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A TRANSVERSE ELECTRON TARGET FOR HEAVY ION STORAGE RINGS

S. Geyer[#], O. Meusel, Goethe University, Frankfurt, Germany
O. Kester, GSI, Darmstadt, Germany

Abstract

A transverse electron target has been constructed and is currently under investigation for the application in storage rings at the FAIR facility. The use of free electron sheet beam in crossed beam geometry promises a high energy resolution and gives access to the interaction region for spectroscopy. The produced electron beam has a length of 10 cm in ion beam direction and a width of 5 mm in the interaction region with electron densities of up to 10^9 electrons/cm^3. The target allows the adjustment of the electron beam current and energy in the region of several 10 eV to a few keV. Simulations have been performed regarding the energy resolution for electron-ion collisions. Also the ion optical behaviour of the target was investigated numerically. The target is integrated in a test bench to study the performance of the electron gun and the electron beam optics. The installed volume ion source delivers light ions and molecules for the characterization of the target performance by measuring charge changing processes. Subsequently the target will be installed temporarily at the Frankfurt Low-Energy Storage Ring (FLSR) for further test measurements.

TARGET DESIGN

The transverse electron target was developed for the investigation of electron-ion interaction processes at ion storage rings. A schematic drawing of the electron target is given in fig. 1. The electron beam is produced by a rectangular BaO cathode, surrounded by tantalum and ceramic shields and placed into the Wehnelt electrode. The anode of the gun system is the first of three electrodes in front of the interaction region which act as electrostatic lens. Another three electrodes with mirror symmetric voltage configuration are installed behind the interaction region. Behind the second lens the electron beam is decelerated and defocused in a collector. For the thermally critical electrodes water-cooling has been implemented. The target can be moved over the ion beam cross section by a stepper motor to determine the overlap between the electron and the stored ion beam. A more detailed description of the target design is given in [1].

EXPERIMENTAL SETUP

For first characterization measurements of the target a test beam line has been designed and constructed. Results of its commissioning are discussed in the next sections.

#geyer@iap.uni-frankfurt-de

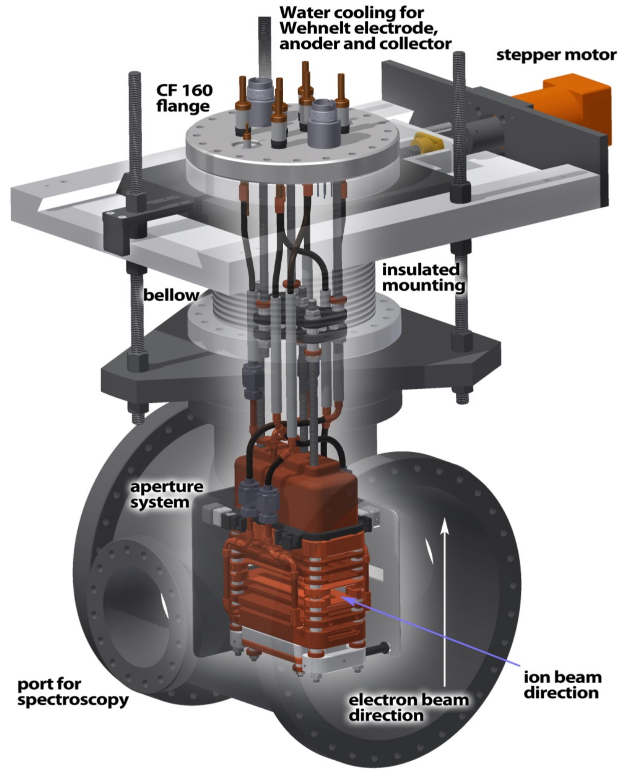

Figure 1: Design of the transverse electron target.

Target Test Beamline

The test beamline is depicted in fig. 2. A volume ion source delivers a continuous beam of different light ion species or molecules with extraction energies of up to 6 keV/q. It is separated from the subsequent beam line by a differential pumping stage. For further measurements with highly charged ions a compact cross over electron beam ion source (XEBIS) is currently under development at Goethe University Frankfurt. The ion-optical system of the test beamline consists of two electrostatic quadrupole doublets, one in front and the other behind the designated target position. Each quadrupole has a length of 100 mm with an aperture radius of 25 mm. The distance between the two quadrupoles of a doublet is 50 mm. As diagnostics for the ion beam a Faraday Cup (FC) with secondary electron suppression (SES) and a magnetic momentum spectrometer are installed. Its dipole has a curvature radius of 0.4 m, a deflection angle of 30° and a gap distance of 40 mm. An aperture with a pinhole of 1 mm in diameter is placed at the spectrometer entrance. For beam detection two Faraday cups with SES under 0° and 30° are used, respectively.

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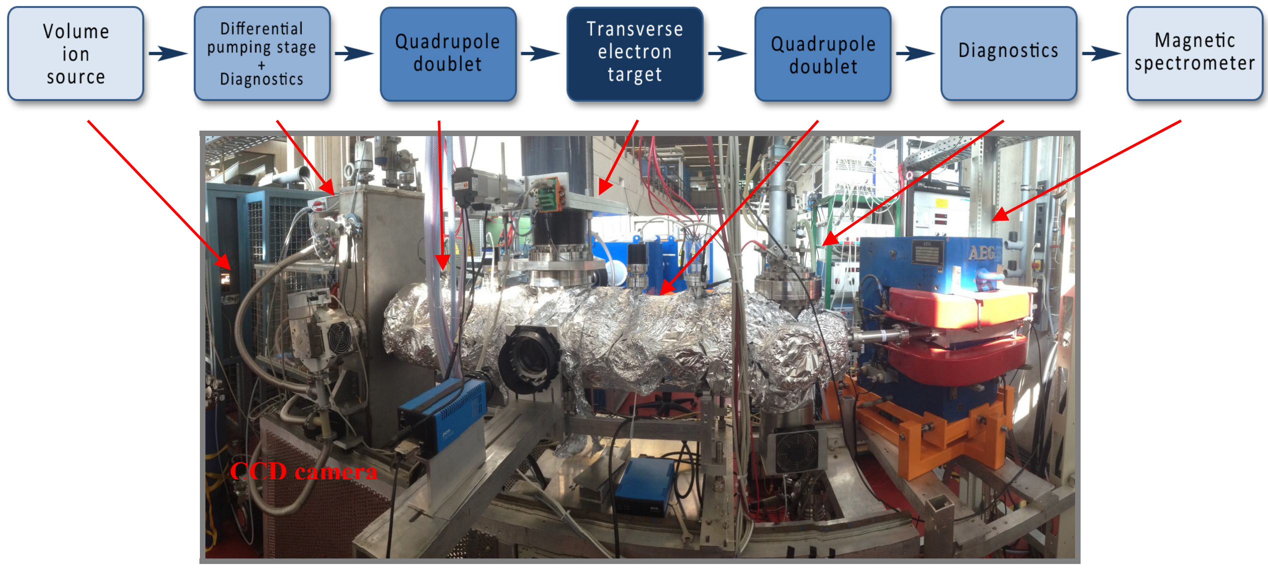

Figure 2: Scheme and photograph of the target test beamline at Goethe University Frankfurt.

In addition a CCD camera is installed with view through an optical window into the interaction region of the target.

Ion Beam Transport

For different quadrupole settings and constant ion source parameters the ion beam current was measured using the FC behind the second duplet. Results are shown in fig. 3. They have been compared to beam transport simulations performed with Tracewin [2] using a measured ion beam start distribution [3] and current. Deviations between both can be caused by differences in the plasma parameters of the ion source and the rescaling of the emittance measurement regarding the ion species and extraction voltage. Beside the difference in transmitted current, the comparison shows an identical behaviour in the dependence on the second quadrupole doublet strength. The reduced current for lower voltages at quadrupole 4 (Q4) is caused by losses on the second quadrupole doublet. For higher voltages the beam becomes more defocused in one direction and over-focused in the other one into the FC.

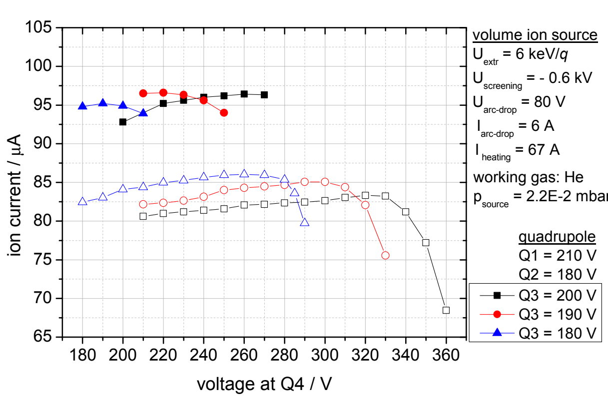

Figure 3: Ion current measurement with the FC behind the second quadrupole for beam transport optimization (solid symbols: measurements, empty symbols: simulation results).

Magnetic Momentum Spectra

First commissioning of the beamline has been conducted with a He ion beam of 6 keV/q. Systematic studies for matching the ion beam parameters to the experimental requirements have been under investigation by characterizing the ion source properties. Fig. 4 depicts a spectrum recorded for different arc voltages. For high values the ionization cross section decreases resulting in a lower production of He^+, while the other source parameters have been kept constant.

A comparison between the theoretical energy resolution $\Delta E/E$ and the measured peak width gives information about the energy spread in the ion beam. The energy resolution $\Delta E/E$ of the spectrometer is given by its properties such as the radius of the entrance aperture r_A, the radius of the detecting FC r_{FC}, the curvature radius r and the deflection angle α as

$$\frac{\Delta E}{E} = \frac{r_{max}^2 - r_{min}^2}{r^2}. \quad (1)$$

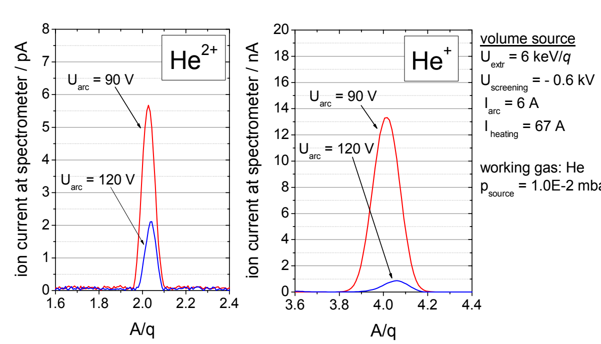

Figure 4: A/q spectrum of He measured with the magnetic momentum spectrometer.

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The curvature radii $r_{\min}$ and $r_{\max}$ of the particle trajectories in the spectrometer assuming neglectable small divergence angles are

$$r_{\max,\,\min} = r \pm r_A - \frac{(r \pm r_A)^2 - (r \mp r_{FC})^2}{2\left((r \pm r_A) - (r \mp r_{FC})\cos\alpha\right)} . (2)$$

For the used momentum spectrometer the $\Delta E/E$ amounts to 6.97%. The energy resolution at 6 keV/q is ± 210 eV/q resulting in the A/q spectrum with a peak width for He^{2+} of $\Delta\, A/q = 0.14$ and for He^{+} of $\Delta\, A/q = 0.28$. These values agree with the observed peak widths and lead to the very expected result that the energy spread of the ion beam is below the energy resolution of the spectrometer. A higher energy resolution could be gained by exchanging the entrance aperture but implying the loss of detection efficiency.

For the investigation of the charge changing processes between ions and crossed electron beam, the distinctness of the production places, either in the ion source, along the flight path by interaction with the residual gas or with the free electrons of the electron target, is mandatory. With a potential difference between the beam boundary and the center of the electron sheet beam of around 80 eV, charge states produced in the electron beam of the target could be clearly separated in the momentum spectrometer for ion energies below ~1150 eV/q.

For different volume ion source settings the relative abundance of He^{+} to He^{2+} was measured for different working gas pressures (see fig. 5). For increasing arc voltages a slight shift towards higher A/q values has been observed, which can be explained by the increment of the plasma potential in the volume ion source. For the highest arc voltages, aberration peaks appear in the spectrum due to a not matched beam extraction connected with high losses and lower currents in the FC behind the second quadrupole doublet.

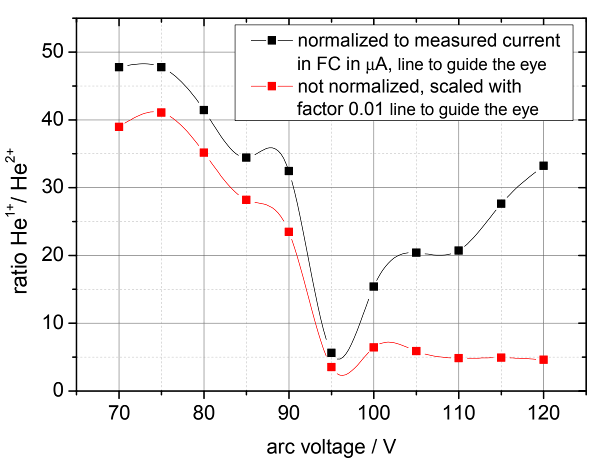

Figure 5: Ratio of He^{+} to He^{2+} depending on the arc voltage. (source parameter: working gas pressure 1.0E-2 mbar, extraction voltage 6 keV/q, heating current: 67 A)

Optical Diagnostics

For optical diagnostic a CCD camera, type "pco.1600" was installed on the atmospheric side of a borosilicate window focused on the ion beam axis. Therewith the beam induced fluorescence (BIF) of the He ion beam with the residual gas was measured spatially resolved over the interaction cross section. In direction of the diagnostic port, the target is encased by a cover with a rectangular aperture of 96 mm in ion beam direction and a height of 12 mm to reduce the background caused by the glowing cathode and scattered light at the different target electrodes. Optionally a monochromator can be installed.

The BIF was measured for different transport scenarios of the ion beam (fig. 6a) and compared to simulations with the matrix code COSY Infinity [4] (fig. 6b) to characterize the interaction partner of the electron beam.

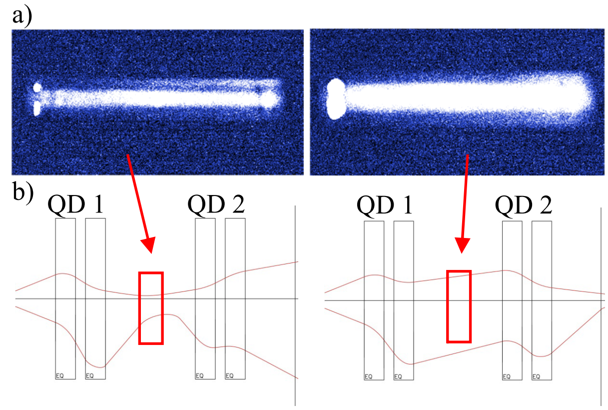

Figure 6: a) Measurements of the BIF for two different beam transport scenarios over the beam cross section. b) According simulations, upper half: the measured vertical plane, lower half: horizontal plane.

CONCLUSION

For the characterization of the transverse electron target a beamline has been set up. First measurements with the installed diagnostics and the ion beam have been performed and the results compared to simulations.

ACKNOWLEDGMENTS

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