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STATUS OF THE ELECTRON LENS FOR SPACE CHARGE COMPENSATION IN SIS18

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Abstract

A prototype electron lens for space charge compensation in the synchrotron SIS18 that could pave the way for pushing the space charge limit of hadron synchrotrons is currently under development at GSI. Accompanied by beam transport simulations, a 3D construction model is being worked out as well as the integration into the existing accelerator facility. The electron gun and collector conceptual design studies are completed and their technical design is ongoing. In a continuing collaboration with GSI, an electron lens test stand was designed and constructed at Goethe-University Frankfurt in order to commission major parts of the electron lens e.g. electron gun, collector and diagnostics. The demonstration of beam extraction from a tungsten cathode heated by an arc discharge, technically realized in the IRME-gun that was developed within the ARIES collaboration [1], is under preparation and first results of this new heating concept look very promising.
In this contribution, the conceptual layout of the electron lens and its major components will be outlined as well as its preliminary technical layout. Furthermore, first measurements of the electron beam extracted from the IRME-Gun will be presented.

OVERVIEW AND STATUS OF ELECTRON LENS DESIGN

The layout of the electron lens for space charge compensation is being continuously improved, and a preliminary 3D design has been developed as shown in Fig. 1. Several changes have been introduced compared to the previous design presented in [2]: The magnetic system was designed for a maximum field of B_{max} = 0.6 T in the gun branch and B_{max} = 0.35 T in the interaction section, which was reduced due to the need for beam expansion. In addition, the collector setup requires a cusp magnetic field and thus an additional magnet. The magnets of the interaction section have to be ramped up within 250 ms according to the SIS18 cycle. For this reason, an Opera [3] model was developed to study the influence of eddy currents and to specify the overall magnetic setup including the corrector magnets.
A preliminary technical design of the gun was prepared with respect to the extraction voltage and vacuum requirements of 30 kV and 10^{-11} mbar. For the technical layout of the collector the necessary power removal of 50 kW was considered, and in particular its integration into the electron lens system required adjustments to the toroidal magnet to gain space for mounting. Some additional space was also found by pulling the coils apart and extending the iron housing to guide the magnetic field lines. However, the integration of diagnostics into the setup and the technical design of the magnets including corrector magnets still need to be defined.

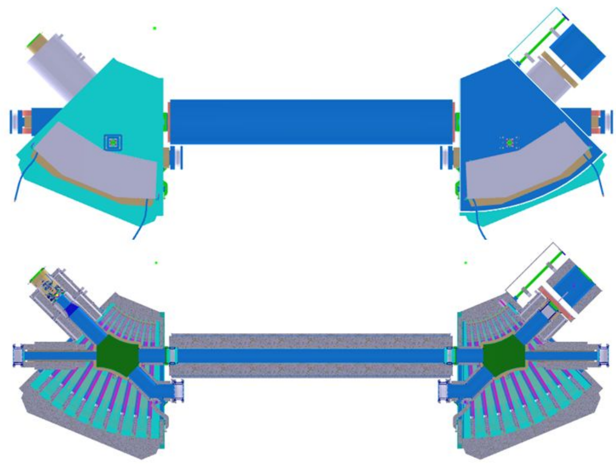

Figure 1: Actual preliminary technical layout of electron lens.

Beam Dynamic Studies

Extended electron beam dynamics simulations using CST-Particle Studio (CST-PS) [4] were performed to study the electron beam behavior within the lens system as well as the influence on the ion beam in the interaction section. Besides

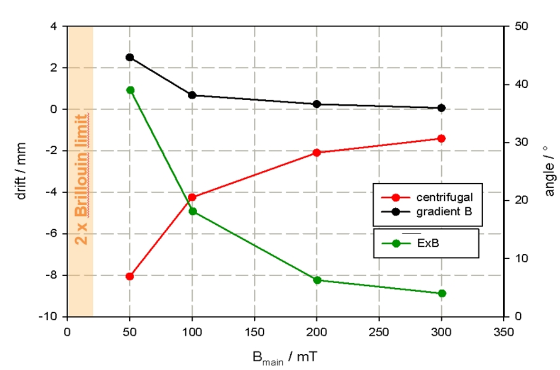

Figure 2: Simulated beam drifts as a function of the magnetic field in the main solenoid.

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the beam expansion of the electron beam within the interaction region to ensure the overlap with the ion beam, another part of the investigations was the influence of the magnetic field on the electron beam dynamics with respect to beam drifts and possible corrections of the beam offsets. Figure 2 shows the expected drifts as a function of the magnetic field. While the gradient beam and the centrifugal drift can be compensated by corrector dipoles in the transport solenoids and toroids, the ExB rotation of the elliptic electron beam has to be taken into account either by providing sufficient margin in beam size or by installing the gun rotated inside the gun solenoid.
Although a higher magnitude of the magnetic fields stabilizes the electron beam dynamics, this may not be true for the ion beam dynamics considering the influence of the magnets in the interaction section - the solenoid and the toroids including the corrector dipoles.
Currently, 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 and the results will influence the choice of the maximum magnetic field of the electron lens.

GUN DESIGN

Status of IRME-Gun Commissioning

As described in previous proceedings of this conference [2,5], the modulated gun design is based on the IRME-gun developed during the ARIES collaboration between Goethe-University Frankfurt (GUF), CERN, Riga Technical University and GSI. The gun concept was inspired by hybrid ion sources [6] using direct cathode heating by an arc discharge. For the proof of concept, an existing gas discharge ion source was modified and the plasma electrode was replaced by a tungsten cathode. The generation of sufficient electron currents requires cathode temperatures in the range of 2200-2800°C. The melting temperature of tungsten of 3422°C has been reached in prior heating experiments. For this reason, stable control of the arc discharge was required, as well as a careful technical redesign of all parts of the plasma generator. A control system developed at GUF is capable of stabilizing the arc power to provide constant cathode temperatures. The electron gun has been optimized for high temperature operation by selecting high efficiency materials for the insulators and for high vacuum operation by redesigning the plasma electrode that supports the cathode and separates the plasma generator from the extractor. The latter also provides a stabilized plasma flow from the arc discharge on the cathode, as there is no directed gas flow into the extractor.
The plasma electrode is made of copper with a stainless steel inlay to seal the plasma generator from the cathode. The graphite seal between the plasma electrode and the cathode was custom designed and is used for high temperature applications up to 3000°C.
The gun was returned to service in March of this year. As a first step, grid extraction experiments were performed, which also provided the opportunity to benchmark the experimental results with the numerical simulations.
Figure 3 shows quite good agreement between the results. In the simulations, the measured temperature gradient on

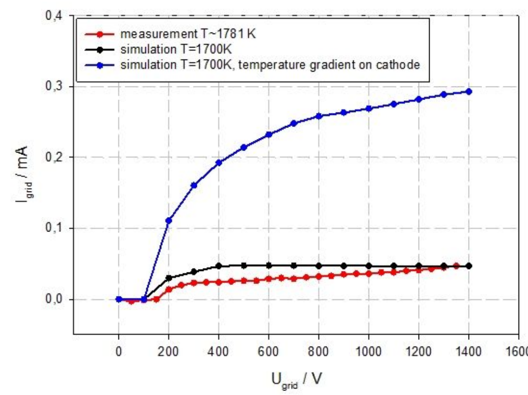

Figure 3: Comparison of simulation using CST-PS and experimental results for grid extraction.

the cathode was implemented according to the pyrometric measurements. However, there is an uncertainty in the temperature determination because the emissivity of tungsten varies with temperature. Currently, the temperature measurement is being calibrated using various methods.
Once the temperature can be reliably measured, the experimental campaign to demonstrate the design operation of the electron gun will be continued.

Status of Homogeneous Emission Gun Design

The IRME-gun is designed to produce a Gaussian beam profile that can be used to study the effect of non-linear transverse current density distribution on the space charge compensation scheme. For continuous operation of the electron lens, a homogeneous beam distribution is required. Therefore, a new electrode system was designed to provide the

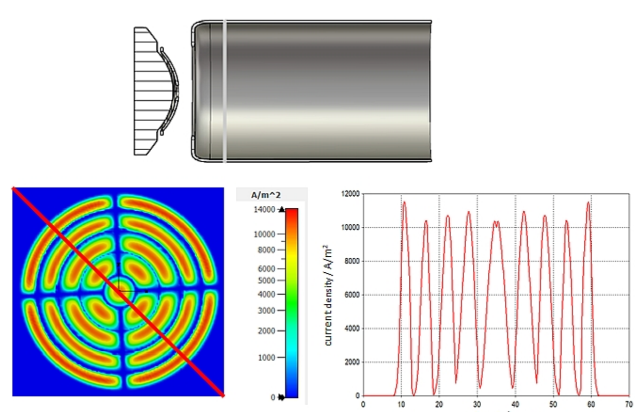

Figure 4: Actual layout of the homogeneous emission gun electrode system (top), current density in x-y plane after extraction (bottom, left) and current density along red line (bottom, right).

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required extraction currents of 10 A at an extraction voltage of 30 kV. The cathode radius was kept to 26.5 mm and the elliptical shape is to be provided by integrated quadrupole air coils. Figure 4 shows the new design, which is comparable to the IRME-gun. Only the cathode and grid electrodes need to be changed, while the anode design remains the same.
Still, the target grid structure affects the electric field of the beam. Simulations of the influence of the electric field of the electron beam on the interacting ion beam show nonlinearities that affect the phase space distribution. A gridded electrode system has been found that provides a homogeneous density profile, but the influence on the ion beam may require further modification of the grid design.

COLLECTOR DESIGN

Different collector designs have been studied to reduce the deposited beam power and the secondary electron emission (SEE). Deceleration of the beam leads to an increase in the beam potential. Electrons in the center may be reflected and therefore not deposited. To overcome this problem, it is advantageous to increase the beam radius within a short distance. A magnetic cusp configuration forces the electron beam to spread out, while the longitudinal energy is reduced and the transverse energy of the beam increases. In a cusp

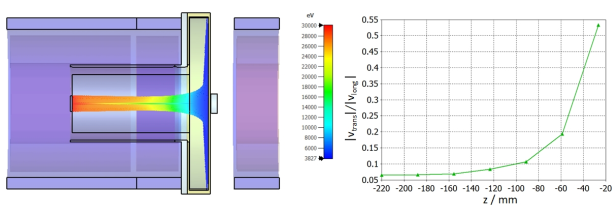

Figure 5: Actual layout of the cusp collector configuration (left) and ratio of transverse and longitudinal electron velocity as a function of beam path in z (right).

configuration, loss channels naturally occur in the center because the magnetic field is zero. This effect represents only a few percent of the total electron current and can be reduced by integrating a permanent magnet. Nevertheless, a significant fraction of the total SEE are electrons that experience elastic collisions at the collector walls. The SEE has been studied in CST Particle Studio based on the Furman-Pivi model [7] and a mitigation strategy needs to be defined.

TEST STAND

The test stand for the commissioning of the main electron lens components at GUF is being successively optimized and used in different stages according to the commissioning requirements [8].
The cooling circuit of the gun has been extended and the pumping power increased to achieve the required vacuum conditions. The solenoid were coupled by an iron bars to optimize the beam transport within the diagnostic box. Figure 6 shows an actual picture if the test stand. Since the gun and the collector are operated on the same platform, the insulation of the beam dump was prepared and support coils were installed to magnetically guide the beam into the dump. After determining the gun operating point in terms of heating temperature, the dump will be installed and beam extraction measurements will be continued.

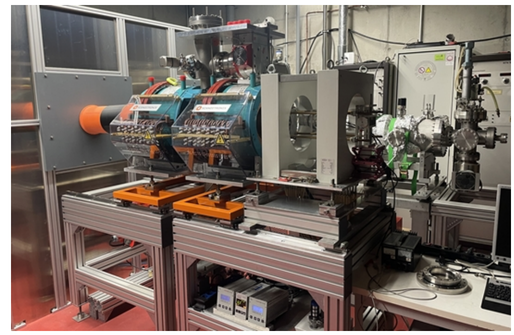

Figure 6: Actual picture of the test stand at Goethe-University Frankfurt.

SIS18 ELECTRON COOLER

Besides the design of a dedicated electron lens, the possibility of using the existing SIS18 electron cooler for space charge compensation is investigated. The magnetic system of the cooler provides a maximum field of 150 mT in the interaction region and 400 mT in the gun magnet. According to simulations (see Fig. 7) this field would be high enough to transport the beam, although drifts of a few millimeters and an ExB rotation of 12° at the exit of the interaction section can be expected. In this scenario, the cooler gun and the

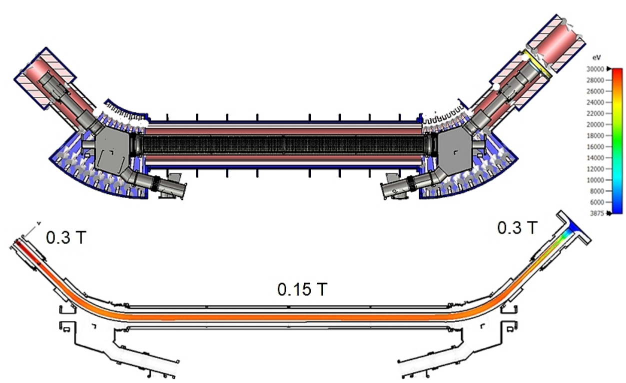

Figure 7: SIS E-Cooler with new designed gun and collector.

collector with its collector magnet would have to be replaced by the components presented in this paper.

CONCLUSION

The technical design of the electron lens for space charge lens is still ongoing and the integration in SIS18 is in process of planning. However, if the feasibility studies are successful, the electron gun and collector might be installed in the existing electron cooler to study the space charge compensation scheme in the near future.

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