STATUS OF THE HYBRID ELECTRON GUN DEVELOPMENT AT ELSA

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Abstract

A redesign of the injector beamline for the S-band linac at ELSA is underway, including the replacement of the existing electron gun by a hybrid gun that combines thermionic emission and thermally assisted photoemission in a single setup. The goal is to offer a new single-bunch injection mode alongside the long pulse mode already provided by the current gun. Measurements have been conducted to verify this emission technique using caesium dispenser cathodes. Another step in the scope of the project is the replacement of the current prebuncher cavity. A new design has been worked on and already undergone different tests of quality factor and bunching capabilities. The development of a dedicated test stand is currently being carried out to facilitate more detailed studies and serve as a prototype for the future injector section. Recent work has concentrated on the lattice and magnet design, as well as on evaluating suitable beam-diagnostic instrumentation.

INTRODUCTION

The ELSA facility (Electron Stretcher Accelerator, located at the University of Bonn) – shown in Fig. 1 – employs a 3 GHz travelling wave linac with both spin-polarised (GaAs photocathode) and non-polarised (thermionic cathode) electron sources, the latter delivers currents of up to 0.5 A. The injector at ELSA, requires modernization due to aging infrastructure, which has resulted in loss of diagnostic capabilities in favor of additional vacuum pumps. Spatial constraints in the injector area complicate replacement planning. Part of the beamline is a 3 GHz prebuncher used for both electron sources. A new dual-mode electron gun is being manufactured to maintain current operational capabilities while enabling single-bunch operation for machine studies in the stretcher ring. The dual mode is realized by using a caesium dispenser cathode, both as thermionic emitter as well as a photoemitter employing thermally assisted photoemission (TAPE).

INFRASTRUCTURE UPGRADES

The ongoing hardware development includes the replacement and modernization of key injector components to improve long-term operational robustness and maintainability. The current work focuses on two main elements of the injector beamline: the electron gun and the prebuncher cavity.

Electron Gun

The design of the gun is realized as a direct replacement of the current electron gun improving maintainability and offering a new mode of operation. The planned gun is employing

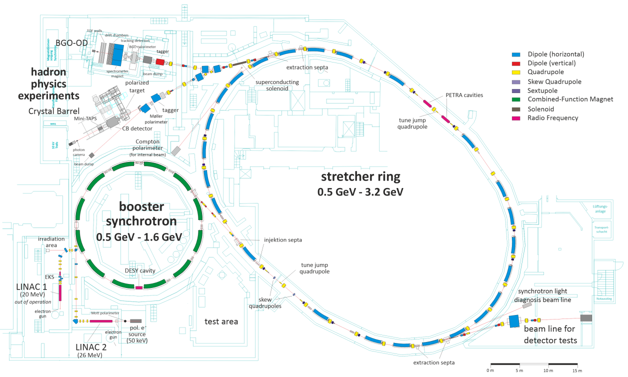

Figure 1: Overview of the ELSA facility.

the Pierce geometry with a 50 keV constant accelerating field. Further details on the gun design are described in [1]. The planned gun design is depicted in Fig. 2. Core of the new design is a gridded caesium dispenser cathode mounted on CF60 vacuum flange. Such cathodes are known to be long lived and operate under vacuum pressures in the range of 10^{-8} mbar to 10^{-9} mbar. During normal operation 1 µs long electron pulses with a charge of 2 µC are produced. The prebuncher compresses the beam longitudinally into multiple short bunches increasing the transfer efficiency through the linac.

In the TAPE mode the heating power is reduced below the emission threshold. The actual emission occurs via laser-induced photoeffect. The heating increases the quantum efficiency (QE) of the cathode. This effect is also known from different kinds of thermionic cathodes. In the case of dispenser cathodes it was observed that a with time decreasing QE can be restored using a heating cycle – rising the surface temperature to the expected values for thermionic operation followed by a reduction back to the TAPE operating temperature. Using the TAPE effect the bunch length can be controlled by the length of the laser pulse. To ensure acceleration of a single bucket within the S-band linac pulse

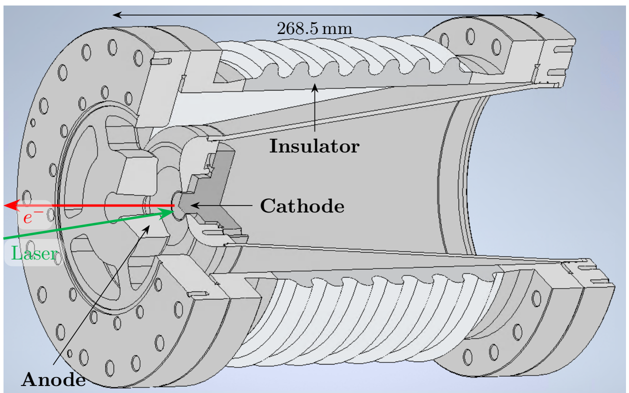

Figure 2: Planned design of new hybrid electron Gun.

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lengths of 70 ps are foreseen. Here the prebuncher will be used as a bunch compressor.

Prebuncher

A 3 GHz aluminium cavity is used as a prebuncher in front of the linac. To maintain the correct phase between prebuncher and linac the RF power is branched off the linac's RF system.

A new optimized design following the existing cavity aimed to increase its quality factor. A prototype for quality factor measurements has been designed and manufactured. Several measurements have been conducted characterizing the quality factor, field strength and coupling. The surface roughness of the cavity was examined as a possible explanation for deviations between simulations and experimental results. Figure 3 shows the simulated dependency of the quality factor on the surface roughness.

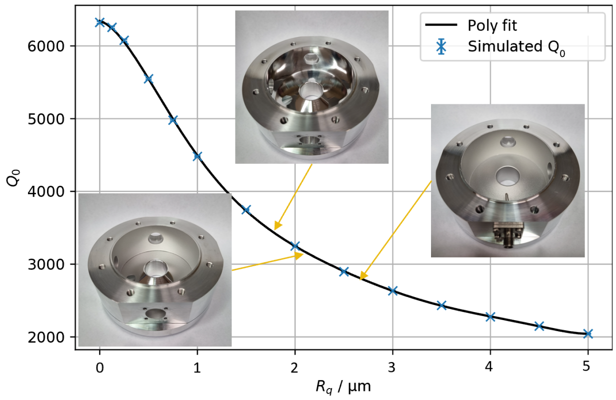

Figure 3: Simulated quality factor for different surface roughness. A face plate of the resonator after different surface polishing stages is shown as reference.

TAPE EFFECT CHARACTERIZATION

The TAPE effect is tested and characterized with a ceasium dispenser cathode similar to types which are foreseen for later usage. For this measurements *CPI EIMAC Y646B* cathodes are used, which had been in operation and were unmounted from the existing gun in the meantime.

The test setup consists of a vacuum chamber housing the cathode and a copper plate, biased with 20 V max., that acts as a pick-up anode. A hole in it offers the ability to both illuminate the cathode by laser as well as measure the temperature of the cathode surface by a in vacuum mounted pyrometer. Shuttering of the laser beam enables quasi-simultaneous dark current and photocurrent measurements. Therefore the quantum efficiency and its development over time could be examined. Also the reactivation of the cathode by a heating cycle was studied. First measurements were performed with a used cathode, which was reactivated in the vacuum chamber. Tests with this cathode confirmed photoemission with a maximum QE of 5.6×10^{-6} (cf. Fig. 4). A half-life time of around 45 min was achieved with a heating cycle taking approximately 10 min. It could be observed that the QE

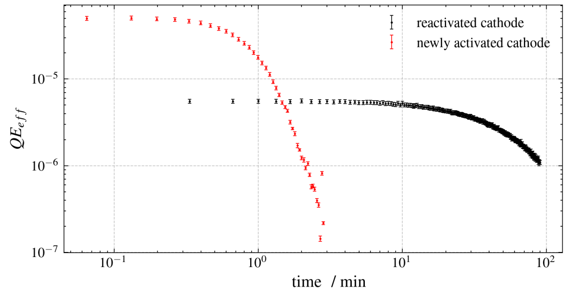

Figure 4: QE measurements on used and new cathode.

strongly depends on the activation scheme (heating power and duration of heating). For further measurements a new cathode was used which was first activated in the test setup. Here, a higher QE in the order of 5×10^{-5} was observed, unexpectedly showing a shorter lifetime in the order of 1 min. Measurements of the used and new cathode are compared in Fig. 4. It was observed that variations of cathode heating power and subsequent cool-off periods had a significant influence on the QE. Best results were obtained at lowest achievable vacuum pressures, suggesting either caesium oxide build up or the general vacuum quality as dominant factors in the TAPE operation mode. Those hypotheses will be investigated at the dedicated gun test stand, which therefore will be equipped with an adequate vacuum system with integrated residual gas analysis.

GUN TEST STAND

A dedicated test stand will be set up for measurements of beam parameters as well as the in-depth characterization of the TAPE effect. It will be built to resemble the low energy injector beamline, which will be designed for the linac. The test stand will be constructed as compact as possible while still offering enough space for all diagnostic elements. An overview of the initial concept is depicted in Fig. 5.

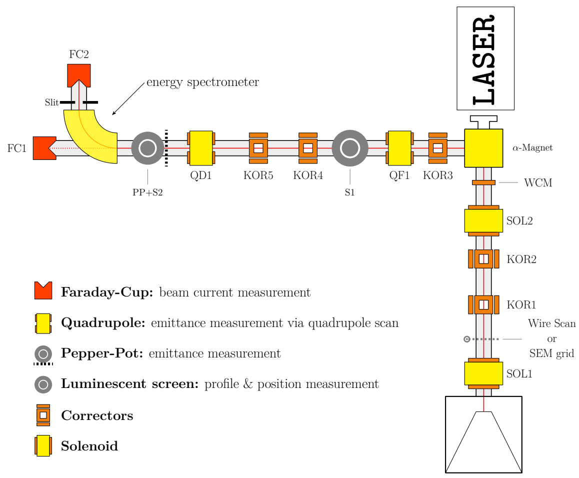

Figure 5: Initial concept of the gun test stand. Dimensions are not to scale.

A split into two parts is planned which are joined by an α-magnet. The magnet acts as an achromatic mirror and allows for measurements of transverse beam properties independent of the beam's energy spread. The first part will house solenoids for initial focusing. Beam diagnostics in this region must be non-destructive for the laser beam which will be fed through a vacuum port at the α-magnet. The second part of the test stand is reserved for additional beam diagnostics, where luminescence screens will be used. For the characterization of the TAPE operation mode a residual gas analyzer will be located in close proximity to the gun. Additionally a needle valve will allow the precise insertion of gases into the vacuum chamber close to the gun to artificially increase the pressure and thus measure vacuum dependency during operation and heating cycles. The operating vacuum pressure is planned to be in the order of 10^{-9} mbar.

Planned Beam Diagnostics

In the first part either an SEM-Grid or a wire-scan is planned to measure both the beam profile and position. Furthermore the longitudinal beam shape will be measured using a wall current monitor, which could also enable a secondary position measurement. In the second part the luminescence screens in conjunction with the quadrupoles allows for transversal emittance measurement using the quadrupole scan technique. Using two quadrupoles allows for cross validation of the experimental results. To ensure result comparison a pepper-pot device will be designed. The final component of the test-stand will be a energy spectrometer, which will utilize a dipole magnet and a Faraday cup with a thin slit in front. The measurement of the absolute beam current is possible using a second Faraday cup with a deactivated dipole.

Beam Tracking Simulations

Several beam tracking simulation frameworks have been used and tested for the simulation of the gun test stand. Emphasis was put on simulating a space-charge dominated beam inside a α-magnet using `RF-Track` [2]. This simulation code offers the possibility to implement the α-magnet as a three-dimensional field map and allows calculations including the influence of space-charge. Furthermore it is able to handle the change in the reference axis induced by the α-magnet. The code is also flexible enough to be used to simulate thermionic and TAPE emission modes with pulse lengths of 70 ps or 1 µs. Focus of the simulation is to optimize the number and position of necessary optical elements and the beam transport through the α-magnet. The path of a single electron through an ideal α-magnet field was simulated and is shown in Fig. 6. As expected the electron's exit and entrance point of the field are identical. Once beam simulations have resulted in a finished beamline layout `RF-Track` also offers the possibility to simulate quadrupole scan and spectrometer measurements and determine necessary magnet properties for the planned experimental program.

In parallel to the ongoing tracking studies the development of XY steerer magnets has begun. Two designs are currently compared based on a window-frame and a H-type design respectively. Main concern in this development is the field homogeneity inside the beam pipe while ensuring

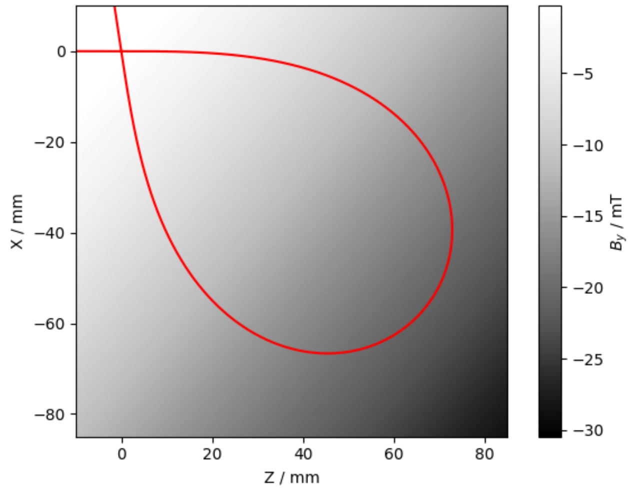

Figure 6: The path of a single electron simulated inside the field of an α-magnet.

a compact design. Initial simulations show significant less field variation for the window-frame design but the influence of mechanical tolerances are not yet analyzed.

CONCLUSION

A new hybrid electron gun utilizing both thermionic and photoemission modes is being manufactured as a replacement of the existing electron gun for the S-band linac at ELSA. Prior research has shown the feasibility of dispenser cathodes as photoemitters utilizing the TAPE effect. Initial verification of this operation mode has been started using *EIMAC Y646B* cathodes. Photoemission could successfully be demonstrated and quantum efficiencies of 5.6×10^{-6} for a reactivated cathode and 5×10^{-5} for a newly activated cathode were measured, although the latter lacked operational stability within the preliminary test setup. Its limitations, e.g. accelerating voltage and vacuum pressure, will be eradicated with the dedicated gun test stand, which will function under normal operating conditions. The test stand is thus intended both for the measurement of general beam properties and for the characterization of the TAPE effect. Recent work was focused on simulating and optimizing the beam optics of the test stand. Besides that development of a new prebuncher has started. A first prototype for quality factor measurements was produced and the dependency on the surface roughness has been studied. A first vacuum tight prototype is in manufacturing and will be tested at a low-energy beamline.

REFERENCES

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