SIMULATION FOR A NEW POLARIZED ELECTRON INJECTOR (SPIN) FOR THE S-DALINAC*

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Abstract

The Superconducting DArmstädter LINear ACcelerator (S-DALINAC) is a 130 MeV recirculating electron accelerator serving several nuclear and radiation physics experiments. For future tasks, the 250 keV thermal electron source should be completed by a 100 keV polarized electron source. Therefore a new low energy injection concept for the S-DALINAC has to be designed. The main components of the injector are a polarized electron source, an alpha magnet, a Wien filter spin-rotator and a Mott polarimeter. In this paper we report about the first simulation and design results. For our simulations we used the TS2 and TS3 modules of the MAFIA programme which are PIC codes for two and three dimensions and the CST PARTICLE STUDIO^{TM}.

INTRODUCTION

These days, polarized electron beams have been widely used for various spin physics experiments at many electron accelerators. In the 1970s, Pierce and collaborators [1, 2, 3] discovered the process of photoelectron emission from (III-V) semiconductor crystals. GaAs and its relatives are mostly used for polarized electron sources. The degree of polarization available in emission from GaAs bulk is limited by about 50 %. Today polarized electron sources reach a degree of polarization of 80 % by using strained or super-lattice structures of GaAs. For a better emission the electron affinity is lowered by vaporized Cs on the photocathode. These prepared photocathodes have a negative electron affinity (NEA).

The S-DALINAC is the only electron accelerator to analyze electric and magnetic activation of nucleus with low energies and momentum transmission world wide. There is still a lot of basic research in modern nuclear physics to do like violation of parity in the nucleus, breakup reactions of light nucleus and determination of low-energy constants. Therefore a new injector concept has to be designed where the new polarized gun will be integrated in the current construction. A detailed discussion of the current layout and properties of the recirculating superconducting electron accelerator S-DALINAC is given in [4]. The present injector consist of a 250 keV thermal electron source followed by a prebuncher/chopper section. After that the electron beam is captured by a 2-cell section and is preaccelerated to $\beta = 0.85$ followed by one 5-cell and ten 20-cell cavities with $\beta = 1$ which leads to a maximum energy of 130 MeV. The new beam will be delivered by a 100 keV polarized electron source using a strained NEA-GaAs photocathode. The beam requirements are to have a beam current of 60 μA. The time structure has to be 3 GHz cw to match with the current accelerating structures with a pulse length of maximum 50 ps in front of the prebuncher. All main components are shown in Fig. 1, the local order and the beam optics are not determined so far.

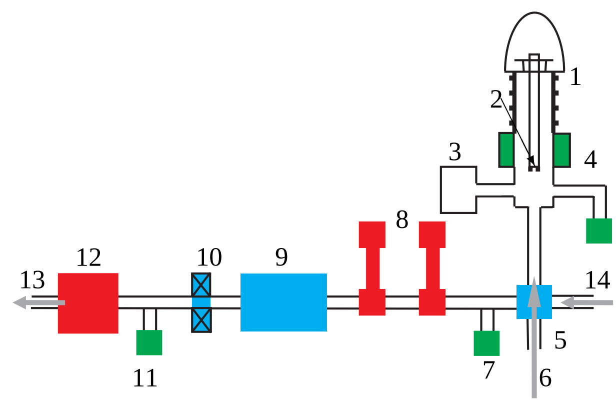

Figure 1: Principal Diagram of the New Low-Energy Injector with 1. Source, 2. Cathode, 3. Load-Lock Chamber, 4. NEG Pump Array, 5. Alpha Magnet, 6. Laser Beam, 7. Differential Pump Stage, 8. Diagnostics, 9. Wien Filter, 10. Solenoid, 11. Turbo Pump Station, 12. Mott Polarimeter, 13. Electron beam to Accelerator and 14. Electron Beam From Thermionic Gun

DESIGN

The polarized 100 keV injector of MAMI [5, 6] was a good choice as a starting point of the design for the new injector of the S-DALINAC. The new injector should realize four main characteristics. The design has to be as compact as possible because of the limited space at the facility. Therefore it is an aim that the beam will leave the gun nearly divergence free to manage the beam without optic elements between gun and alpha magnet. Also a simple handling is essential to realize short maintenance time and the source should have a long life time to make a long op-

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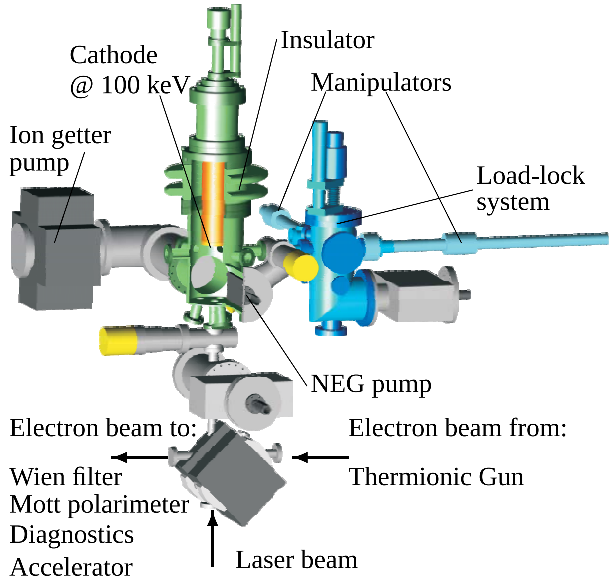

Figure 2: Design of the Injector from Gun to Alpha Magnet

eration time possible. The life time of the photocathode is the main factor of the operating time of the polarized electron source. A strained NEA-$GaAs_xP_{1-x}$ photocathode can easily be disturbed by ions produced by the beam or the rest gas in UHV in the low 10^{-11} mbar range. For a long life time an efficient preparation and a fast replacement of the $GaAs_xP_{1-x}$ cathodes is needed. At MAMI and SLAC a load-lock system under UHV conditions which is connected with the gun chamber is operating successfully. Also the maximum electric field at the photocathode surface should not be higher than 1 MV/m and 4 MV/m at the remaining parts of the cathode surface to avoid field emission and voltage breakdown.

After the gun the electron beam has to bend around $90°$ to get in the current beam line. An alpha magnet is an easy and compact system to bend a low energy electron beam around $90°$ (real $270°$). An important possibility is that you can regulate the electron optic characteristics so that the beam will come out nearly divergence free. The actual design of the gun with the load lock and vacuum system to the alpha magnet is shown in Fig. 2.

SIMULATION RESULTS

The cathode in the present work is designed with the help of MAFIA TS2. MAFIA TS2 is used to find the optimal cathode structure because one can approximate the source as a cylindrically symmetric structure. The design starts with the Pierce gun design. Because of the limiting factor that the electrical field has to be smaller than 1 MV/m at the photocathode itself the Pierce gun has to be varied. These parameters are necessary to reduce the problem of field emission and voltage breakdown. Therefore the Pierce angle $67.5°$ is changed finally to an angle of $86.7°$ and the ramp ends at a “nose” which reduces the electric field at the photocathode to below 1 MV/m and to about 4 MV/m

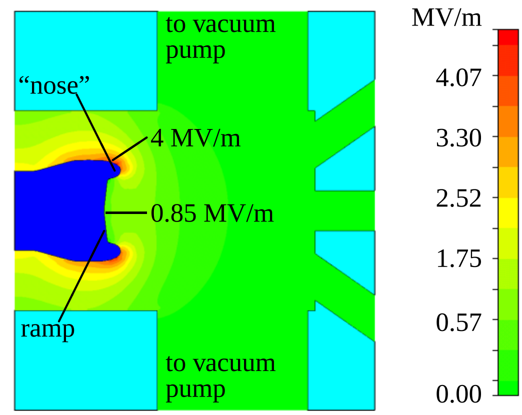

Figure 3: $|\vec{E}|$ in the source yz plane

at the electrode. The absolute value of the electric field is shown in Fig. 3, where also the gun configuration can be seen.

The electron optic of this design is nearly the optimum. The nose compensates the effects of the different angle and protects the photocathode. The electron optic is designed that the beam leaves the gun almost divergence free ($<$ 0.5 mrad). Fig. 4 shows two cases. In the first case, A), the electron beam is generated in the center of the photocathode and in the second case B), with an offset of 1 mm from the center.

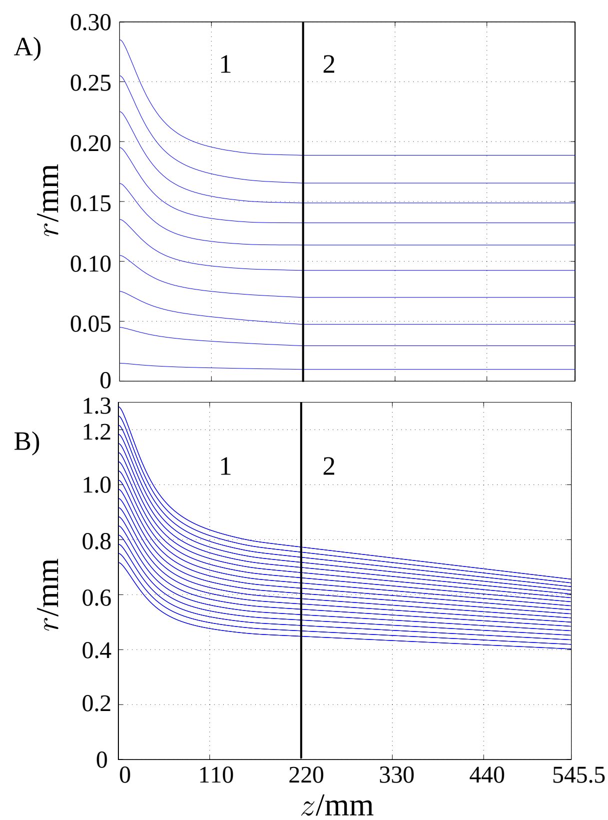

Figure 4: Trajectories of Electron Beam from Photocathode to Alpha Magnet A) by a centered shot and B) by offset shot of 1 mm (1: gun, 2: drift space to alpha magnet)

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In case A) the beam leaves the gun nearly divergence free. All beam characteristics are fulfilled, but one can use the photocathode only a single time. If the photocathode surface is damaged one has to replace the photocathode, though the life time can be a problem. To get a longer life time one has to generate the beam out of the center. If one goes to far away from the center the desired beam characteristics will be lost. Though you have to find an optimum between life time and beam characteristics. In case Fig. 4 B) the offset is 1 mm. Therefore in the optimal case one can generate 10 times longer an electron beam by generating a beam with a laser spot diameter of 0.3 mm. The beam has a small divergence of about 0.4 mrad. After the drift space to the alpha magnet the beam center has an offset of about 0.5 mm. The two parameters break our optimal design case at the first view but the small divergence and offset can be corrected in and after the alpha magnet. The offset can be compensated by the adjustment of the drift tube behind the alpha magnet and the divergence should be compensated by the electron optics of the alpha magnet and/or steerers.

The design of the alpha magnet was performed in CST PARTICLE STUDIO^{TM} and MAFIA TS3. The beam data is transferred from previous calculations of MAFIA TS2 to MAFIA TS3 by using an interface. Therefore the calculation of the beam is from the photocathode through the alpha magnet complete. As one can see at the Fig. 5, the three typical parts of the magnetic flux density the fringing fields, the homogenous field and the strong back flow. The steepness of the fringing magnetic flux is important for the beam curve through the alpha magnet. The simulations show that the homogeneous magnetic flux has to be between 30 and 50 mT for the operating range of the alpha magnet. In this range the alpha magnet works nearly divergence free and the deflection is 90° (real 270°).

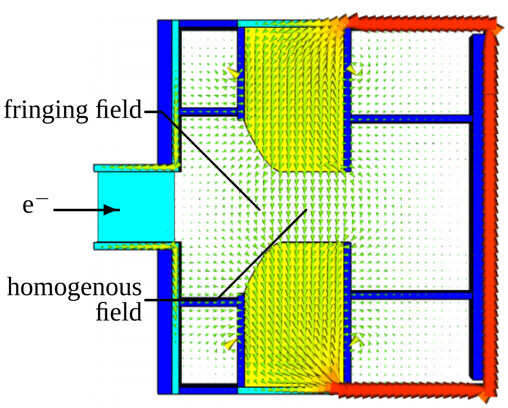

Figure 5: Magnetic Flux Density in the Alpha Magnet

The trajectories are shown in Fig. 6. The electron beam is exactly deflected by 90° (real 270°). That means that the outgoing beam has the same characteristics as the incoming beam.

The simulation also shows that the alpha magnet design of MAMI [7] can be adapted for the S-DALINAC.

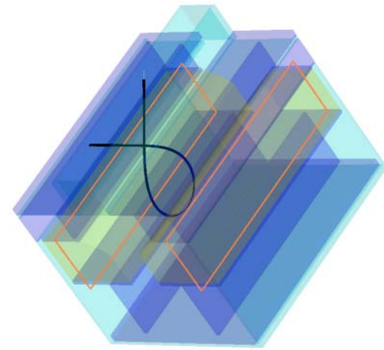

Figure 6: Trajectories in the Alpha Magnet

CONCLUSION

In this paper the design and the simulation results of the cathode and alpha magnet have been presented. A compact design of the optimized gun is achieved. A long life time can be expected because of the load lock system for a quick replacement of the photocathode and the elimination of field emission and voltage break down. As expected, the design of the alpha magnet of MAMI is transferable to the S-DALINAC. All together an easy handling and short maintenance time is expected.

The next steps are the construction of the first components and to mount them at the test facility of the injector. A further step is to measure the first test beam. Furthermore the simulation and design of the beam optic elements and the Wien filter will start. Therefore the transversal and longitudinal beam dynamics calculation is of immediate importance.

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