STRONGLY SPACE CHARGE DOMINATED BEAM TRANSPORT AT 50 keV*

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Abstract

A pulsed (100 nC in 1 µs), low energetic beam of polarized electrons is routinely provided by an inverted source of polarized electrons at ELSA. The beam transport to the linear accelerator is strongly space charge dominated due to the beam energy of 50 keV. Thus, the actual beam current has an impact on the beam dynamics, and the optics of the transfer line to the linear accelerator must be optimized with respect to the chosen beam intensity. Numerical simulations of the beam transport demonstrate that an intensity upgrade from 100 mA to 200 mA is feasible. In order to successfully adjust the focussing strength of the magnets according to the final results of the simulation, dedicated beam diagnostics like wire scanners suitable for extreme-high vacuum applications are required.

INTRODUCTION

Since 2006, experiments on baryon spectroscopy are performed at the University of Bonn, requiring circularly polarized photons which are generated by bremsstrahlung of longitudinally polarized electrons [1]. The polarized electrons cannot be produced via self-polarization according to the Sokolov-Ternov mechanism [2] due to a considerably long polarization time. Thus, in Bonn, polarized electrons are generated in a dedicated source [3] and are transported to the experiment while aiming at the highest possible conservation of polarization.

The main parameters of the source are determined by the properties of the injector chain of the ELSA stretcher ring. A beam energy of 48 keV is required for the buncher section of the pulsed injector linac and leads to a strongly space charge dominated beam transport to the linear accelerator. A pulse length of 1 µs and a repetition rate of 50 Hz are determined by the booster synchrotron.

Polarized electrons are generated by irradiating a strained-layer superlattice photocathode with circularly polarized laser light from a flash lamp pumped pulsed Titanium Sapphire laser [4]. The emitted current (by default 100 mA) is controlled by space charge limitation. In order to vary the beam intensity, the perveance[1] can be adjusted by changing the distance between the anode and the cathode.

For future hadron physics experiments, a significantly higher beam intensity of approximately 200 mA is re-

quired. Such intensities will have an impact on beam dynamics, and the optics of the transfer line to the linear accelerator has to be optimized. In this paper, the results of numerical simulations of the strongly space charged dominated high current beam transport at 50 keV will be presented. In addition, the optics and beam diagnostics of the transfer line, indispensable for the verification of the optimal settings of the focussing and steerer magnets, will be shown.

BEAM TRANSPORT

Transfer Line

Figure 1 shows a schematic drawing of the transfer line. In the linear accelerator, the pressure, mainly dominated by water vapour, is in the range of 10^{-7} mbar, because the existing structure cannot be baked-out. In order to avoid a degradation of the ultra high vacuum in the operating chamber[2], the transfer line has to provide a 6 m long differential pumping section. Therefore, the beam pipe has a diameter of 35 mm which is a compromise between a small aperture for differential pumping and a large aperture for the quasi lossless beam transport. In Figure 1, the decrease in total pressure measured by dedicated vacuum gauges along the transfer line is indicated.

The folded beam line mainly consists of two α-magnets, an electrostatic deflector as well as solenoids and quadrupoles for focussing the beam. All in all, there are 41 magnets in the transfer line, and the beam is three times deflected by 90 degrees.

The set-up was chosen due to the following reasons:

- The electron beam can easily be separated from the laser beam.
- The height of the operating chamber of 1.5 m allows for an easy access.
- Backstreaming ions produced in the linear accelerator cannot hit the photocathode.
- A mirror symmetric set-up of the magnetic optics reduces the amount of required beam diagnostics and reverses any deformation of the cylinder symmetric beam shape caused by the magnetic deflections.

α-magnets deflect the beam energy independently and act like a free drift, but provide a different effective drift length

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[1] The perveance is the constant of proportionality between the emitted current and the applied voltage and is only dependent on the geometry.

[2] A difference in the partial pressures of the contaminating gases of at least 6 orders of magnitude between the linear accelerator and the operating chamber has to be achieved.
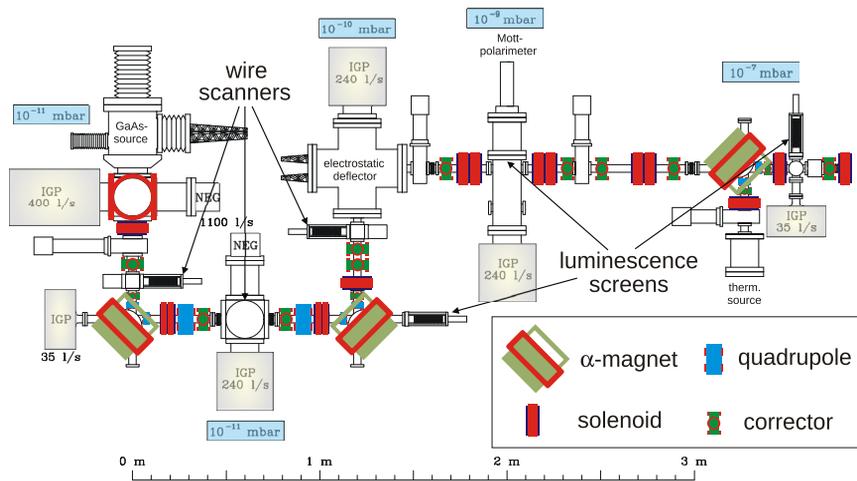
Figure 1: The transfer line between the operating chamber and the linear accelerator.

for each plane. Thus, a beam focus at the point of symmetry has to be achieved by using quadrupoles. Hence the cylinder symmetry[3] of the beam is disturbed, which has to be taken into account for the numerical simulation of the beam transport.

The electrostatic deflector rotates the longitudinal spin transversely to the momentum, ensuring a conservation of polarization in the following circular accelerators. Behind the deflector, mainly double solenoids are used for focussing the beam to achieve a vertically oriented spin at the injection into the booster synchrotron. The polarization is measured by means of a Mott polarimeter.

Beam Fynamics and Umulation

The transversal beam dynamics of a low-energy electron beam with a homogeneous, elliptical charge distribution in presence of external electromagnetic fields assuming a "laminar" flow are described by the so called paraxial differential equations [5, 6]:

$$\frac{\mathrm{d}^2 x}{\mathrm{d}s^2} + [k_x(s) + S(s) + T(s)] \cdot x - \frac{\varepsilon^2}{x^3} - \frac{2K}{x+z} = 0 \,, \quad (1)$$

$$\frac{\mathrm{d}^2 z}{\mathrm{d}s^2} + [k_z(s) + S(s) + T(s)] \cdot z - \frac{\varepsilon^2}{z^3} - \frac{2K}{x+z} = 0 \,. \quad (2)$$

The linear term represents the restoring forces of quadrupoles $(k_{x,z}(s))$, solenoids $(S(s))$ and the electrostatic deflector $(T(s))$. The expansion of the beam due to the emittance ε and the space charge[4] is included in the third and fourth term.

In order not to degrade the vacuum the beam must be transported quasi lossless to the linear accelerator. Due to the high intensity, the beam transport is strongly space

[3]The emitting surface of the photocathode is a full circle resulting in a homogeneous, cylinder symmetric charge distribution of the beam when operating in space charge limitation.

[4]K is called the generalized perveance and depends on the beam current and energy.

charged dominated. Thus, the focal lengths of the magnets are dependent on the actual beam current and have to be adjusted accordingly. In order to examine whether a beam transport of 200 mA is feasible using the existing magnets in the transfer line, their focussing strengths were optimzed by iteratively feeding adjusted parameter sets into a software package used for the numerical intergration of the differential equations. The optimization criteria were a minimal beam envelope along the whole transfer line and a beam focus in the symmetry planes.

Figure 3 shows the final results of the simulations and presents the beam envelope for optimal settings of the focussing strengths of the magnets for currents of 100 mA and 200 mA. Due to the geometry of the electrodes the beam is focused, leading to a beam waist close by the anode. The waist position was chosen as the initial point of the simulation, whereas its position varies for different currents and diameters of the emitting surface. The initial parameters, like the position of the waist, the beam envelope at the waist and the emittance, were taken from numerical simulations using the software EGUN [7].

In Figure 3, the evolution of the beam envelope is presented by solid lines. The origin of the diagram was set to the position of the first beam waist for 100 mA.

The beam envelope is always smaller than one third of the aperture in case of a beam current of 100 mA, which implies that a quasi lossless beam transport should be possible, assuming a well-defined beam shape (no halo) and the absence of strong disturbing fields. The operational experience with a current of 100 mA shows that an overall transfer efficiency close to 100 % could be obtained routinely and validates the simulation results.

The beam envelope for a current of 200 mA is larger than for 100 mA due to the higher space charge. Except near the α-magnets, the envelope is always smaller than one half of the aperture, so that a quasi lossless transport appears to be feasible with 200 mA as well.

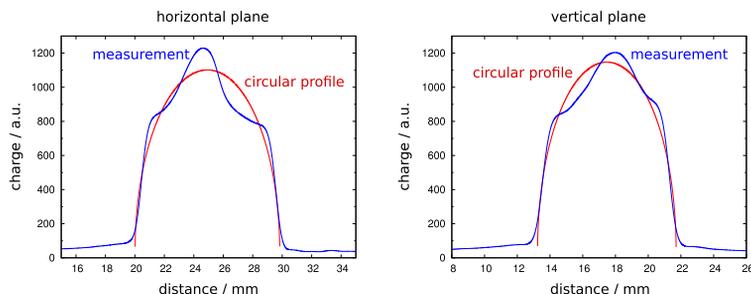Table 1 compares the focal lengths f of the (double)

Figure 2: Beam profiles in both planes recorded with the first wire scanner in the transfer line.
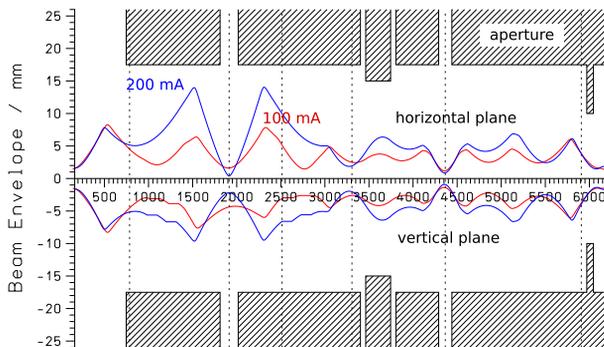

Figure 3: Final results of the numerical simulations for a beam current of 100 mA (diameter of the photocathode $\varnothing_{pc} = 8$ mm) and 200 mA ($\varnothing_{pc} = 10$ mm). The optimization criterium of a minumum beam envelope at the symmetry points is fullfilled for both currents.

Table 1: Focal lengths f of the (double (d.)) solenoids in the transfer line.

magnet	100 mA $f_{simulated}$	100 mA $f_{operation}$	200 mA $f_{simulated}$
solenoid 1	188 mm	195 mm	165 mm
solenoid 2	200 mm	215 mm	200 mm
solenoid 3	200 mm	215 mm	200 mm
solenoid 4	145 mm	172 mm	180 mm
d. solenoid 1	120 mm	116 mm	200 mm
d. solenoid 2	120 mm	118 mm	200 mm
d. solenoid 3	190 mm	233 mm	300 mm
solenoid 5	150 mm	186 mm	115 mm
solenoid 6	100 mm	unknown	100 mm

solenoids in the transfer line in case of a beam current of 100 mA (simulated and used in operation[5]) as well as in case of a beam current of 200 mA (simulated only)[6]. The slight changes of the focal lengths necessary for a quasi lossless beam transport in case of a current of 200 mA are in the adjustment range of the existing magnetic optics.

To verify the assumption of a cylinder symmetric, homogeneous and sharp-edged beam profile, which is required by the paraxial differential equations and in order to adjust the focussing strength of the magnets based on the final results of the simulation, dedicated beam diagnostics are needed. The available beam diagnostics consist of wire scanners and luminescence screens (see Figure 1). Near the operation chamber, only wire scanners are installed in order not to degrade the vacuum while scanning the beam profile.

The two beam profiles shown in Figure 2 were recorded with the first wire scanner in the transfer line at a beam current of 100 mA. Because the emitting surface of the photocathode is a full circle, a homogeneous, cylinder symmet-

ric charge distribution of the beam when operating in space charge limitation is expected before the beam has passed through the quadrupoles. The measurements are in good agreement with the expected profile and legitimate the assumptions made for the paraxial differential equations. The slight charge redistribution visible in Figure 2 is caused by inhomogeneous fringe fields of a permanent magnet belonging to an ion getter pump.

CONCLUSION

Since 2000, the source of polarized electrons reliably provides a beam of 100 mA and a polarization degree of 80 %. The optimized results of the simulation of the stronlgy space charge dominated beam transport show that an intensity upgrade to a current of 200 mA is feasible with the actual set-up of the source and its transfer line.

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[5]The focal length of solenoid 6 is unknown due to a missing calibration.

[6]The deviation of the simulated and adjusted focal lengths can be explained by the influence of undesired, inhomogeneous magnetic fields from ion getter pumps and vacuum gauges, which were not included in the simulation and have to be additionally compensated by the solenoids.