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# DEVELOPMENT OF A HYBRID THERMIONIC AND PHOTOEMISSION ELECTRON GUN AND DEDICATED TEST STAND FOR ELSA

S. Kronenberg*, K. Desch, P. Hänisch, D. Proft
Physikalisches Institut, University of Bonn, Germany

*Abstract*

A new electron gun is currently being designed for the S-band linac injector for ELSA. The objective of this development is to realize a new single-bunch injection mode in addition to the standard long pulse (multi-bunch) mode along with an improvement of the current beam parameters (e.g. emission current & transverse emittance) achieved by the existing gun. A dual mode design is being developed that utilizes a caesium dispenser cathode both as a thermionic and a photocathode using thermally assisted photoemission. In addition to the novel electron gun, a dedicated test stand is currently being designed to allow detailed characterization of both operating modes. The refined design of the gun and the current status of the test stand including beam parameter simulations are presented.

## INTRODUCTION

The injector at ELSA (Electron Stretcher Accelerator), an electron accelerator operated by University of Bonn, is to be modernized, requiring the replacement of the existing electron gun assembly. A new electron gun is currently under design to maintain and improve the currently available operation mode and to ensure a reliable operation of the electron source. Initial optimization steps have been undertaken [1]. Subsequent refinements incorporate considerations such as the vacuum system and thermal stability. This new gun aims to enhance ELSA's capabilities by enabling single-bunch operation of the injector, facilitating high-current single-bunch operation in the stretcher ring alongside the preservation of the current multi-bunch mode. Additionally, an increase in electron current of the gun is targeted. A dedicated test stand is also in development for experimental verification and characterization.

## EXISTING INJECTOR INFRASTRUCTURE

The ELSA facility (see Fig. 1) currently utilizes a travelling wave linear accelerator (referred to as LINAC2), operating at a frequency of 3 GHz, equipped with two electron sources. The injector is capable of both the acceleration of spin-polarised and non-polarised electrons, either from a GaAs photocathode or a thermionic cathode. Both sources operate in a pulsed mode, with electron pulses of 1 µs at an acceleration voltage of 50 kV. The thermal electron source currently in operation is capable of delivering an electron current of up to 0.5 A. To suppress dispersion effects in the injector beamline, an alpha magnet is used as a beam switch. In addition to the gun itself, the beamline connecting the thermal gun to the entrance of the linac suffers from ageing. This has resulted in the loss of diagnostic capabilities, with the installation of additional vacuum pumps as a countermeasure. The limited space available on-site represents a significant factor in the planning of the gun replacement.

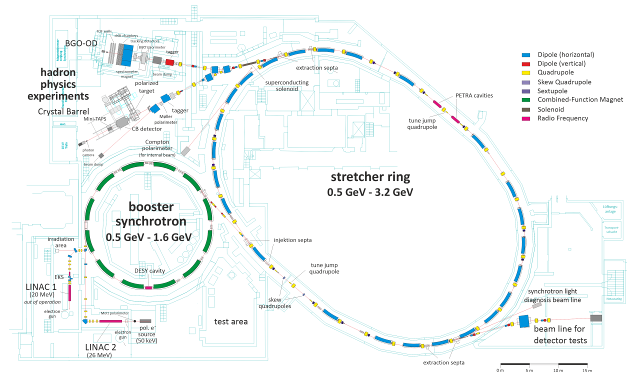


Figure 1: Overview of the ELSA facility.

## ELECTRON GUN UPGRADE

The upgrade aims to extend the operational range of the electron source and to enhance the ease of maintenance and operation, as well as to address age-related issues. The proposal includes an increase of the electron current to 2 A for accelerator operation and aims for a beam quality matching the current setup, with a targeted transverse emittance of 8.3 mm mrad or lower.

### *Operation Modes*

The current injector setup operates solely in so-called multi-bunch mode.The pulse is seperated into approximately 3000 bunches by a prebuncher in front of the linac. The pulses are formed by the use of a grid in front of the cathode in a triode setup. The required pulser electronics is mounted directly within the high-voltage cone holding the cathode. In contrast, a new operational mode, the single-bunch mode, is to be added. In this mode, electrons should only be injected into one RF bucket of the linac. Consequently, a considerably shorter pulse length is required. The anticipated acceptance of a 3 GHz signal is in the range of a few picoseconds. In order to facilitate the requirements pertaining to the bunch length in the single bunch mode, the existing prebuncher can be employed as a bunch compressor. This allows to inject a bunch length of 70 ps. To achieve the same pulse current as today a pulse charge of 140 pC is required.

* s.kronenberg@uni-bonn.de

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## CONCEPT OF THE NEW ELECTRON GUN

To avoid the mechanical exchange of the pulser electronics for short and long pulse operation, as had been realized in former gun setups at ELSA [2], thermally assisted photoemission (TAPE) will be utilized for the single-bunch operation.

### *Thermally Assisted Photoemission*

TAPE is a promising approach to create short pulses off a thermal dispenser cathode. To realise this mode of operation the cathode material is heated up to a point, where thermionic emission is prevented. The remaining necessary energy is induced via illumination by a laser pulse through the photoelectric effect. Thus, the time structure of the electron pulse is determined by the laser pulse.

Dispenser cathodes are suitable for photoemission operation in a broad wavelength range, especially in the visible range [3, 4], which makes operation more convenient compared to metal cathodes, which typically require UV laser wavelengths.

### *Hybrid Gun Design*

The thermionic gun design is known to be reliable and durable, making it especially suitable for the intended application at the ELSA facility. In addition, the concept of photoemitters greatly simplifies the setup for a short pulse electron gun. Due to limited space, installing two individual electron guns is not feasible. Hence, thermionic emission and thermal-assisted photoemission concepts are realised in a single assembly. Optical simulations were conducted using the Python package LightPipes [5] to investigate the impact of the cathode grid on the laser pulse. The results demonstrate that the effect is insignificant, indicating that no special adjustments to the thermionic design are necessary for the realization as a hybrid gun. Consequently, the gun was designed as an inverted triode gun following the Pierce geometry.

## GUN DESIGN

The preliminary gun design was reported previously [1]. Besides the principal concept remaining unchanged, several improvements were made both targeting the beam quality as well as structural improvements. The new design is depicted in Fig. 2.

### *Vacuum Improvements*

Due to manufacturing limitations, it was determined that the internal high-voltage cone should be shortened in comparison to Ref. [1] and that the anode should align flush with the outer surface of the vacuum flange. Consequently, the required vacuum pumps can only be connected to the anode from the exterior. In order to enhance the vacuum quality within the gun assembly, it is planned to create cut-outs in the outer part of the anode. Moreover the anode will serve to adapt from the CF150 flange of the insulator to a CF100 flange, thereby reducing the volume of the assembly to comply with the space constraints. Extensive simulations were conducted using CST [6] to ascertain that the cut-outs maintain the original field distribution within the acceleration gap, preserving the beam properties. The main goal was to maximize the volume of the cut-outs while maintaining the beam quality. At the same time, the bending radii were selected to prevent the occurrence of corona discharge.

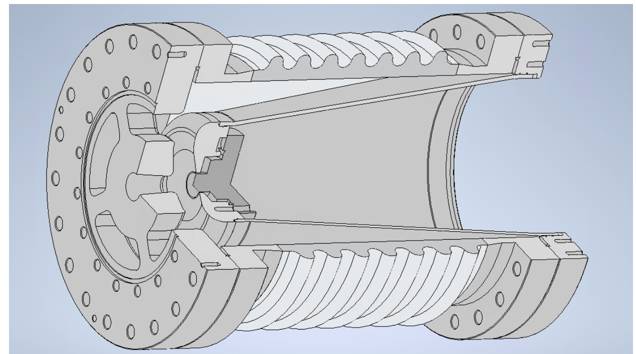

Figure 2: Mechanical design of the new gun assembly.

### *Improvement of the Anode Design*

In order to fulfil the requirements for the potential in the acceleration gap [7], it is necessary that the anode is positioned along an equipotential surface. Assuming a cylindrical symmetrical structure, the anode surface can be described by the distance to the origin $r$ and the longitudinal distance $z$ from the cathode. The equipotential surfaces are then given by:

$$d^{-\frac{4}{3}}\left(r^2+z^2\right)^{\frac{2}{3}}\cos\left(\frac{4}{3}\tan^{-1}\left(\frac{r}{z}\right)\right)=1, \qquad (1)$$

where $d$ is the distance between cathode and anode along the $z$-axis. However, precise manufacturing of this geometry is not feasible. The geometry of the anode was therefore adapted to approximate such an equipotential surface.

In addition, the aperture in the anode acts as a defocusing electric lens. A reduction in the ratio of the aperture radius to the length of the acceleration gap $d$ leads to a reduction of the defocusing effect. Nevertheless, a small aperture may result in increased particle loss. In the current design, the aperture is therefore planned to be conically enlarged towards the exterior of the anode.

### *Simulated Beam Properties*

The evaluation of the enhanced design was conducted using CST [6]. The gun assembly has been designed to be compatible with a number of commercially available cathodes with varying maximal emission currents. The beam properties shown in Table 1 have been simulated for an emission current of 2 A, which is in line with the planned operational parameters. A view of the equipotential lines in the acceleration gap as well as simulated particle tracks are shown in Fig. 3

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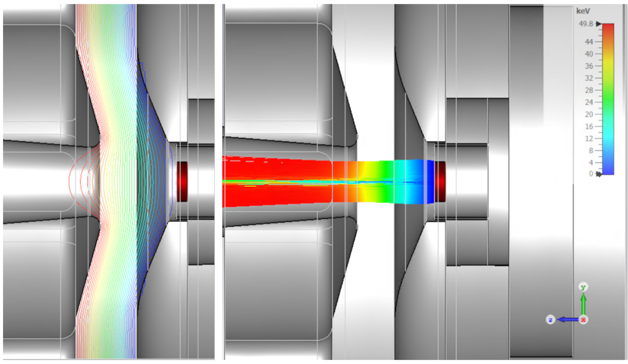

Figure 3: Simulated potential in acceleration gap (left) and particle tracking simulation of the current gun design (right).

Table 1: Simulated beam properties at the outer edge of the anode.

| $\epsilon_x$ | $\epsilon_y$ | divergence | envelope | I |
|---|---|---|---|---|
| 4.38 µm rad | 4.37 µm rad | 32.26 mrad | 5.89 mm | 1.5 A |

## TEST-STAND

In order to undertake future injector upgrades or optimisations, it is essential to have a comprehensive understanding of the gun's behaviour and beam properties. Consequently, it is beneficial to analyse the beam extensively. Moreover, further investigations of the TAPE effect is required to optimize the operation parameters of the injector. To address these requirements, a dedicated test stand is being designed and will be constructed at our facility.

The goal of the test stand is to determine the elementary beam parameters, including beam size, emittance, energy spread, and emission current utilizing multiple measurement techniques per parameter wherever feasible. For instance, the emittance is to be determined using both quadrupole scans and pepper-pot measurements. An initial conceptual depiction of the design can be found in Fig. 4. At present, initial beam simulations employing ASTRA [8] are carried out to determine the specifications for the magnet optics.

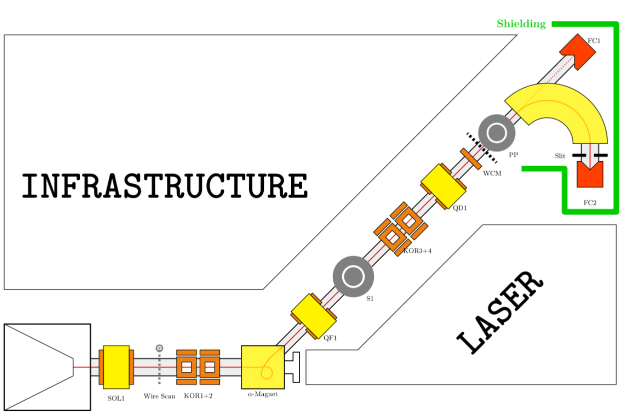


Figure 4: Initial concept of the test stand. Dimensions are not to scale.

### *Quantum Efficiency Measurement Setup*

We intend to perform comprehensive measurements with variable laser wavelength, heating power and vacuum pressure. For these measurements a test environment originally used for photocathodes is currently modified for the measurements with dispenser cathodes. Here only small accelerating voltages can be used, thus limiting the emission current due to space-charge effects.Therefore quantum efficiency measurements for high extraction currents are planned to take place at the test stand.

## CONCLUSION

For the replacement of the existing electron gun at LINAC2 at ELSA the installation of a hybrid electron gun is planned. The new gun will enable the use of a thermionic dispenser cathode in thermionic mode as well as an photoemitter. Prior research and operation at other facilities has proven the feasibility and reliability of this type of cathode used as a photocathode. Using the TAPE effect, a single-bunch mode will be enabled along with the already used multi-bunch mode. With first manufacturing steps already ongoing, the design was refined to improve the vacuum as well as the beam quality. To further validate the beam properties of the gun and the TAPE effect on dispenser cathodes a dedicated test stand as well as a quantum efficiency measurement setup is currently being developed.

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