E-GUN AND TEST STAND DEVELOPMENT FOR THE PULSED ELECTRON LENS FOR SPACE CHARGE COMPENSATION AT GSI[*]

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Abstract

At GSI the design of a prototype electron lens to demonstrate space charge compensation in bunched ion beams is being continued. The ultimate goal is to increase the beam intensity for FAIR by compensating for the space charge forces in the synchrotrons operating with high intensity beams by overlapping with a pulsed electron beam in the electron lens. The development of the key components — e-gun and collector — is currently underway with the aim of installing them in the SIS18 e-cooler and demonstrating the concept for the first time.
The conceptual design of the RF-modulated electron gun is completed, construction will start in mid 2026 and delivery is scheduled for autumn 2026. In the meantime, a test stand is being designed and will be set up at GSI to commission the e-gun and subsequently the collector.
In this contribution, an overview of the ongoing activities regarding the details of the gun design, collector and the test stand set-up will be presented.

INTRODUCTION AND OVERVIEW

In many low-energy hadron synchrotrons, the beam intensity is limited by its own space charge. To increase this limit, GSI is developing a prototype pulsed electron lens for space charge compensation. Electron lenses compensate for space charge by overlapping a high-intensity electron beam with a positively charged ion beam. To compensate for a bunched ion beam, the electron beam must be modulated at the RF frequency to follow the bunch profile.

The potential of pulsed electron lenses has been characterized in simulations for the SIS100 synchrotron. Using a low number of symmetrically distributed electron lenses is expected to increase the space charge limit by up to 50%, and using a larger number of lenses is expected to increase it by up to 100% [1]. Realizing such a lens is challenging since it requires very high electron intensities. The objective is to generate, transport, and dissipate beam currents of up to 15 A at a beam energy of 35 keV with a time structure ranging from DC to full modulation at frequencies from 0.4 to 1 MHz.
For this reason, an rf-modulated electron gun and collector have been developed to meet these specific requirements. They are scheduled to undergo testing in the SIS18 electron cooler in the near future.

RF-MODULATED E-GUN

The concept of the rf-modulated electron gun, as well as its preliminary technical design, has been developed over the past few years. It has been further optimized in collaboration with the company NTG in recent months and production is set to begin in the coming weeks. Figure 1 represents the preliminary design proposed by GSI and new design that was developed in collaboration with NTG.
For beam modulation, a grid is installed near the cathode - for beam extraction the grid will be operated on cathode potential and on -3 kV below the cathode potential to block the beam. As the grid imprints its structure on the electron beam, different kinds of grids were designed and will be tested in order to investigate the impact on the ion beam in the synchrotron. The cathode radius has been set to 30 mm, but the beam can be further expanded in the magnetic field to completely overlay the ion bunch.
A key consideration during the design optimization was the temperature management of the structure in the area around the cathode. Thermomechanical simulations for a cathode temperature of 900 °C were performed to deduce the temperature distribution of the environment and revealed that the e-gun chamber must be cooled. Nevertheless, the main ceramic insulator that isolates the electrode system from ground becomes very hot, still about 300 °C. The experience

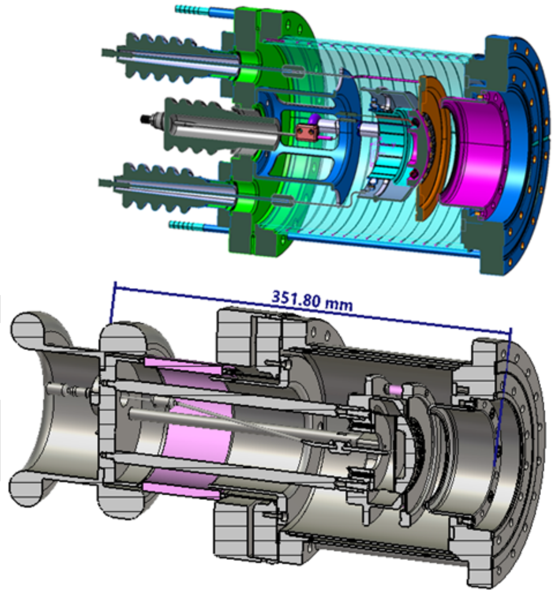

Figure 1: Preliminary design by GSI (top) and optimized design (bottom) during the procurement process of the rf-modulated e-gun.

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of CERN colleagues has shown that ceramic insulators must be protected from excessive heat and sputtering from the cathode to maintain the system's high-voltage resistance. For this reason, the main ceramic insulator was removed from the high vacuum region and positioned at the back of the e-gun to take advantage of convective cooling. By this measure, a temperature reduction of more than 200 °C was achieved. However, the positioning of the ceramic insulator that separates the cathode and the grid did not seem to pose a problem, since it only needs to withstand a potential of -3 kV.

In this context, Alumina (Al_2O_3) was selected as the insulation material due to its high electrical resistivity (e.g. 10^8 Ω·cm at 800°C). It was decided to manufacture a pair of grids from molybdenum and another from graphite. Graphite combines low secondary electron yield, high temperature stability, and good thermal conductivity, enabling stable operation and efficient heat dissipation. However, the outgassing behavior of the proposed graphite is unclear, so further investigations are necessary. The focussing electrode will be made of molybdenum and the other gun components will be made of stainless steel. A type 311XM BaO dispenser cathode from SpectraMat will be installed in the gun. The design was also optimized with respect to the dielectric strength: in the UHV region the electric field strength was kept well below 10 kV/mm and metal-ceramic junctions were shielded. Also in air, additional shields as well as toroids were designed to keep the electric field strength below 1.5 kV/mm.

COLLECTOR

Unlike in other applications, the collector chamber designed for the electron lens is placed between two solenoids of opposite sign creating a magnetic cusp field. The advantage of this configuration is the strongly reduced beam potential by rapid expansion of the beam which results in a reduced power deposition requirement for the chamber design and, as a bonus, the beam power is distributed over a large area. The conceptual design was already presented in [2].

A remaining open question was the suppression of secondary electrons produced at the chamber wall. To numerically investigate the production of secondary electrons and their suppression, the Furman-Pivi model was used, which is implemented in CST Particle Studio [3]. It was found that a major problem is the suppression of elastically backscattered electrons. Various suppression methods were examined, but the integration of a suppressor electrode appears to be the most effective approach. Of course, correct sizing and positioning are important for effective suppression. In this way, the secondary electron backflow was reduced to a few mA, and the collector efficiency was increased from 90% to 99.8%.

However, the new cusp field concept makes the mechanical design very challenging. The chamber must have a small height compared to the diameter to fit between the magnets.

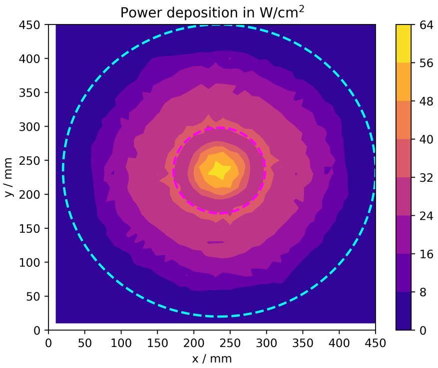

Figure 2: Distribution of power deposition on the collector back wall of the preliminary design. The cyan colored circle represents the inner diameter of the collector chamber and the magenta colored circle the outer diameter of the insert (see the magenta-colored part of the collector back wall in Fig. 3).

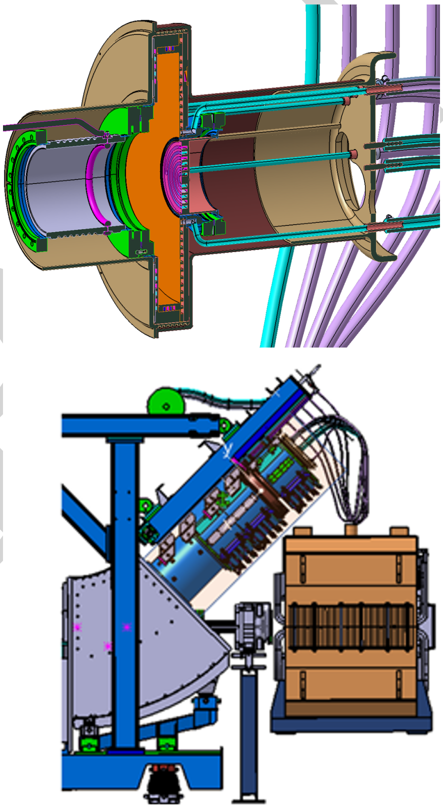

Figure 3: Preliminary design of the cusp collector chamber by GSI (top). Installation situation of the chamber within the modified e-cooler section in the accelerator tunnel of SIS18 (bottom).

The beam power is not uniformly distributed and separate cooling channels are required to allow deducing beam power distribution from the temperature of the water backflow. Figure 2 shows the simulated distribution of deposited peak beam power over the collector back wall corrected by the duty factor of 0.3 since the electron lens will only be operated during the injection phase of the SIS18 cycle.

When installing the collector chamber, the magnets are typically slid over the beam tube so they can be mounted there. However, this is no longer possible with the cusp collector design. For this reason, the rear wall of the chamber is made up of two parts, allowing the collector to be mounted onto the existing beam tube. Figure 3 shows the preliminary collector chamber design by GSI (top) and the installation situation in the accelerator tunnel of SIS18 (bottom).

Overall, the challenging chamber design requires the use of advanced manufacturing methods. As a part of EPITA WP11* starting in May of this year, a prototype chamber will be produced by additive manufacturing and will be finally tested on a test stand at GSI. A magnet system that comprises three solenoids for creating a cusp field and integrating the collector system into the cooler has been designed and will be procured within the next year.

TEST STAND

A test stand is currently being set-up at GSI in order to commission the key components of the e-lens and ultimately demonstrate the design parameters.

It will be placed in a bunker to meet safety requirements and constructed in stages: in the first stage only the supports with the vacuum chamber and pumping station will be installed in order to perform the high-voltage acceptance tests of the e-gun.

In the second stage as presented in Fig. 4, the rf-modulated e-gun will be commissioned using an existing collector, which will be operated up to its performance limits, and diagnostics will be defined. Beam transport simulations were conducted to determine the maximum beam currents that can be transported, taking into account the limitations of the existing collector — namely, a reduced aperture of 50 mm and a maximum power deposition of 10 kW — and a maximum of 2.4 A was achieved (see Fig. 5). The majority of the equipment needed for the setup during the first two phases is from the 100 keV COSY electron cooler provided by FZ Jülich. This includes several power supplies, the isolating transformer, and the solenoids along with their mounting frames. The production and procurement of other required components as vacuum chamber and supports has started, and the modification of existing parts in the machine shop at GSI is ongoing. Once the collector chamber is manufactured, the magnetic system to create the cusp field will be integrated which represents the final stage of the test stand. The cusp collector will be tested up to it's design power and the electron beam will be characterized.

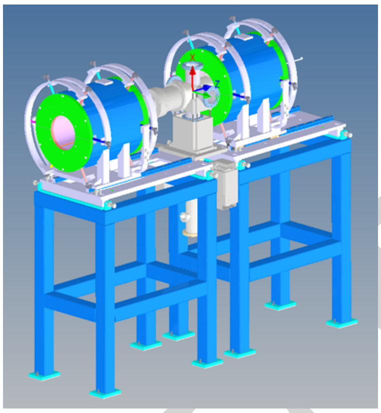

Figure 4: Layout of the test stand in the second stage.

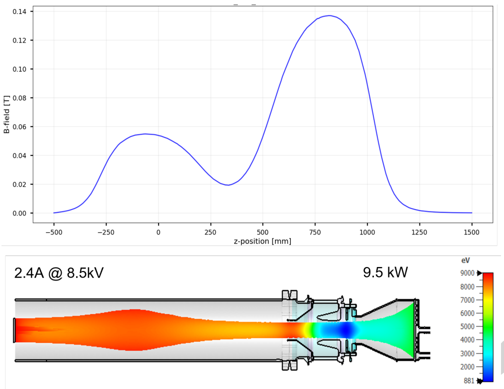

Figure 5: Beam transport simulations for the test stand in the second stage the e-gun's operating parameters.

The e-gun can only be operated in the required frequency range with a power modulator designed for that purpose. The conceptual design of this modulator has been finalized [4]. However, it has not yet been procured, and this represents the next necessary step for testing space charge compensation in the SIS18.

CONCLUSION

The development of a prototype electron lens for space charge compensation at GSI is progressing steadily toward a first experimental demonstration in SIS18. The design of the electron gun has been finalized, addressing key challenges such as high-current beam generation, thermal management, and high-voltage insulation and will go in production soon. In parallel, the collector design has been further refined, achieving efficient suppression of secondary electrons and a high collector efficiency of about 99.8%, while meeting the demanding mechanical constraints imposed by the cusp magnetic field configuration.

A dedicated test stand is currently under construction and will allow stepwise commissioning of electron gun and collector, as well as validation of the design parameters.

Upcoming work will focus on the completion and commissioning of the hardware, procurement of the power modulator, and preparation of the experimental studies in SIS18.

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