Upgrade of the inverted source of polarized electrons at ELSA

D. Heiliger, W. Hillert and B. Neff
University of Bonn, Physics Institute, Nussallee 12, 53115 Bonn, Germany
E-mail: heiliger@physik.uni-bonn.de

Abstract. Since 2000 an inverted source of polarized electrons at the electron stretcher accelerator ELSA routinely provides a pulsed beam with a polarization degree of about 80%. One micro-second long pulses with 100 nC charge are produced by irradiating a strained-layer superlattice photocathode with laser light from a flashlamp-pumped Ti:Sa laser. A rectangular pulse shape is achieved by operating the source in space charge limitation.

The proposed hadron physics program requires an intensity upgrade to 200 mA which can be achieved by enlarging the emission area or by improving the quantum efficiency (QE). The resulting changes of the beam parameters (like emittance and space charge) and of the optics of the transfer line were investigated in numerical simulations.

In order to enhance the source performance a new load lock system with crystal storage and atomic hydrogen cleaning will be installed in the near future.

1. 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 actual set-up of the source of polarized electrons and its load lock system is shown in figure 1. The operating chamber is build as an inverted structure. 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. The generated laser pulse with a pulse length of 10 µs shows a spiking behaviour and is chopped into a 1 µs long pulse [4].

For the acceleration in the linear accelerator a rectangular current pulse is desirable. To generate a rectangular current pulse even though the laser pulse is not rectangular 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 required. Such intensities will have an impact on the 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 focusing and steerer magnets, will be shown.

2. Intensity upgrade

Since the end of 2009 the Be-InGaAs/AlGaAs-photocathode used in the last years was replaced with a new GaAs/GaAsP-photocathode, which has an eight times higher quantum efficiency and a larger emission area. With this new photocathode the desired current of 200 mA can be generated for regular operation. In the following the transfer line used for the transportation of the generated beam from the operating chamber to the entrance of the linear accelerator will be detailed. Afterwards the numerical simulation of the beam transport will be presented.

2.1. Transfer line

Figure 2 shows a schematic drawing of the transfer line. Due to the pulsed operation and the resulting small cw-current-equivalent the lifetime of the photocathode is mainly limited by the partial pressures of contaminating gases like water vapour and carbon dioxide and not by ion back-bombardment. In the linear accelerator the pressure, especially of 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

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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.

\(^2\) There is a difference in the partial pressures of the contaminating gases of 6 orders of magnitude between the linear accelerator and the operating chamber.
Figure 2. The transfer line between the operating chamber and the linear accelerator.

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 2 the decrease in total pressure measured by dedicated vacuum gauges along the transfer line is indicated.

The folded beam line mainly consists of two \( \alpha \)-magnets, an electrostatic deflector and 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 be easily 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 magnetic optic (one symmetry plane is located between the \( \alpha \)-magnets, a second in the Mott polarimeter) reduces the required beam diagnostics to three wire scanners and three luminescence screens.

\( \alpha \)-magnets deflect the beam energy independent and act like a free drift, but provide a different effective drift length 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 (see chapter 2.2).

The electrostatic deflector rotates the longitudinal spin transverse to the momentum, which is necessary to conserve the 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.

### 2.2. Beam transport

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

\(^3\) 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.
described by the so called paraxial differential equations [5, 6]:

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

(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 the emittance \(\varepsilon\) and the space charge 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 charged dominated. Thus, the focal length of the magnets are dependent on the actual beam current and have to be adjusted accordingly. In order to find out if a beam transport of 200 mA is feasible using the existing magnets in the transfer line, their focussing strengths were optimized by iteratively feeding adjusted parameter sets into a program for the numerical solution 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 and 200 mA. Due to the geometry of the electrodes the beam is focused leading to a beam waist downstream and 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].

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In figure 3 the evolution of the beam envelope is presented by solid lines, above the abscissa for the horizontal and below the abscissa for the vertical beam plane. The shaded areas indicate the aperture of the transfer line. 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 alpha magnets, the envelope is always smaller than one half of the aperture, so that a quasi lossless transport appears to be feasible as well with 200 mA.

To verify the assumption of a cylinder symmetric, homogeneous and sharp-edged beam profile required by the paraxial differential equations and 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 are wire scanners and luminescence screens (see figure 2). Near the operation chamber only wire scanners are installed in order not to degrade the vacuum while scanning the beam profile. A wire scanner consists of two wires with a diameter of 50 μm mounted on a frame. The wire scanner is able to scan both planes of the beam by moving the wires through the beam and collecting the charge. The collected charge is converted into a voltage signal, amplified, integrated (every 20 ms for a duration of 1 μs) and digitalized. A very low background which can be reached by the use of a complete coaxial set-up of the scanners is of great importance due to the small currents of maximum 500 μA collected within the duration of scanning.

\( K \) is called the generalized perveance and depends on the beam current and energy.
Figure 3. Final results of the numerical simulations for a beam current of 100 mA (blue lines, diameter of the photocathode $\varnothing = 8\,\text{mm}$) and 200 mA (red lines, diameter of the photocathode $\varnothing = 10\,\text{mm}$). Above the abscissa the horizontal and below the abscissa the vertical beam envelope is presented. The optimization criterium of a minimum beam envelope at the symmetry points is fulfilled for both currents.

Figure 4. Beam profiles in both planes recorded with the first wire scanner in the transfer line.

The two beam profiles shown in figure 4 were recorded with the first wire scanner in the transfer line. Because the emitting surface of the photocathode is a full circle a homogeneous, cylinder symmetric 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 well-defined beam profile (red curves) and legitimate the assumption for the paraxial differential equations. The slight charge redistribution visible in figure 4 is caused by inhomogeneous fringe fields of a permanent magnet of an ion getter pump.

3. New load lock system
In addition to the intensity upgrade an extreme high vacuum load lock system with an activation chamber, a storage chamber and a loading chamber (see figure 5) will be installed.

A new photocathode is brought into the loading chamber and is cleaned with atomic hydrogen while heating the photocathode to moderate temperatures ($< 400\,^\circ\text{C}$) for a better removal of surface oxidations. Afterwards it is transported to the storage chamber via an elevator. In the
Figure 5. The new load lock system with an activation chamber, a storage chamber and a loading chamber with atomic hydrogen cleaning (from the left to the right).

storage chamber up to five photocathodes can be stored in extreme high vacuum comparable to the vacuum in the operating chamber. The activation is done with cesium and oxygen in the activation chamber, before the photocathode is transported into the gun for operation. The storage of up to five photocathodes will increase the reliability and uptime of the source, because the replacement of the photocathode in the operating chamber will take only a few hours compared to the 2 weeks required with the actual set-up. Furthermore the storing of different types of photocathodes with various diameters of the emitting surface will allow a quick change of the operation parameters like the emitted current and polarization degree. Additionally tests of the quantum efficiency, polarization degree and the success of atomic hydrogen cleaning of different types of photocathodes can be done during regular operation.

4. Conclusion
Since 2000 the source of polarized electrons provides very reliably a beam of 100 mA and a polarization degree of 80%. The emitted current is controlled by space charge limitation. An intensity upgrade to a current of 200 mA is feasible with the actual set-up of the source and its transferline. Additionally an extrem high vacuum load-lock system with crystal storage and atomic hydrogen cleaning will enhance the source performance.

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