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DESIGN OF A NEW PHOTO AND THERMIONIC HYBRID MODE 50 kV PULSED ELECTRON GUN FOR ELSA

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Abstract

For the Linac travelling wave S-band injector at ELSA a new electron gun is being designed, to enhance the beam parameters of the old gun. Furthermore, a new single bunch injection mode is to be realized alongside the standard long pulse (multi bunch) mode, allowing to use the gun for normal operation for the experimental program as well as enabling single bunch operations for accelerator research and development. For that matter a dual-use design is pursued utilizing a dispenser cathode both as photo- as well as thermionic cathode. First steps including the design of the gun assembly and studies about its usability as a photoemitter are conducted. A preliminary design of the gun assembly and simulation results are presented.

INTRODUCTION

The injector at ELSA, an electron accelerator at the University of Bonn, was facing significant challenges due to ageing, particularly with regard to vacuum issues, which necessitated the replacement of the existing assembly. In order to overcome these challenges and to retain a reliable source of electrons, a new electron gun has been designed, optimised and will now be subject to experimental verification and implementation. This new gun offers the opportunity to extend ELSA's capabilities in accelerator research and development by introducing single-bunch operation of the injector and therefore high-current single-bunch operation in the stretcher ring. In addition, an increase in the electron current is targeted. In order to achieve these objectives, an extensive review of different electron gun types was carried out. Here we present the design process, including a discussion of the considerations that led to the selection of the new gun type and the optimisation results. In addition, the preliminary simulated performance evaluation of the new gun is presented, demonstrating the potential of the new assembly to advance ELSA's research goals.

EXISTING INJECTOR INFRASTRUCTURE

The existing injector at ELSA (see Fig. 1 for an overview of the facility), the so-called LINAC2, is a travelling wave linear accelerator using a 3 GHz acceleration frequency. Two electron sources are connected to this accelerator. One is a thermal source and the other is a source of spin-polarised electrons based on a GaAs photocathode. Both sources provide electrons with a kinetic energy of approx. 50 keV. The thermal source delivers an electron current of about 0.5 A. An alpha magnet is used in the transfer beam line,

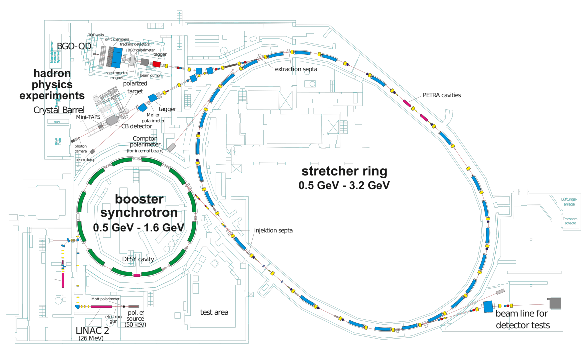

Figure 1: Overview of the ELSA facility.

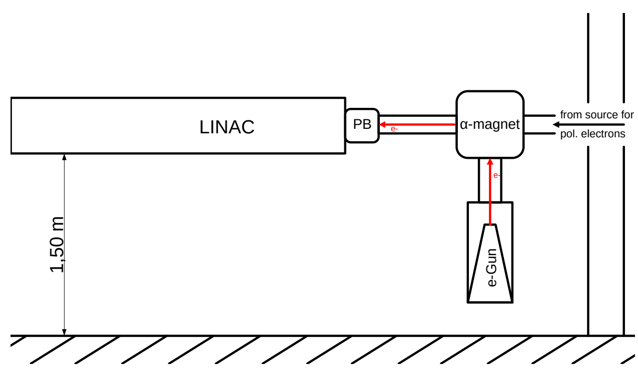

Figure 2: Schematic drawing of the transfer beamline connecting the electron sources to LINAC2.

which serves as a beam switch to connect both sources to the linac. In particular, the beamline between thermal gun, alpha magnet and linac shows clear signs of ageing. In recent years, the quality of the vacuum in this area has deteriorated. As a result, diagnostic elements in this part of the beamline had to be replaced in favour of additional vacuum pumps. However, this implies that the ability to experimentally characterise the thermal gun was lost. Apart from the vacuum problems, the facility has operated successfully in the years since commissioning (2000). One challenge is the limited space available on site, which had to be taken into account in the planning (see Fig. 2).

UPGRADE PLANS

The aim of this upgrade is to expand the possibilities for accelerator research and development and to simplify recurring maintenance work. The physical improvements are focused on increasing the beam current from the cur-

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rent ≈ 0.5 A to 2 A and introducing a new operating mode. In terms of beam parameters, it is desirable to match the characteristics of the current gun. This requires a transverse emittance of 8.3 mm mrad or less.

Multi-bunch Mode

The multi-bunch or long-pulse mode is the currently available mode of operation. In this mode, a 1 microsecond long electron pulse is emitted from the gun and a pre-buncher in front of the linac is used to achieve bunching. Multiple RF buckets inside the linac are filled. This will also be the standard operation mode in the future.

Single-bunch Mode

The aim of single-bunch mode is to fill only a single RF bucket in the linac and thus also in the ELSA stretcher ring. To achieve this, the same pre-buncher is used as a pulse compressor. Aiming for a pulse current of 2 A, a charge of 140 pC wit pulse lengths of 70 ps is desired.

Conceptual Design

The design of the new gun was preceded by a search for a suitable type, so adherence to thermal emission was not a prerequisite. This research showed that a thermal gun was most desirable for our use because of its reliability and longevity. However, implementing the single-bunch mode posed a challenge in terms of generating the required short electron pulses (70 ps), which we were already aware of Ref. [1]. A similar setup featured two pulser electronics to implement both operating modes in a thermionic gun. To change the operating mode, these electronics had to be swapped. Due to the spatial conditions at LINAC2, this solution is highly unsatisfactory. A photocathode comes with the advantage that the *pulsed* electron beam can be generated directly by a pulsed laser. Due to the shorter lifetime of suitable photocathodes and the higher cost, it was decided not to use such a cathode.

THERMALLY ASSISTED PHOTOEMISSION OFF DISPENSER CATHODES

Previous research into the applicability of a thermionic dispenser cathode as a photoemitter has been carried out by groups at MAX-lab [2] and SSRL [3].

Using the so-called TAPE (**T**hermally **A**ssisted **P**hoto**E**mission) operation mode, the efficiency can be increased. For this operation the cathode is heated, to a temperature, where emission of electrons due to thermal excitation is still surpressed. If the heated cathode is used as a photoemitter the quantum efficiency is increased.

Both groups achieved successful operation with laser operating in the UV range. However, measurements of the quantum efficiency depending on the laser wavelength (see Fig. 3) have shown, that the operation of a dispenser cathode in the blue or green wavelength range could be feasible.

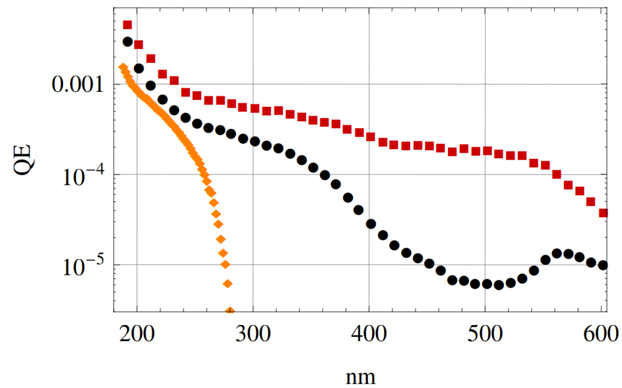

Figure 3: The quantum efficiency (QE) of a thermionic dispenser cathode was measured for different wavelengths of the illuminating source. Measurements are compared for the unheated (black) and heated (red) operation. The results are compared to the quantum efficiency of a copper cathode (orange) (from Ref. [3]).

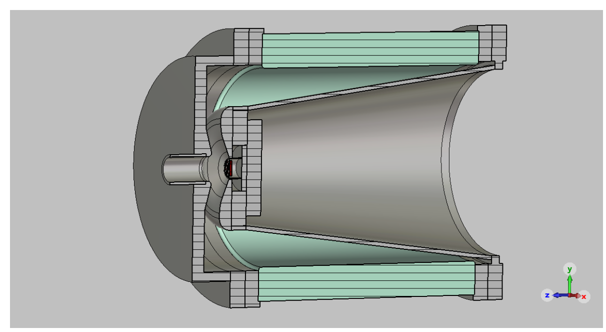

Figure 4: Preliminary Design of the new gun assembly.

At SSRL pulse charges of approx. 1.8 nC were achieved for a pulse length of 2 ps [3].

It was also shown that dispenser cathodes, which are used as photoemitters are still long lived and reliable electron sources. Also moderate vacuum requirements compared to other photocathodes are an argument for such an operation mode.

PRELIMINARY DESIGN

In order to meet the requirements for our upgraded electron gun, we have designed a hybrid electron gun that uses a thermionic dispenser cathode both as a thermal cathode and as a photocathode. This design is expected to provide a durable and reliable gun, as well as a simple approach for the single bunch mode. It was found that a combination of both operation modes is possible. Furthermore our design of the thermionic gun is suitable for the TAPE operation mode and no changes of the design are needed.

The design was refined and the beam parameters were optimized in several steps. The optimized layout can be seen in Figure 4. The optimized value of the cathode anode spacing was found to be $d = 15$ mm. The Pierce geometry is used to counteract space charge effects. Special emphasis was put

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Table 1: Preliminary Laser Requirements

Property	Requirement
Pulse length	70 ps
Repetition rate	50 Hz (ext. triggered)
Wavelength	400 nm to 532 nm
Peak power	23.31 kW(@532 nm) - 31.00 kW(@400 nm)
Pulse energy	1.63 µJ(@532 nm) - 2.17 µJ(@400 nm)
Spotsize	⌀ ≈ 10 mm (variable)

into the simplification of recurring maintenance tasks. The design is optimized for the installation of different types of dispenser cathodes to evaluate their utility as photocathodes at a dedicated test stand, that is currently planned.

Preliminary Laser Requirements

Based on the evaluations presented above, preliminary laser requirements were derived (see Table 1). To ease the operation of the laser system the visible range was selected. In the region of 400 nm to 532 nm e.g. a frequency-doubled Nd:YAG Laser would be suitable. There are several Laser systems commercially available suitable for this operation.

A vacuum window at the existing α-Magnet (comp. Fig. 2) will be used, for guidance of the laser in the vacuum structure. The laser beam will then be directed onto the cathode. Due to the rather large desired spotsize it is sufficient to have the optical system placed outside the structure and to use a single, movable converging lens upstream of the vacuum window to alter the spotsize.

For the thermal multi-bunch operation mode a cathode equipped with a grid is necessary. Several analyses were performed to explore the influence of the grid on the laser beam. Diffraction effects were observed, however, the influence was rated as tolerable.

Preliminary Performance

To evaluate and optimize the performance of our preliminary design, we conducted simulations using CST [4]. At this moment only the thermionic operation mode could be simulated, due to the absence of a suitable simulation tool for TAPE operation mode. Nevertheless this means, that the TAPE operation mode can only be evaluated experimentally, which will be done in the future.

Considering the design goals several commercially available cathodes are suitable. The simulation of the assembly was performed for this cathodes. Within one assembly the design goals could not be met for all cathodes, as can be seen in Table 2. It can also be concluded that the beam envelope and divergence with the designed structure do not meet the design objectives. A further redesign of the transfer beamline from the thermionic gun towards the alpha magnet and the linac will be carried out. This redesign will also focus on solving these issues and optimizing the focussing of the beam.

Table 2: Achieved performance metrics. (*) optimizable via solenoid near gun exit.

Metric	Design Goal	Y845	HWEG 101244	NJK 2221A
ϵ_x / mm mrad	≤ 8.3	6.9	11.9	7.7
ϵ_y / mm mrad	≤ 8.3	6.9	11.9	7.1
beam divergence / mrad	≤ 22	42*	45*	68*
beam envelope / mm	≤ 8.00	7.29*	8.64*	9.12*
I/A	2.00	0.94	2.17	3.89*

CONCLUSION

For the replacement of the existing electron gun at LINAC2 at ELSA a hybrid electron gun was planned. The new gun will enable the use of a thermionic dispenser cathode as a thermal- as well as an photoemitter. Prior research has proven the feasibility and reliability of this type of cathode used as a photocathode. Thermally assisted photoemission will be used to increase the quantum efficiency of the cathode and therefore ease the laser requirements. Using the new technique a single bunch mode will be enabled along the already used multi bunch mode. Manufacturing of the new gun will start soon. In the future a new gun test-stand will be setup at the facility to serve the validation of the new gun setup and to investigate the TAPE operation of different dispenser cathodes further.

ACKNOWLEDGEMENTS

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