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GSI ELECTRON LENS FOR SPACE CHARGE COMPENSATION

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Abstract

The electron lens for space charge compensation is an R&D project to increase the primary beam intensity and thus the accelerator efficiency of SIS18 and eventually SIS100 for FAIR operation. As a first step, the principle of space charge compensation will be demonstrated in SIS18 with a single lens, aiming at a tune shift of 0.1 for several ion species. However, the design should also be compatible with the SIS100. Following the conceptual design studies, a technical design of the electron lens has been prepared and the main components of the electron lens are currently under development. This contribution gives an overview of the development of the electron lens, with particular emphasis on the main lens components and the studies carried out on the dynamics of the ion beam.

STATUS OF ELECTRON LENS DESIGN

The electron lens will initially be used and tested at the GSI heavy ion synchrotron SIS18. The SIS18 lattice thus sets the boundary conditions for the design and the length of the interaction section is limited to about 3.4 m. A major part of the design effort during the last months was therefore the integration of the lens, as well as the technical design of the RF-modulated electron gun and the collector (see Fig. 1). The details are described in the next sections.

The lens is currently designed to transport a modulated electron beam of 10 A peak current. The working range of the lens in relation to its magnetic field is max. 150 mT in the straight section and 400 mT in the gun and collector branch, which allows an expansion of the electron beam.

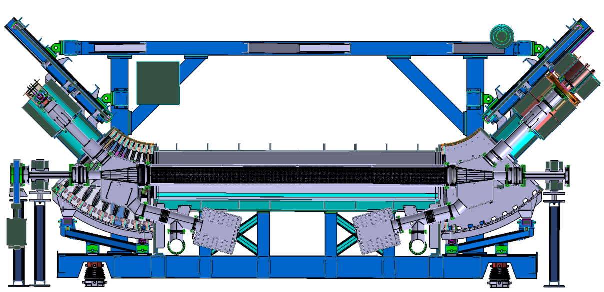

Figure 1: Actual preliminary technical layout of the electron lens.

Status of RF-modulated E-Gun

A prototype grid modulated gun with a tungsten cathode heated by a plasma stream as well as a scaled modulator was developed within the ARIES project [1,2]. Based on this previous design, an additional electron gun with a dispenser cathode which allows adjustments of the electrode system is under preparation at GSI. But unlike the prototype, which was designed for a transverse Gaussian current density profile for full compensation of the ion bunch, the new design will provide a homogeneous profile aiming at linear compensation.

It is designed to operate within a maximum magnetic field

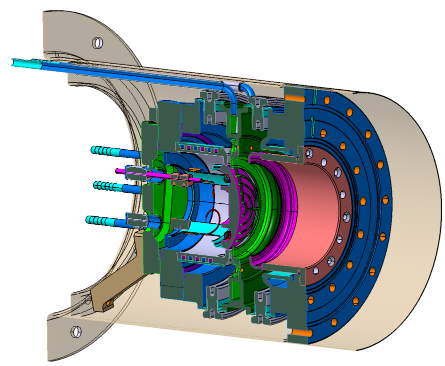

Figure 2: Mechanical design of the gridded electron gun for a target grid.

of 400 mT on a high voltage platform of maximum 35 kV. The active cathode radius is 32 mm. Two electrode system designs have been prepared, one for a target grid structure delivering 15 A (at 35 kV) and another with a honey comb grid delivering 10 A (at 35 kV). The differing currents result from the coarseness of the different grid structures. Both electrode systems can be integrated into the gun design shown in Fig. 2.

The modulator has to provide modulation frequencies in the range of 400 kHz to 1 MHz with a bandwidth of up to 10 MHz. A conceptual study concerning the modulator design was carried out to investigate its realization with respect to semiconductor or tube technology and its positioning inside or outside the SIS18 tunnel. In any case the modulator has to be placed close to the experiment in order to reduce the "ringing effects" introduced by reflections in the system which easily pushes the power demand into the kW-range.

The most promising approach is a design based on semiconductor technology. Either SiC-MOSFETs can be used, which have been tested to be radiation hard [3] and could be placed close to the experiment, which may still require a design with redundancy. Another solution would be to position the modulator close to the experiment but outside the tunnel.

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Cusp Collector Design

The collector will be operated on a high-voltage platform together with the gun. Here the design challenge is to fully dump the beam and to reduce power deposition as much as possible. By slowing down the beam, the beam potential increases. For conventional collector designs, the collector potential would have a bias of +10 kV with respect to the gun potential, to avoid central electrons being reflected. This would result in power depositions of 100 kW. A magnetic cusp field helps to rapidly expand the beam and thus reduce the beam potential as presented in [4]. The beam and thus the power deposition is distributed over a larger area. For the presented design in Fig. 3, the power deposition could be reduced to 50 kW. A disadvantage seems to be the necessity of an exact positioning of the collector in the cusp field. Nevertheless, the second magnet can be used to control the position of incident electrons. In the mechanical design of the collector, the cooling circuits are split: the back consists of three radial distributed cooling circuits, while the wall and the front each have a separate cooling circuit as well. This allows an indirect diagnostic about the distribution of the power deposition by the return temperature. However, the mitigation of rediffused and backscattered electrons is still a work in progress and a strategy needs to be defined.

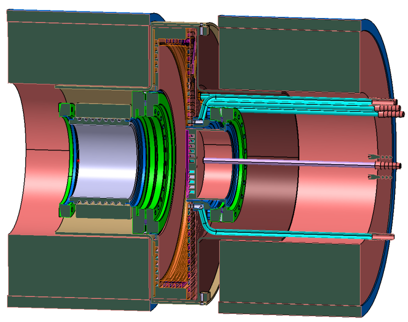

Figure 3: Mechanical design of the cusp-collector.

ION BEAM DYNAMIC STUDIES

Studies have been carried out to investigate the effect of the electron lenses in SIS 18 distributed symmetrically around the circumference of 216 m in the 12 periodic sectors - mainly for three or more electron lenses - in order to compensate for the transverse space charge force [5]. However, the space charge compensation scheme will be initially demonstrated in SIS18 with a single lens in sector 10.
In preparation for demonstration experiments, machine experiments have been performed with the SIS18 e-cooler at the end of 2023, and beam dynamic simulations are currently underway to study the effects on the ion bunch introduced by the electron lens. The effects being studied can be divided into the influence of 1. the electron beam and 2. the magnetic field of the electron lens:

1. The electron beam has a focusing effect on the ion bunches and presents a localized error in the lattice. A working point has to be defined to obtain a significant tune shift without causing a large beating amplitude of the optical functions. Furthermore, the modulation grid of the gun imprints a structure on the electron beam which results in a transversely perturbed electric focusing field, potentially leading to unwanted emittance growth and beam loss after multiple turns.
2. The toroid magnets have a B_y-component which causes a deflection of the ion bunches and requires a closed orbit correction scheme for higher magnetic fields. As the field strength increases, the focussing effects and coupling of the solenoid must be taken into account to avoid resonances and beta-beating.

The following simulation results should provide an initial indication of the operation range of the lens for the demonstration experiments. However, these initial results need to be complemented by more comprehensive multiturn tracking simulations and we are currently looking for a suitable simulation tool.

Impact of Electron Beam

In order to study the effect of a single electron lens in sector 10 of SIS18, the focusing effect of the electron beam was reproduced using the code elegant [6] by a number of thin lens kicks acting on the ion beam according to [7]. The influence of the solenoidal field and the velocity of electrons is being neglected in this study. Figure 4 shows the beta functions β_x, β_y for an electron beam current of 1 A and 10 A. Preliminary results of the multiturn tracking simulations indicate an electron current of 5A as a possible operating point to transport the ion beam without transmission losses, without considering the effect of the magnetic field and the

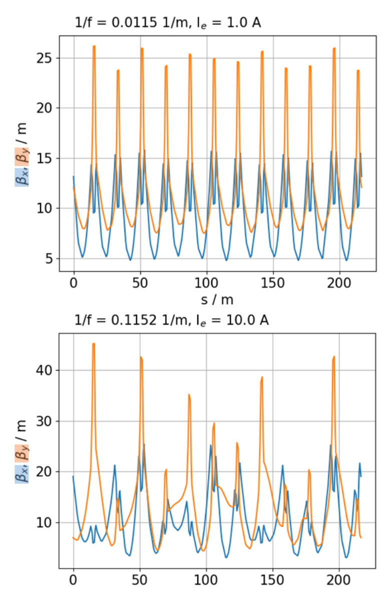

Figure 4: Optical functions at presence of a single electron lens with 1 A (top) and 10 A (bottom) electron beam current in sector 10 of SIS18.

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grid, and therefore need to be confirmed by further studies. In order to investigate the influence of the grid structure imprinted on the electron beam and thus the electric focusing field, tracking simulations for a single passage of the ion beam through a static electric field have been performed using the CST particle studio [8]. This electric field was generated via particle tracking of the electron beam in a parallel magnetic field of B_z=400 mT to avoid beam rotations and loaded into another tracking set-up as a static distribution. In the case presented (see Fig. 5), three different electric field distributions have been calculated for an electron beam with honey comb and target structure according to the studied grid designs and are compared with a perfectly homogeneous distribution and thus a linear electric field. To account for the influence of the solonoidal field, tracking simulations for a single passage of a C^{6+}-ion beam with 11.4 MeV/u were performed for 0 mT, 150 mT and 300 mT, but only the phase space projection for x-x' is shown. A KV-input distri-

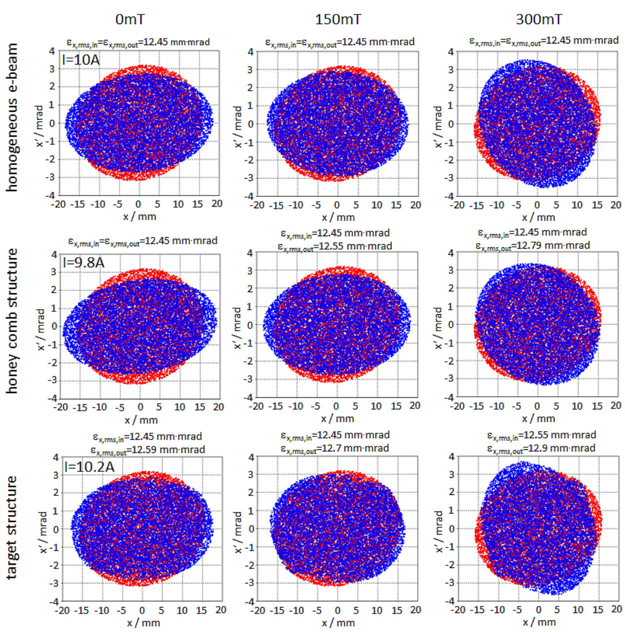

Figure 5: Phase space projection x-x' of the ion beam before (red) and after (blue) a single passage through a homogeneous electron column (top), an electron colum with honey comb structure (middle) and an electron column with target structure (bottom) for different solenoidal field strengths.

bution of $\epsilon_{x,y}$=50 mm×mrad was chosen with β_x=12.75 m, α_x=1.26, β_y=12.67 m and α_y=0.44 which are the expected Twiss parameters at the entrance of the interaction section for the undisturbed lattice. The emittance is three times smaller than usual to ensure that the ion beam does not pass through the outer, non-linear part of the electric field.

In Fig. 5 the input distribution is depicted in red and the output distribution in blue and, as expected, no emittance growth is observed for the homogeneous input distribution. This is not the case for the honey comb and the target structure. With increasing magnetic field, the rms emittance also increases slightly for the honey comb structure. This is already the case without magnetic field for the target structure and aberrations can be observed for increasing magnetic field strengths. The coarseness of the grid seems to have an influence on the transport quality. However, this could change if we no longer assume a frozen electric field and needs to be further investigated.

Longitudinal Magnetic Field of the E-Lens

In November 2023, machine experiments were carried out in order to study the possible correction of the bump at the SIS18 e-cooler for an increased magnetic field of 100 mT (with respect to standard operation at 60 mT). The operating field of the electron lens will be even higher e.g. up to 150 mT but for technical reasons, this value could not be reached during the experiments. Four elements are used to shift the orbit in the cooler section: two corrections coils up- and downstream of the cooler section and the two steerers before the entrance and the exit of the interaction section. For a machine tune of Q_x=4.13 and Q_y=3.3 far away from the coupling resonance, the orbit could be corrected for the higher magnetic field of the cooler without any further adjustment of the steerer magnets compared to standard operation. The measured orbit can be seen in Fig. 6. The orbits differ in the range of less than 1 mm, which is acceptable. Currently,

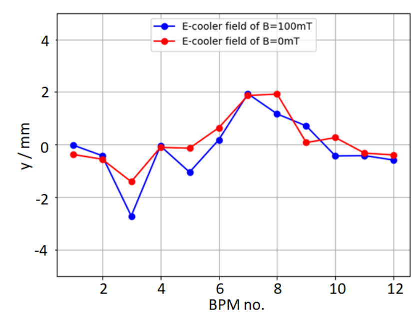

Figure 6: Measured orbit correction of N^{7+}-ions with 11.36 MeV/u in SIS18 without cooler and for a magnetic electron cooler field of 100 mT.

the mitigation of the strong longitudinal fields affecting the ion beam dynamics in the SIS18, namely the compensation of resonances and beta-beating, as well as a closed orbit correction for the interaction section are being investigated numerically.

CONCLUSION

The technical design of the electron lens for space charge lens is ongoing. Major progress was made in the development of the gun and collector and in the technical feasibility of the modulator. Several tasks remain to be addressed, such as the secondary electron mitigation strategy, diagnostics, and the final decision on the grid design.

In order to prepare the demonstration experiments, the operating point of the lens in terms of current and magnitude of the solenoid field has to be finally defined and the impact of the grid structure to be evaluated.

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