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DESIGN AND OPTIMIZATION OF A 100 kV DC THERMIONIC ELECTRON GUN AND TRANSPORT CHANNEL FOR A 1.3 GHz HIGH INTENSITY COMPACT SUPERCONDUCTING ELECTRON ACCELERATOR (HICSEA) *

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Abstract

Here we present the design and optimization of a 100 kV DC thermionic electron gun and a transport channel that provides transverse focusing through a normal conducting solenoid and longitudinal bunching with the help of a single gap buncher for a 1.3 GHz, 40 kW, 1 MeV superconducting electron accelerator. The accelerator is proposed to treat various contaminants present in potable water resources. A 100 kV thermionic electron gun with LaB_6 as its cathode material was intended to extract a maximum beam current of 500 mA. To minimize beam emittance, gun geometry, i.e., cathode radius and height and radius of the focusing electrode, is optimized. The minimal obtained emittance at the gun exit is 0.3 mm.mrad. A normal conducting focusing solenoid with an iron encasing is designed and optimized to match and transport the beam from the gun exit to the superconducting cavity. Finally, a 1.3 GHz ELBE type buncher is designed and optimized to bunch the electron beam for further acceleration.

INTRODUCTION

Accelerator technology is proven very efficient for treating harmful pollutants in water resources [1,2]. A 1.3 GHz, 1 MeV, 40 kW high intensity compact superconducting electron accelerator (HICSEA) is proposed by IIT Bombay and Japanese institutions (KEK, Tohoku etc.) to treat various pollutants present in the limited usable water resources. The proposed accelerator will be a 3 m long with an industrial-grade thermionic electron gun followed by a transport channel for transverse and longitudinal focusing, a single-cell Nb_3Sn accelerating cavity, a bending magnet, and finally a raster magnet. A schematic of the proposed accelerator is shown in Fig. 1. In this paper, we discuss the design and optimization studies for a dedicated electron source, i.e., a 100 kV thermionic diode electron gun followed by a transport line that constitutes a normal conducting solenoid and a buncher cavity.

The electron gun is based on a DC thermionic cathode and operates at 100 kV in the intensity range of 100 mA to 500 mA. Thermionic electron emission sources (W, CeB_6, and LaB_6) are cheaper, compact, can operate under lower vacuum conditions, and provide greater brightness for large-area illumination [3]. There are several other advantages

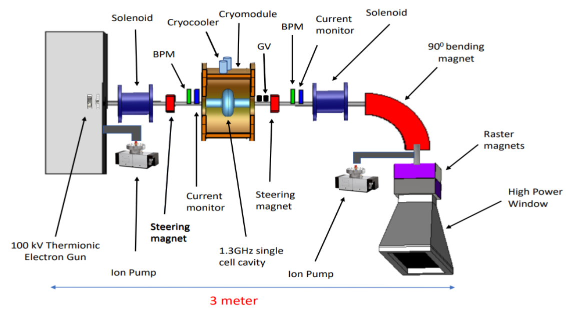

Figure 1: Schematic of proposed accelerator.

of using thermionic cathodes, such as emission capability, ease of maintenance, and ease of finding supplies. The thermionic cathode is also cost-effective, compact, simple in operation, and can produce large current densities of 10-100 A/cm^2. As the proposed accelerator operates with a beam current of 500 mA, space-charge forces will play a significant role and may lead to emittance growth. Therefore, the design of an optimized transport channel constituting a buncher for efficient bunching of the DC beam produced by the thermionic electron gun and a solenoid for transport confinement is an essential part of the linac design. Followed by the thermionic gun optimization, we performed modeling and optimization studies for a normal conducting solenoid and a single-gap buncher cavity to bunch, transport, and match the beam from the electron gun to the single-cell accelerating cavity while keeping a minimum emittance growth throughout the accelerator.

GUN DESIGN

The gun design comprises a planar cathode with a focusing electrode, and an anode. A flat symmetric cathode of circular cross section was chosen for this study. The cathode material used for this study was LaB_6 (work function = 2.67 eV) because of its better emission properties such as uniform emission density, smooth surface and high resistance against contamination [4]. Here, cathode along with the focusing electrode is held at -100 kV and anode was grounded. The design of the electron gun is such that the maximum current up to 500 mA can be extracted efficiently from it. For the current of 1 A, further optimizations or more geometry modification such as inclusion of an extra electrode might be needed.

A cross sectional view of cathode is shown in Fig. 2. To minimize the beam emittance, various geometry parameters

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such as cathode radius, height and radius of focusing electrode, distance between cathode and anode, are optimized. The final parameters are listed in Table 1.

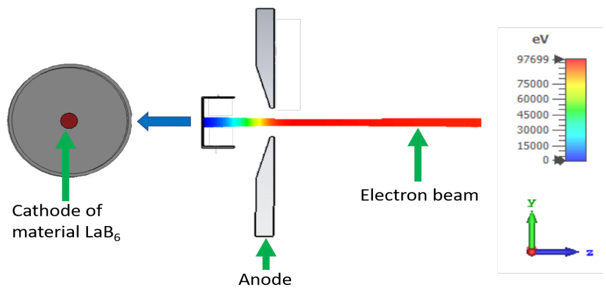

Figure 2: Cross-sectional view of the electron gun.

Table 1: Final Optimized Parameters for the Electron Gun

Parameter	**Values**
Operating temperature	1940K
Applied potential	100 kV
Maximum current	0.5 A
Distance between anode and cathode	20 mm
Cathode radius	1.25 mm
Radius of focusing electrode	13 mm
Height of focusing electrode	5 mm
Beam diameter	5 mm
Normalized RMS transverse emittance	0.3 mm.mrad

The role of focusing electrode is to bend the equipotential lines to cause uniform extraction from cathode and focus the beam. Here, focusing electrode is a cylindrical shaped electrode held at same potential as that of cathode. The equipotential lines generated is shown in Fig. 3.

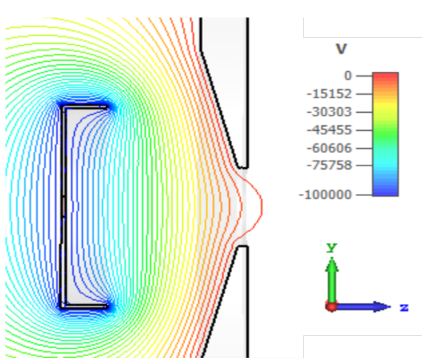

Figure 3: Equipotential lines generated due to the applied potential of -100 kV on cathode.

The most critical geometry parameter of the electron gun is cathode radius. The cathode radius of 1.25 mm was chosen depending on the current required for a particular application the cathode radius is chosen. Here, the required maximum current is 0.5 A and for that the normalized emittance is minimum for cathode radius of 1.25 mm. Therefore, radius of 1.25 mm is chosen for further studies.

SOLENOID DESIGN

The purpose of the solenoid is to match and transport the beam from the electron gun to the 1.3 GHz buncher cavity [5]. Therefore, a 8 cm long solenoid is designed and the schematic view of the solenoid is shown in Fig. 4. The design incorporates the use of iron shielding for the solenoid coil.

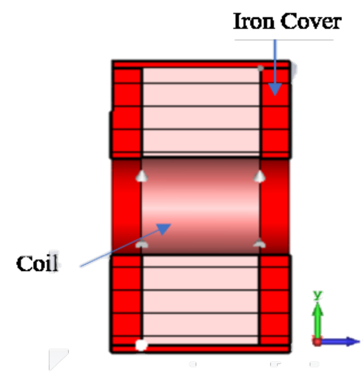

Figure 4: A schematic view of solenoid.

The iron has significant impact on the fringe field of solenoid. Iron provides additional contribution to the peak magnetic field. Here, the objective of shielding by iron is to optimize the fringe field and provide magnetic shielding to the other component of accelerator from the solenoidal field. The effect of iron on magnetic field is shown in Fig. 5.

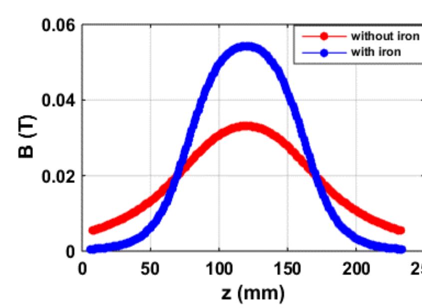

Figure 5: Magnetic field with and without iron cover.

Various parameters such as length, coil current, number of turns, inner and outer radius of the solenoid, thickness of iron cover etc. were optimized to get the required focusing through the solenoid and the final parameters are listed in Table 2.

Our beam dynamics simulation demonstrate the desired focusing with optimized solenoid at the input of the buncher cavity as shown in Fig. 6.

The normalized transverse beam emittance and beam diameter passing through the solenoid is shown in Fig. 7.

BUNCHER DESIGN

A buncher cavity is required between the electron gun and the accelerating cavity, in order to bunch the beam [6, 7]. An electron beam having beta $\beta = 0.54$ will be injected into

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Table 2: Final Parameters of Optimized Solenoid

Parameter	Value
Length	8 cm
Coil current	1 A
Inner radius of solenoid	3.5 cm
Outer radius of solenoid	10 cm
Thickness of iron cover	2 cm
Number of turns	2000
Peak magnetic field	0.027 T

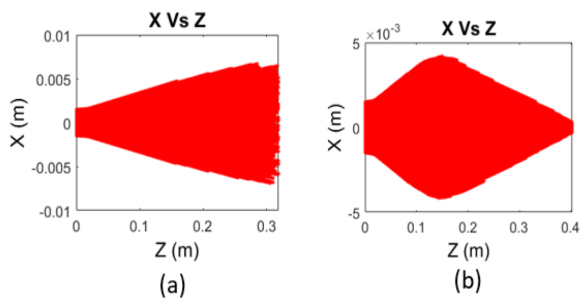

Figure 6: Z-X profile of beam (a) without solenoid, (b) with solenoid.

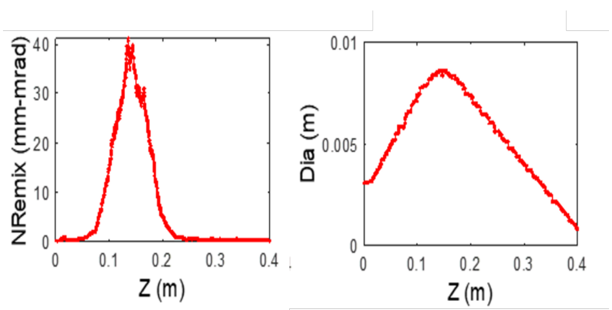

Figure 7: Change in normalized RMS transverse emittance (left) and beam diameter (right) with direction of propagation.

the buncher cavity to obtain electron bunches with acceptable beam quality. The frequency of the buncher cavity is equal to the frequency of main linac i.e. 1.3 GHz. The design of the buncher cavity is shown in Fig. 8. Various parameters required for the design of buncher cavity are summarized in Table 3.

A beam dynamics study is going on to realize the bunching through the buncher [8]. A initial simulated beam with $\beta = 0.54$ were injected into the designed buncher cavity (z = 0 to z = 120 mm). The beam projection after ejected for the cavity is shown in Fig. 9. The particles exit the buncher, four electron bunches can be seen.

CONCLUSION

A DC thermionic electron gun, a solenoid and a 1.3 GHz buncher cavity is designed and optimized for high intensity compact superconducting electron accelerator. A beam dynamics studies was also performed on designed structures using self written particle tracking scripts and MATLAB code which was developed by our team. The results are briefly described here.

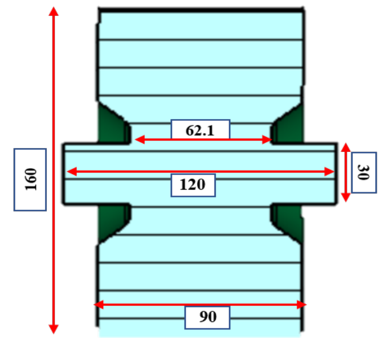

Figure 8: Cross sectional view of buncher cavity (units in mm).

Table 3: Final Parameters of Optimized Buncher Cavity

Parameter	Value
Energy of the electrons	96 keV
Beta of electrons	0.54
Beam current	0.5 A
Resonant frequency	1.3 GHz
Maximum accelerating voltage	1 MV/m
Peak surface electric field	3.3 MV
Bunch length	45 ps
Bunch current	0.548 A

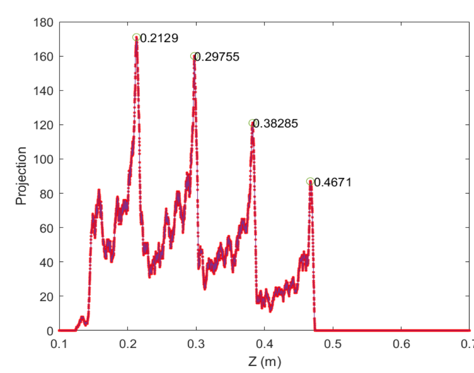

Figure 9: Beam projection after ejected from the buncher (every peak represent a bunch).

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REFERENCES

[1] S. He *et al.*, "Enhancement of biodegradability of real textile and dyeing wastewater by electron beam irradiation", *Radiation Physics and Chemistry*, 2015. doi:10.1016/j.radphyschem.2015.11.033

[2] Capodaglio, Andrea, "High-energy oxidation process: an efficient alternative for wastewater organic contaminants removal", *Clean Technologies and Environmental Policy*, 2017.

[3] K. Togawa *et al.*, "Low Emittance 500 kV Thermionic Electron Gun", in *Proc. LINAC'04*, Lübeck, Germany, Aug. 2004, paper TU202.

[4] M. A. Bakr *et al.*, "Comparison between Hexaboride Materials for Thermionic Cathode RF Gun", in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper TUPEC029, pp. 1782–1784.

[5] M. Asgarpour, E. E. Ebrahimibasabi, S. A. H. Feghhi, M. Khorsandi, and N. Khosravi, "Design, Simulation and Optimization of a Solenoid for ES-200 Electrostatic Accelerator", in *Proc. RuPAC'12*, Saint Petersburg, Russia, Sep. 2012, paper WEPPC024, pp. 498–499.

[6] V. Veshcherevich and S. Belomestnykh, "Buncher Cavity for ERL", in *Proc. PAC'03*, Portland, OR, USA, May 2003, paper TPAB008.

[7] S. V. Kutsaev, "Electron bunchers for industrial RF linear accelerators: theory and design guide", *The European Physical Journal Plus*, vol. 136, Issue. 4, 2021. doi:10.1140/epjp/s13360-021-01312-3

[8] M. Reiser, *Theory and design of charged particle beams*. John Wiley & Sons, 2008.