Design & 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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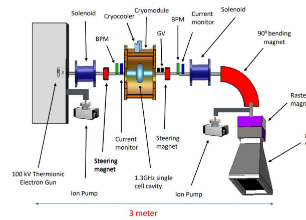
ABSTRACT

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.



Schematic of proposed system

MOTIVATION

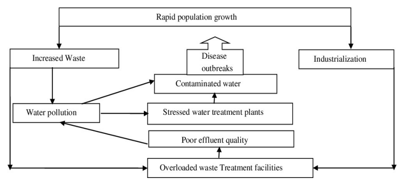


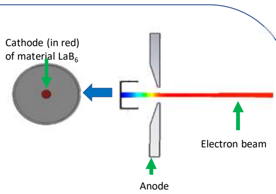
Figure 1: The chart Illustrates events and problems caused by population pressure on inadequate water facilities

- Due to rapid population growth and industrialization demand of water increased which has resulted into a water crisis which demand a new technology.
- The use of electron beam accelerator for water treatment is introduced here.

GUN DESIGN

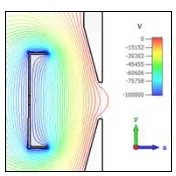
Geometry of thermionic diode gun comprises of

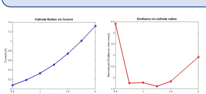
- Planar cathode of LaB_6,
- Focusing electrode, and
- Anode



- To minimize the beam emittance, various geometry parameters such as cathode radius, height and radius of focusing electrode, distance between cathode and anode, are optimized.
- A 100 kV of potential is applied on cathode and focusing electrode, while anode is at ground potential.
- The role of focusing electrode is to bend the equipotential lines to cause uniform emission from cathode and focus the beam

Equipotential lines generated due to the applied potential of -100 kV on cathode





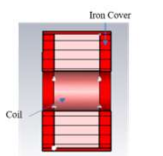
The required maximum current is 0.5 A and for that the normalized emittance is minimum for cathode radius of 1.25 mm.

Parameter	Value
Operating temperature	1940 K
Potential	100 kV
Current	500 mA
Distance b/w anode-cathode	20 mm
Cathode radius	1.25 mm
Height of focusing electrode	5 mm
Radius of focusing electrode	13 mm
Beam diameter	5 mm
Normalized RMS transverse emittance	0.3 mm.mrad

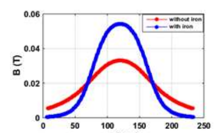
Beam parameters are reported at the location of the solenoid which is 6 cm away from the cathode

SOLENOID DESIGN

- To match and transport the beam from the electron gun to the 1.3 GHz buncher cavity.

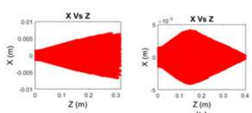


Cross sectional view of solenoid

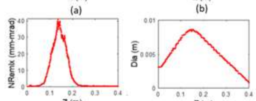


Effect of iron cover on magnetic field

- Iron provides additional contribution to the peak magnetic field.
- The objective of shielding by iron cover is to optimize the fringe field and provide magnetic shielding to nearby components.
- The effect of solenoid field on the electron beam after the gun exit significantly reduces the beam diameter.



z-x profile of the beam
(a) Without solenoid,
(b) With solenoid

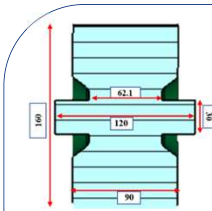


Normalized RMS transverse beam emittance and beam diameter with direction of propagation

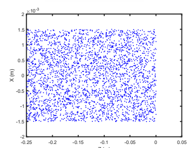
Parameter	Value
length	8 cm
Coil current	1 A
Number of turns	2000
Inner radius of solenoid	35 mm
Outer radius of solenoid	100 mm
Thickness of iron cover	1 mm
Magnetic field	0.027 T
Beam diameter	3 mm
Normalized RMS transverse emittance	0.4 mm.mrad

Beam parameters are reported at the location of the buncher cavity

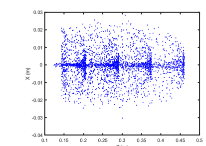
BUNCHER DESIGN



- Buncher is required between electron gun and accelerating cavity to bunch the beam
- ELBE type bunch cavity is designed
- Beam dynamics study is going on to realize the bunching through the buncher cavity

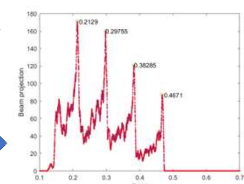


Electron distribution before buncher



Electron distribution after buncher

The particles have initial beta = 0.54, which after going through buncher become 0.7 for accelerating gradient of 1 MV/m.



Beam Projection

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

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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.

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