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DESIGN AND OPTIMIZATION OF A 1.3 GHZ GRIDDED THERMIONIC ELECTRON GUN FOR HIGH-INTENSITY COMPACT SUPERCONDUCTING ELECTRON ACCELERATOR (HICSEA) *

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Abstract

The design and optimization of the proposed 1.3 GHz gridded thermionic electron gun aims to drive a conduction cooled superconducting electron accelerator that will be used to treat contaminants of emerging concern in water bodies. The gun geometry is Pierce-type and optimized for beam current of 1A with LaB_6 as cathode material at cathode potential of -100 kV. The final optimized cathode radius and angle of inclination of the focusing electrode are found to be 1.5 mm, and 77° respectively. For an emittance compensation electrode, the optimized values for thickness and potential are 2 mm and -50 kV respectively, and separation between cathode and compensator is 8 mm. Beam dynamics calculations have been performed with self-developed particle tracking code that assumes space charge interactions and imported fields. The beam dynamics simulations show that with an initial pulse length of 50 ps having a bunch charge of 5 pC, the pulse length of the bunch reduces to 33 ps. The diameter, transverse and longitudinal emittance obtained are 2.8 mm, 1 mm-mrad, and 5 mm-mrad respectively.

INTRODUCTION

Our aim (IIT Bombay in collaboration with Tohoku, KEK, Hiroshima, Waseda, Nihon, Osaka university, Japan) is to design and develop a compact, high intensity superconducting electron accelerator which will provide beam energy of 1 MeV and beam current of 100 mA for wastewater treatment. The preliminary stage of the project demands a start to end physics design that include, (a) design and optimization of a thermionic electron gun, (b) transport channel, and (c) a single cell, superconducting tesla cavity as shown in Fig. 1.

With an objective of delivering a high intensity electron beam, a thermionic electron gun is designed and optimized. In this gun, a gridded cathode [1] with RF and DC bias signals is used to produce electron bunches with high repetition rate. Such bunching mechanism makes the linac compact and portable. The major disadvantage of this method is the significant increase in beam emittance due to the presence of the grid. The design and optimization of such a gridded gun and the beam dynamics are the main emphasis of this paper. Our preliminary beam dynamics simulations with codes like CST demonstrate a significant dependence of beam parameters on mesh density and therefore we chose to develop our own beam dynamics code for reliable results with shorter computation time using PIC [2] algorithm. This paper thus also focuses on the discrepancies in the results obtained using CST and compares it with our own particle tracking code.

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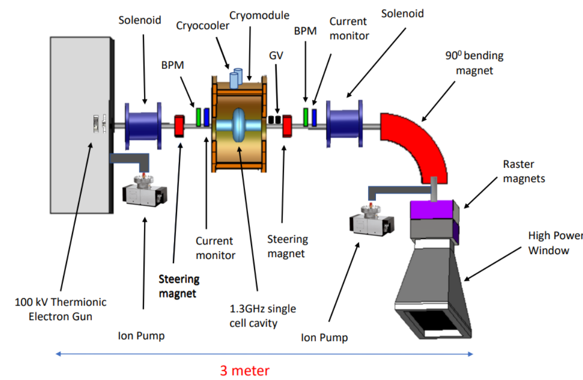

Figure 1: Schematic of proposed high-intensity, compact super-conducting linear electron accelerator.

GUN GEOMETRY

Thermionic electron gun designed here is configured by cathode, anode, Wehnelt and focusing electrode. The geometry of these electrodes is optimized for good beam quality and high beam current (1A) where the quality of the beam is assessed by measuring the RMS normalized emittance. Optimization to minimise the emittance is performed by varying: (a) Cathode radius, (b) angle of inclination of focusing electrode, (c) cathode-wehnelt gap, (d) Wehnelt thickness, and (e) Wehnelt voltage.

Cathode and Cathode Assembly

Our calculations suggests that the electron emission capacity of LaB_6 is better than tungsten and CeB_6 at same temperature as shown in Fig. 2.; therefore, LaB_6 is chosen as a cathode material for our electron gun. LaB_6 also has a low thermionic work function (2.66 eV) and a high melting point (2715°C), in addition to it's long life and lower sensitivity towards air exposure than typical dispenser cathodes [3].

Initially, the focusing electrode's angle is tuned for lower emittance. Figure 3 (a) depicts the results of simulations for angle of inclination of focusing electrode. It demonstrates that with the angle of inclination of 77°, emittance is reduced to 3.75 mm-mrad. The cathode radius was optimised with 77° of inclination angle as shown in Fig. 3(b). It has been observed that at 1.5 mm of cathode radius, the emittance is decreased to 2.52 mm-mrad. As a result, cathode radius of 1.5 mm and inclination angle of 77° was considered for further optimizations.

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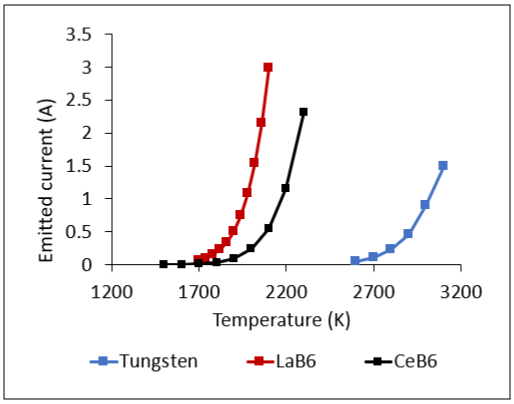

Figure 2: Maximum current emitted by cathode materials at given temperature.

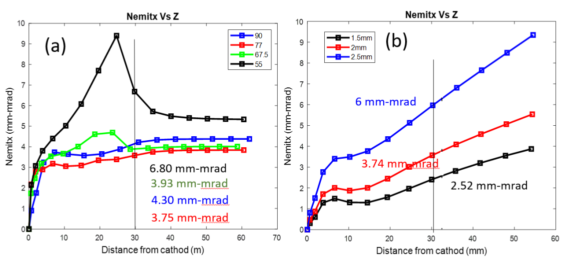

Figure 3: (a) Transverse emittance variation with angle of inclination of focusing electrode, (b) emittance variation due to cathode radius along bunch propagation direction (z).

Wehnelt

This is an extra electrode that is used to focus the beam. When electrons leave the cathode, the Wehnelt's circular aperture repels them, driving them back towards the axis. The effect of Wehnelt is investigated for various Wehnelt voltages, thicknesses, and distance from the cathode to minimise transverse emittance. The optimised parameters are illustrated in Fig. 4 (a), Fig. 4 (c), and Fig. 4 (e), and are reported in Table 1 and shown in Fig. 5. The parameters are varied in the range of constant emission current of 1A as shown in Fig. 4 (b), Fig. 4 (d), and Fig. 4 (f).

Table 1: Optimized Parameters of the Designed Gun

Parameters	Value
Cathode material	LaB_6
Cathode Radius	1.5 mm (0.059 in)
Pierce angle	77°
Cathode Potential	−100 kV
Cathode-Wehnelt distance	12 mm (0.472 in)
Anode Potential	0 V
Wehnelt thickness	2 mm (0.079 in)
Wehnelt Potential	−50 kV
Cathode-Anode Distance	16.5 mm (0.65 in)

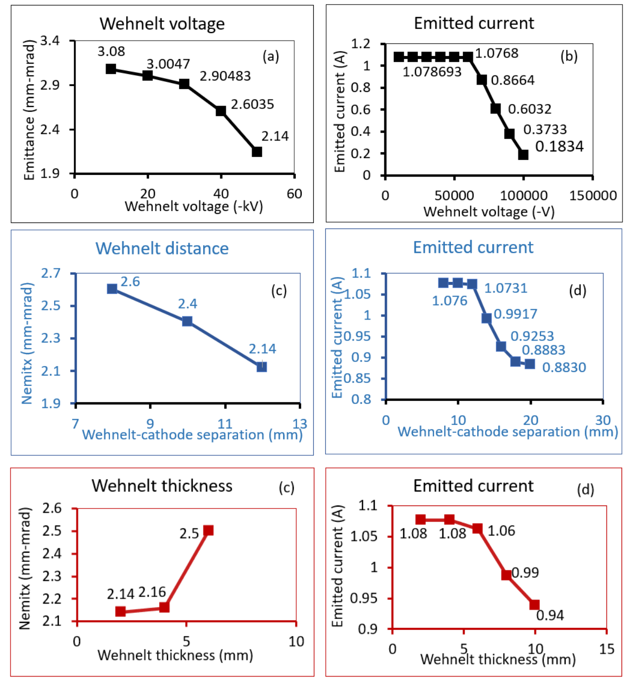

Figure 4: (a) Transverse emittance and (b) current variation with Wehnelt voltage, (c) Transverse emittance and (d) current variation with cathode-Wehnelt seperation, (e) Transverse emittance and (f) current variation with Wehnelt thickness.

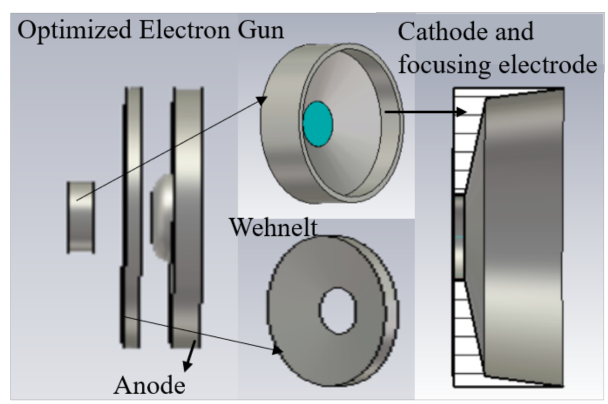

Figure 5: Design of an optimized Electron Gun.

CST BEAM DYNAMICS SIMULATIONS

Our grid-less thermionic gun optimization studies using microwave CST and with hexahedral mesh shows convergence at a mesh density of 0.70×10^7. After placing the grid, mesh of 1.86, 3.65 and 4.5×10^7 was considered and the results obtained are shown in Fig. 6. The obtained results for beam emittance and beam size shows a plateau region between a mesh density of 3.65 - 4.5×10^7 but increases further as we increase the mesh density beyond 4.5×10^7 as shown in Fig. 6. This deviation has inspired us to develop our own particle tracking code to achieve numerical convergence and accuracy.

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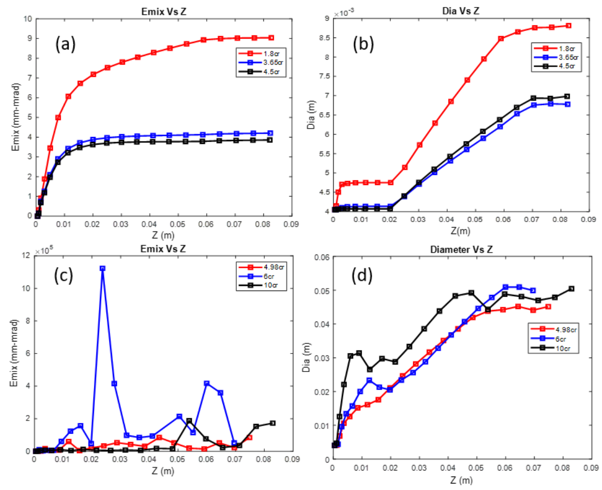

Figure 6: (a) Transverse emittance and (b) diameter variation of the beam with mesh density 1.8, 3.65 and 4.5 × 10^7, (c) transverse emittance and (d) diameter variation of the beam with mesh density 4.98, 6 and 10 × 10^7 along bunch propagation direction (z).

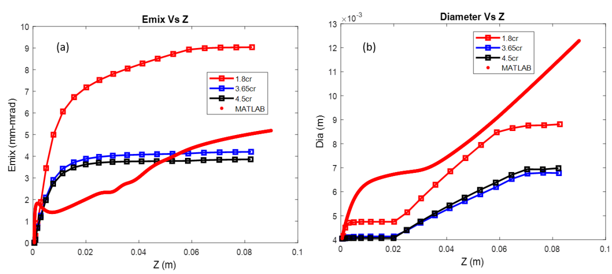

Figure 7: (a) Transverse emittance and (b) diameter comparison of the beam along bunch propagation direction (z).

Code Development for Particle Tracking

We performed particle simulations through self written PIC scripts in the presence of applied field and self-field. Field distribution from optimized geometry for the tracking is exported from CST: electrostatic solver. Self-field is calculated by poisson solver. The particle position and velocity are then advanced in time in the presence of self-field and external field by the Euler-symplectic method. The process is repeated for the next time step to track the particles.

Comparison of Code and CST Results

After tracking the particles with our code, through the cathode-anode field, the results of RMS normalized transverse emittance and beam diameter were found to be matching with CST PIC results for the mesh density of 3.65 and 4.5 × 10^7 as shown in Fig. 7.

Beam Dynamics

Beam dynamics of the particles is studied under the effect of space charge and the field of designed and optimized thermionic gridded gun. An electron bunch of 50 ps and bunch charge of 5 pC is tracked through the designed gun.

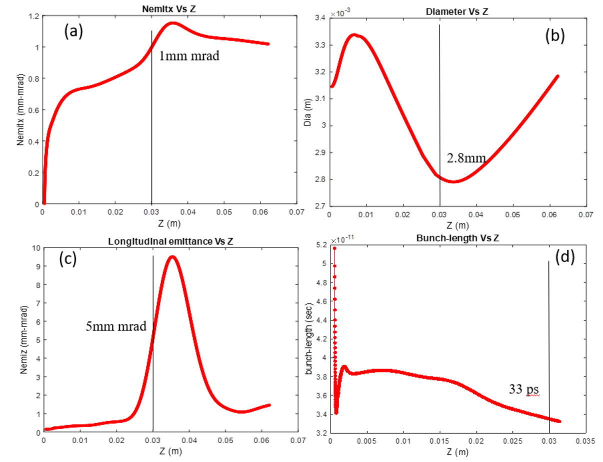

Figure 8: (a) Transverse emittance, (b) diameter (c) longitudinal emittance and (d) bunch-length variation along bunch propagation direction (z).

Obtained results shows the final RMS transverse and longitudinal emittance of 1 and 5 mm-mrad respectively, diameter of 2.8 mm and bunch-length of 33 ps as shown in Fig. 8.

CONCLUSION

A thermionic gridded electron gun is designed and optimized for a good beam quality, with a bunch charge of 5 pC and bunch length of 50 ps. Particle tracking code is developed using MATLAB to solve the discrepancies observed with CST PIC during mesh convergence study. Beam dynamics results obtained using our code shows reasonable agreement with CST PIC at mesh density of 3.65-4.5 × 10^7 with final RMS normalized transverse emittance at the gun exit of 1 mm-mrad, bunch diameter of 2.8 mm, RMS normalized longitudinal emittance of 5 mm-mrad and the bunch length of 33 ps at gun exit.

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REFERENCES

[1] P. Sprangle *et al.*, "A gridded thermionic injector gun for High-average-power Free-electron lasers", *IEEE Transactions on Plasma Science*, vol. 40, 2012. doi:10.1109/TPS.2012.2201962

[2] R. W. Hockney, and J. W. Eastwood. "Computer Simulation Using Particles Taylor and Francis", USA, 1988. doi:10.1201/9780367806934

[3] D. Bhattacharjee, *et al.*, "Design and development of a 40 kV pierce electron gun", in *Proc. ISDEIV'14*, 2014. doi:10.1109/DEIV.2014.6961753