_{xx} M_{p_x p_x} - M_{x p_x}^2}$	0.033 π mm mrad
t_b	$2 \cdot \sqrt{M_{zz}}/(\beta \cdot c)$	30 ps
E	$(1 - \sqrt{1 + M_{p_z}^2}) \cdot m_0 c^2$	100 keV
ΔE	$\sqrt{M_{p_z p_z}} \cdot E_0$	17.6 eV

The distribution of the normalized transverse and longitudinal emittance is shown in Fig. 1. The transverse emittance is represented by ϵ_x, and 1σ is equivalent to the black ellipse. The longitudinal emittance is described here by the values of bunch length and energy.

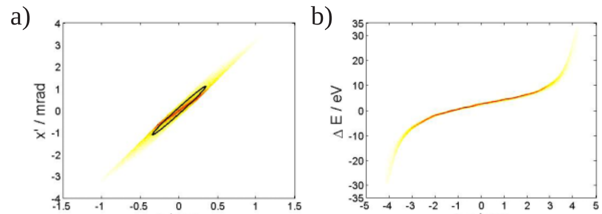

Figure 1: a) Transverse and b) longitudinal emittance at the end of the polarized 100 keV gun.

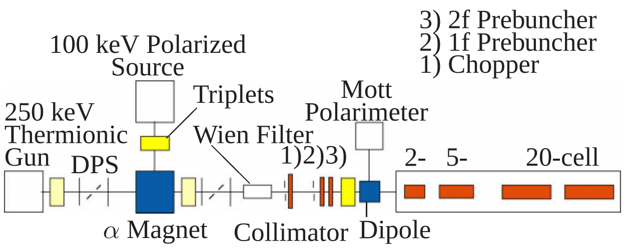

Figure 2: Sketch of the S-DALINAC injector in the accelerator hall.

INJECTOR DESIGN

Fig. 2 displays the present planning status of the injector in the accelerator hall. From the two-cell capture cavity the existing layout of the accelerator is taken. The space between the thermionic gun and the superconducting part of the injector is fixed. The transverse beam dynamics of the polarized source at the offline test stand is discussed in [7]. Because of the limited space in the accelerator hall the set-up is slightly changed. Moreover the beam line is shortened to fit into the available space.

The 100 keV polarized electrons are focussed by a vertical triplet directly behind the gun through the alpha magnet, the differential pumping stage (DPS), the Wien filter and the collimators of the chopper. A second triplet focusses the beam to the measurement of the polarization degree at the Mott polarimeter or at the 2-cell capture cavity. For the 250 keV beam of the thermionic gun two focus elements should transmit the beam through the two pumping stages. The second triplet should also focus the 250 keV beam at the 2-cell cavity. The important challenge is to realize an injector design that ensures a high transmission for both sources.

CHOPPER / PREBUNCHER SYSTEM

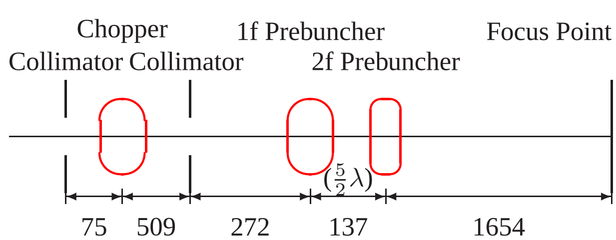

Figure 3: Chopper / prebuncher System (all values in mm).

The chopper/prebuncher system schematically shown in Fig. 3 is adapted from the MAMI system where the accelerator frequency is slightly different, 2.45 GHz instead of 3 GHz. The optimization of these cavities is described in [8]. The chopper cavity is a cylindrical resonator operating at TM_{110} mode. The magnetic field of the mode deflects the electrons on an elliptic orbit. Behind the chopper a collimator cuts out the predefined length of the bunch of 50 ps. The fundamental and the first harmonic prebuncher cavity are also cylindrical resonators working at TM_{010} and TM_{020} modes. The two-cavity harmonic prebuncher system has the advantage of a better flexibility and bigger capture efficiency. The two-cavity harmonic prebuncher system compresses the electron bunch from 50 ps to the required length of 5 ps for further acceleration at the S-DALINAC. The bunch compression progress in the injector is illustrated in Fig. 4.

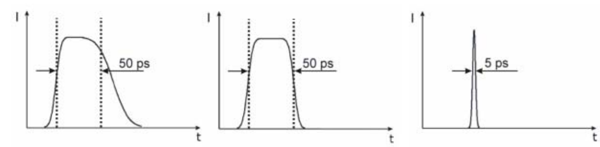

Figure 4: Bunch length represented by the longitudinal current density behind the gun, chopper and prebuncher.

An important point is the influence of the chopper/prebuncher system on the energy and the energy spread. Fig. 5 shows the mean energy and the relative energy spread distribution through the chopper/prebuncher system if the electrons move only on the axis. For the minimal energy spread behind the superconducting injector the two prebuncher cavities cause a slight upwards shift to about 100.7 keV from 100 keV and the relative energy spread increases to $3.5 \cdot 10^{-3}$.

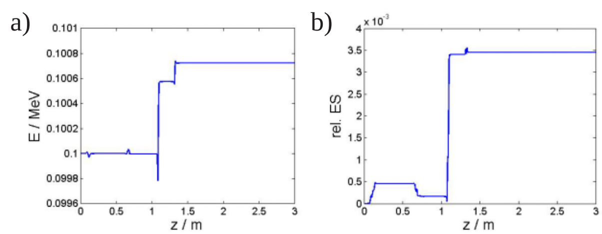

Figure 5: a) Mean energy and b) relative energy spread of the chopper/prebuncher system as shown in Fig. 3.

BEAM DYNAMICS SIMULATION RESULTS

In V-Code the chopper cavity in combination with a collimator can not be simulated because of solving phase space distribution functions and its influence on energy and energy spread distribution are small compared to the prebuncher system. Furthermore possible magnetic bunching effects of the alpha magnet are so far not included in the V-Code simulations. Therefore the bunch length in front of the 1f prebuncher is defined to be 50 ps which should be cut out by the chopper and the subsequent collimator.

As the drift spaces between chopper resonator and slit and between the prebuncher cavities and the two-cell capture section are shorter than at the existing beam line, the necessary radio-frequency (RF) power is high. Because the power P relates to the electric field strength squared E^2 that means the power loss in a prebuncher cavity depends on $(\beta\gamma)^6$. The power loss for 250 keV electrons are around a factor of 23 higher than for the 100 keV electrons. Reducing the voltage of the thermionic gun from 250 kV to 200 kV, the factor reduces to 11. In that case the power loss in the chopper/prebuncher resonators by using copper is acceptable for the planned RF amplifier. The estimated values for the chopper and the prebuncher cavities are summarized in Table 2.

Table 2: Power loss approximation for the chopper/prebuncher system

	100 keV	200 keV	250 keV
chopper	70 W	95 W	110 W
1f prebuncher	4 W	42 W	90 W
2f prebuncher	0.65 W	7 W	15 W

100 keV Beam Line and Superconducting Injector

In the 100 keV beam line, two triplets provide for a high transmission. As one can see in Fig. 6a, the vertical triplet has a long focus point to get the electron bunch through the alpha magnet and to all small apertures. The second triplet focuses the electron beam for the polarization measurement at the Mott polarimeter or for the further acceleration at the two-cell capture cavity. The two-cavity harmonic prebuncher system compresses the bunch from 50 ps to 5 ps at the two-cell structure, Fig. 6b. The mean energy is changed minimally but the relative energy spread grows to $8.8{\cdot}10^{-3}$, Fig. 6d. The two-cell capture cavity and the five-cell cavity, optimized for a β of 0.74, catches the electrons and accelerates them nearly to $\beta = 1$. The following two 20-cell S-DALINAC standard cavities increase the beam energy to around 11.5 MeV, Fig. 6c. The bunch length (Fig. 6b) stabilizes to 3.5 ps. Because of the optimized matching during the capturing and acceleration of the electron beam, the relative energy spread decrease during the acceleration (Fig. 6d) to $3.5 \cdot 10^{-6}$ at the end of the injector. This is nearly two orders of magnitude below the required $\cdot 10^{-4}$.

CONCLUSION

The requirements for the 100 keV polarized electron beam are fulfilled very well with the presented set-up. For the limited space the injector has got a very compact form where nearly no space is left for more beam line elements dedicated to the 250 keV beam.

Especially this causes problems for the 250 keV thermionic electron beam. Reducing the pre-acceleration from 250 kV down to 200 kV will reduce the required RF power and the same chopper/prebuncher system as for the 100 keV polarized beam can be used. A high transverse transmission of the now 200 keV electron bunch can be reached by reducing the transverse emittance of the thermionic gun to

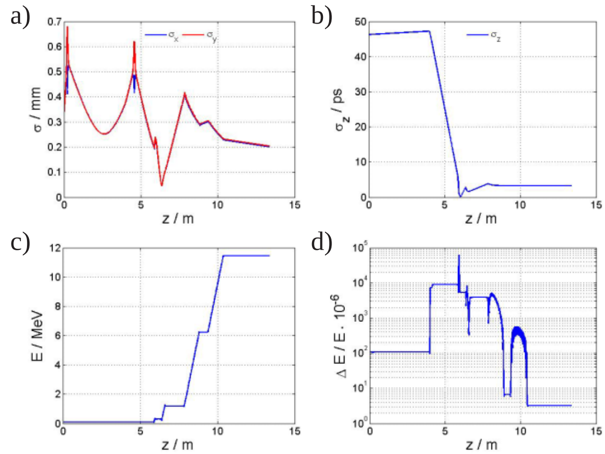

Figure 6: a) transverse trajectories, b) bunch length, c) mean energy, d) relative energy spread in the 100 keV injector.

$0.3\ \pi$ mm mrad. Preliminary simulations show that two solenoids and the horizontal triplet suffice to reach a high transmission of the 200 keV beam through the injector.

Future simulations will include more effects, e.g. alpha magnet, bending magnets and Wien filter. Therefore the database of the V-Code is being extended. Further optimization of the combined beam line of the 100 keV polarized beam and the 200 keV beam from the thermionic gun is needed.

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