ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOTK014

100 keV ELECTRON SOURCE DESIGN FOR THE NEW 3 GeV SYNCHROTRON FACILITY IN THAILAND

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Abstract

The Synchrotron Light Research Institute (SLRI) is developing a new synchrotron light source with an electron beam energy of 3 GeV. The DC thermionic electron gun was chosen because it is simple and less cost. The design process is well known. The operation is more stable compared to the RF gun. The cathode Y-646B was considered because it had already been used at the old synchrotron machine and the possibility of sharing the stock outweighs other disadvantages. Moreover, it is used in many synchrotron facilities, so it is easy to find references. The present of the focusing electrode was discussed. The focusing electrode will increase the complexity of the gun, but it is necessary to get a high-quality beam from the gun. The designed electron gun can produce 1.1 A beams current with the normalized emittance of 0.910π mm mrad, which satisfied the requirement of the linac injector. The design and study results will be discussed in this report.

INTRODUCTION

The Synchrotron Light Research Institute (SLRI) is developing a new synchrotron light source with electron beam energy of 3 GeV. A DC thermionic electron gun was considered as an electron source for the new synchrotron. This is considering its simple design and less fabrication cost. The DC gun is part of the 150 MeV linac pre-injector to the 3 GeV booster ring. This gun is a conventional triode electron gun, which is a gridded gun with a thermionic cathode. The gun structure will be designed to fit the cathode-grid assembly Y-646B manufactured by EIMAC. It is used in many synchrotron facilities, so it is easy to find reference [1–3]. This cathode has a circular area of 0.5 cm^2, which is equivalent to 10 mm in diameter. It has a grid cathode spacing of 0.15 mm. This paper presents the structure design of the DC gun to fit this cathode.

The DC electron gun will be used to generate the electron beam for the injector of the new synchrotron. Therefore, the requirements and constraints from downstream systems like storage ring, booster ring, linear accelerators, and bunching system, will be considered thoughtfully. They are from both beam parameters and technical limitation. The gun will operate at 1100 °C temperature of cathode. It requires a focusing electrode for focusing the electron through the gun exit. Maximum potential between cathode and anode is 100 kV. The target electron beam current is 1 A. This gun should be able to operate at lower beam current. It should be optimized to get emittance of 1 mm mrad at the exit. It should produce the beam that can further be accelerated by downstream accelerators.

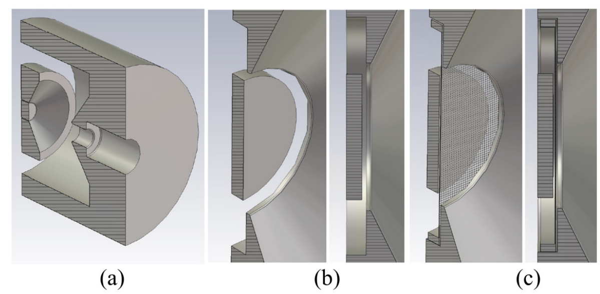

Figure 1: The model of electron gun in CST with (a) a complete model, (b) a gun-without-grid model, and (c) a gun-with-grid model.

DESIGN WORKFLOW

Usually, the DC electron gun has cylindrical symmetry which allow 2-dimensional (2D) simulation. 2D simulation is fast and accurate. The popular software in accelerator community is EGUN [4]. However, with the inclusion of the rectangular grid with the Y-646B cathode, the cylindrical symmetry broke. Therefore 3-dimensional (3D) software will be used. CST Studio Suite ®(CST) [5], which can solve electromagnetic field and particle trajectory will be used. The CST equips with many modules, electrostatic and tracking solver of the particle studio module will be used for designing the DC gun. The following workflow was done for the design process.

Firstly, modelling the gun with CAD software to check the integrity of the model. Solidworks [6] is used to cooperate easily with engineers. After the integrity check, model of the gun is constructed in CST according to the model from Solidworks. It is known that imported model can create inconsistency from different software. So, the model is not imported directly from Solidworks. The model in CST can be fully parametrized for further optimization.

Secondly, the simulation setup with the background set as vacuum. The gun parts is set as perfect electrical conductor (PEC). The potential of the gun parts will be set according to the requirement. Anode is fixed to ground potential, while the focusing electrode and the grid is floated at 100 kV. The cathode potential is referenced to the grid potential. It can be modified with a bias and pulse voltage. The source of the particle will be created at the cathode surface. Thermionic emission model is used with a maximum temperature of

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1373 K (1100 °C) and with particle kinetic at the same temperature. For a specific checkpoint, the space charge limit emission (SCL) model is used to check the emission limit. The emission voltage is set to the cathode potential and the reference voltage is set to the anode potential.

Thirdly, the beam monitors is set perpendicular to the beam direction. Initially, a monitor will be set every 5 mm starts from the cathode to the gun exit. These monitors are used to monitor beam parameters, for example, emittance, beam size, and beam energy. The meshing difficulty of the model is located at the grid wire. The wire dimension is very small compare to other parts. So, the mesh cells need to be very small there. Initially, the hexahedral meshing is used in the simulation. Compare to the tetrahedral mesh, the hexahedral mesh is faster to create and calculate and it requires less processing and memory but provides far lower accuracy.

Then, the simulation is split into two cases, a gun-with-grid case and a gun-without-grid case. The gun-without-grid model simulation is used mainly to optimize the focusing electrode before the actual run of the gun-with-grid model. Simulation time of each simulation can differ 10-20 times. Moreover, exclusion of the grid does change the field distribution near the cathode, but not for other parts of the gun. The focusing of the beam is approximately the same with or without grid. Therefore, it is a good idea to optimize the electrode independently from the grid.

After a rough dimensions of the electrode is obtained from the gun-without-grid model, the optimization for the suitable parameter set is done on the gun-with-grid model. The dimensions of the gun parts will be optimized. The cathode bias and pulse voltage will be optimized to get the beam at 200 mA and 1.0 A. Finally, after the simulation is done and the result is processed, the engineering model will be created in collaboration with a mechanical engineer.

The output from CST simulation will be converted to ASTRA or PARMELA input format using an external tool. The simulation may be re-done if the simulation result of the whole injector indicates need to change the beam parameters from the gun.

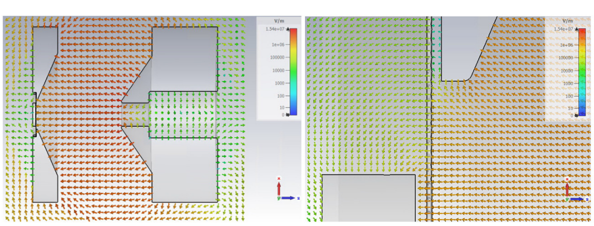

Figure 2: The electric field of the electron gun. The field near the cathode, grid and focusing electrode is shown on the right.

ELECTRON GUN DESIGN

The model of electron gun in Fig. 1 is used in the design and optimization process. It is a modified version of the SSRF design [1]. Simulation results are listed in Table 1. The electric field inside the designed electron gun is shown in Fig. 2 and the electron beam trajectory of the gun illustrated in Fig. 3. The beam emittance and kinetic energy is shown in Fig. 4. The envelope of the beam and rms beam size are shown in Fig. 5.

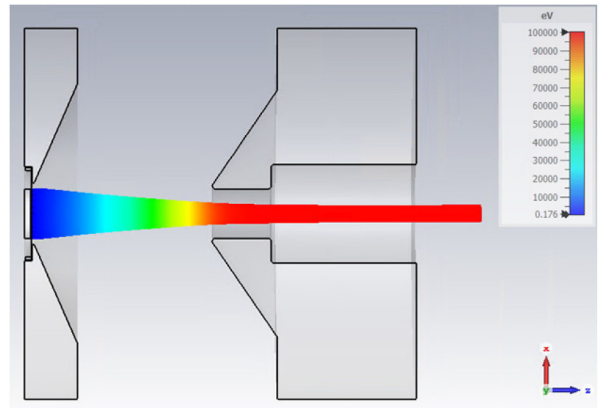

Figure 3: The electron beam trajectory of the electron gun.

Table 1: Electron Gun Properties

Parameters	Value
Beam current emitted from cathode	2.229 A
Beam current at gun exit	1.167 A
Space charge limited current at cathode	7.941 A
Normalized beam emittance (95 %) at gun exit	0.904π mm mrad
Beam envelope at gun exit	0.512 mm
RMS beam size at gun exit	0.205 mm

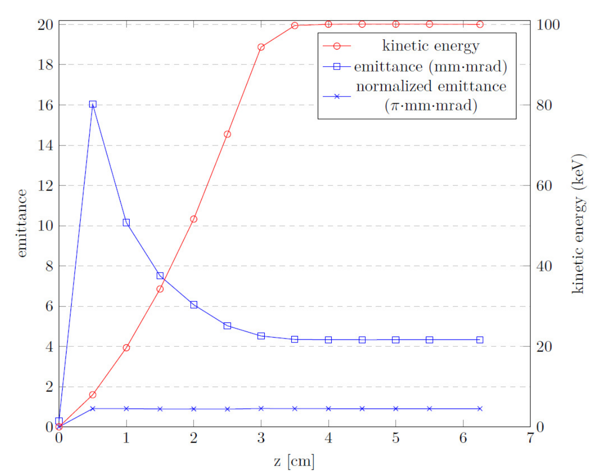

Figure 4: The emittance and kinetic energy of the electron gun along the beam trajectory.

The study started by using the SSRF electron gun as an initial model. The result of the SSRF gun model was particularly good, even after adding the grid and enlarge the hole

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on the focusing electrode to include the grid. However, after changing the dimension of the grid to the actual dimension, the result beam blows up. The focusing electrode cannot focus the beam and most of the beam hit the anode. The reason is the distance from cathode to the focusing electrode is too large, thus, the field near the cathode is too weak to compensate the space charge force. The attempts to fix this issue by moving the focusing electrode toward the anode and reduce the angle of the focusing electrode could improve the focusing of the beam. However, the current emitted from the gun reduced because the field is concentrated at the focusing electrode and does not reach the cathode. The solution to problem was found by creating a "nose" feature on the focusing electrode that make the focusing electrode closer to the cathode. This solves both focusing and emitted current problems. Moreover, the nose also reduces the effect of misalignment of the cathode.

The effect of the cathode-to-grid voltage has been studied. The result showed that the beam emittance will be better at higher cathode-to-grid voltage. The higher voltage should be study to find the lowest emittance. With the selected voltage of 110 V, the emittance is well below the 1.0π mm mrad stated in the requirement. Moreover, at 110 V the beam exits the gun parallelly. The beam exits the gun diverting if the voltage is below 110 V and converging if the voltage is above 110 V. Thus, at 110 V the requirement that the focal point should be around the gun exit is fulfilled.

The effect of the cathode temperature has been studied. It is found that the beam current exiting the gun of 1 A can be archived at the cathode temperature of 1090 °C, 10 degree below the expected operating temperature.

The model with cathode-to-grid voltage of 13 V has been studied to find the condition for 0.2 A beam current as required by top-up injection. The result showed that 0.207 A can be archived. The result also showed that the beam emittance and beam size are increased by almost two times and the beam start to diverse before exit the gun. However, the result is still within the requirements. Therefore, it should be able to produce 0.2 A beam with cathode-to-grid voltage of 13 V.

CONCLUSION

The physics design of the electron gun was done with all the requirements and constraints were fulfilled. The simulation result indicated that the gun can produce electron beam with 1.167 A current with the normalized emittance of 0.910π mm mrad. The electron beam is well focused at the gun exit.

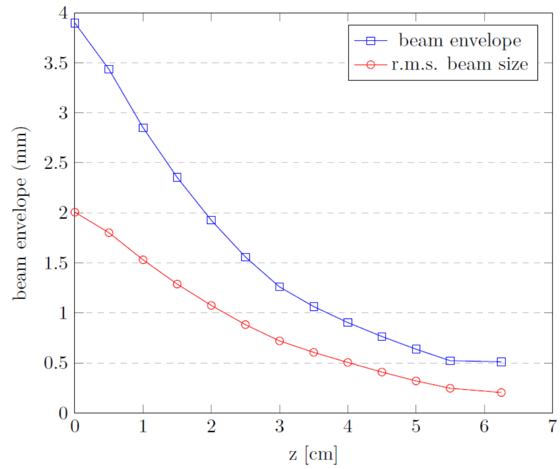

Figure 5: The beam envelope and rms beam size along the beam trajectory.

The effect of the cathode temperature has been studied with the cathode temperature of 1090 °C is used. The operational of the electron gun of normal injection with 1A beam current required has been studied. The cathode-to-grid voltage of 110 V is used to produce 1A beam current with the emittance is well below the 1.0π mm mrad. It will be adjusted to 13 V for 0.2 A top-up injection. This gun design is now in the prototype fabrication phase for validating its performance.

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