Design and simulation of Electron gun and Magnet of C-Band 80MW klystron for CEPC LINAC

Noman Habib[1,2], Zu-Sheng Zhou[1,2*], Munawar Iqbal[1,3], Ou-Zheng Xiao[1], Yu Liu[1,2], Yi-Ao Wang[1,2], Abid Aleem[1], Wen -Bing Gao[1,2], Han Xiao[1,2], Fan-Yu Wang[1,2]

[1]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing-China
[2]University of Chinese Academy of Sciences, Beijing-China
[3]Centre for High Energy Physics, University of the Punjab, Lahore-Pakistan
*Corresponding Author Email: zhouzs@ihep.ac.cn

Abstract

The design and simulation of the complete electron gun and electromagnet for 80 MW C-band klystron of CEPC LINAC. At an acceleration potential of 425 kV, a space charge beam current of 425A is achieved with an average cathode loading of less than 9.0 A/cm^2. It has been calculated that the maximum surface electric field at the high voltage ceramic seal and beam optics is less than 23 kV/mm and 4.80 kV/mm, respectively. With an average beam radius of 5.40 mm, the electron beam is successfully transported to the interaction cavity with a beam ripple rate of around 5.0%. The 3-D CST simulation validates and finds agreement with the results of the 2D-GUN, and POISSON simulations.

Klystron Fundamentals

Definition: Klystron is an electron-beam vacuum tube in which the beam interacts with standing-wave RF fields in several consecutive & collinear RF cavities to produce high power RF wave.

Madidate : RF Amplifier of the accelerator to accelerate the particles close to the velocity of light.

Principle: 1.Electron Gun: The cathode is heated to ~1000C and applied (Pulsed or DC) to several 100kV. Electrons are accelerated from the cathode towards the anode at ground, which is isolated from the cathode by the high voltage ceramics. The electron beam passes the anode hole and drifts in the drift tube, **2. Magnet :** The beam is focused by the cathode coil and a solenoid, **3. Cavities:** By applying RF power to input cavity , the beam is velocity modulated. On its way to the out put cavity, the velocity modulation converts to density modulation due to additional buncher cavities. The beam is decelerated in the out put cavity by applying a negative electrode. The electrons lost energy which is converted into RF power, **4. Window:** This RF power is coupled out by a window through a wave guide, **5 Collector:** The residual beam is dumped in the collector. Fig 1, is the cross-sectional view of the Klystron.

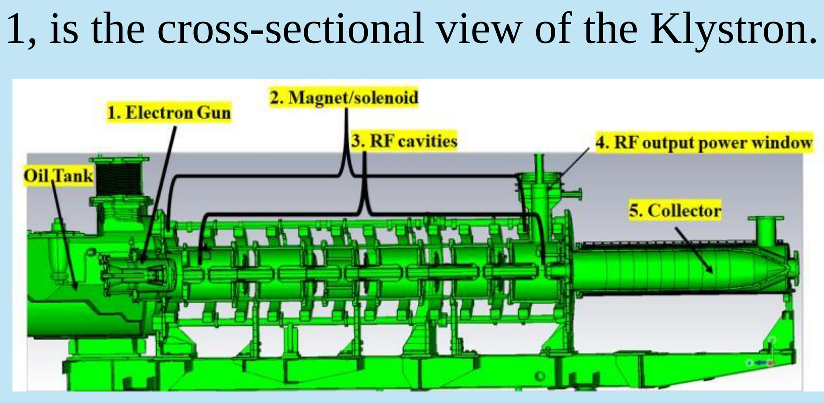

Figure 1: 3-D cross sectional view of Klystron.

Applications:

Some important application are mentioned as below:

1.Colliders: Particles are accelerated at High Energy through Klystrons and then collided to explore the mysteries of the Universe. LHC,CERN, SUPERKEKB, JAPAN, BESIII, China, etc. are Colliders.

2. Linear Accelerators : Accelerate particles at high energy by Klystron to produce electrons and photons for *Medical Applications* like cancer diagnosis and treatment.

3. Free Electron Lasers: High energy electron beam produced through LINAC is used both for lasing & pumping by itself produced *high power LASER light* while passing through a undulator magnet.

4.RADARs: The main applications are defense surveillance systems, navigation and locating enemy targets. High frequency radars are also used to plot or to map the terrain in the area. The transmitter produces the microwave pulses emitted by the radar which propagates through Antenna. The transmitter's main components is Klystron.

Electron Gun Design

Table 1: Beam Optics Design Parameters

Parameters	Units	Values
Anode Diameter	mm	120
Focusing electrode diameter	mm	68.304
Cathode - anode spacing	mm	76.1
Cathode - focusing electrode spacing	mm	1.1
Cathode diameter	mm	87.8

A 2D & 3D view of the Klystron electron gun shown in figure 2, was modeled in DGUN & CST Code with parameters given in table 1. This is a thermionic diode gun having cathode, focusing electrode and anode.

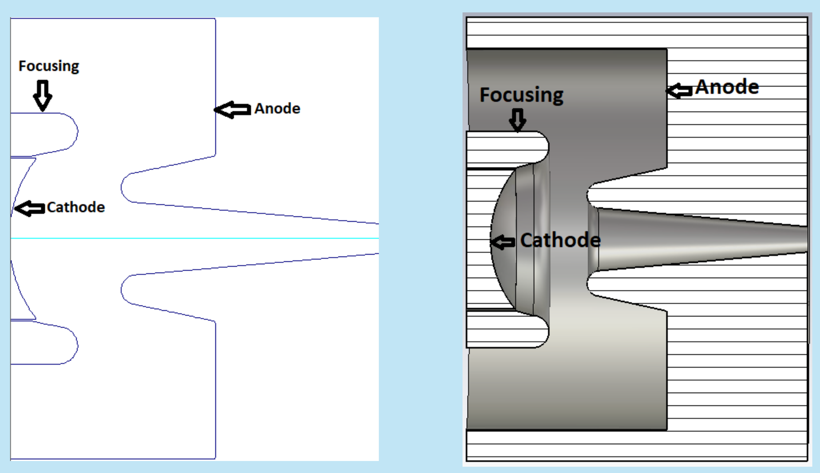

Figure 2: 2-D & 3-D model of the gun produced by DGUN &CST.

Magnet Design

We used POISSON and CST code to design solenoid as given in Fig. 3(a , b) with a Reverse Current Coil at the cathode for beam trajectories matching in the field free region. The obtained magnetic field comparison of POISSON and CST in Excel is given in Fig 4.

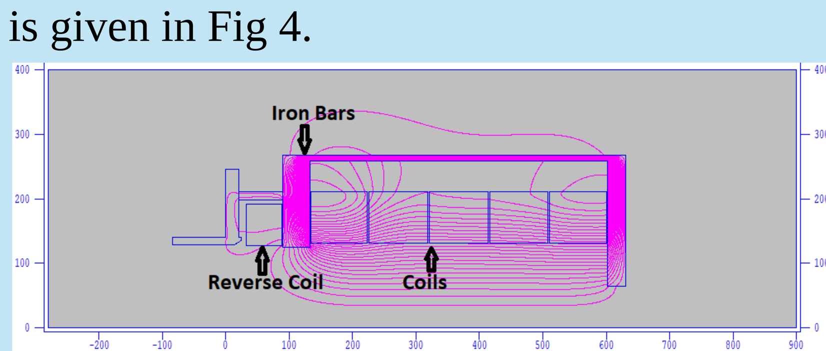

Figure 3a:Design of the solenoid in POISSON

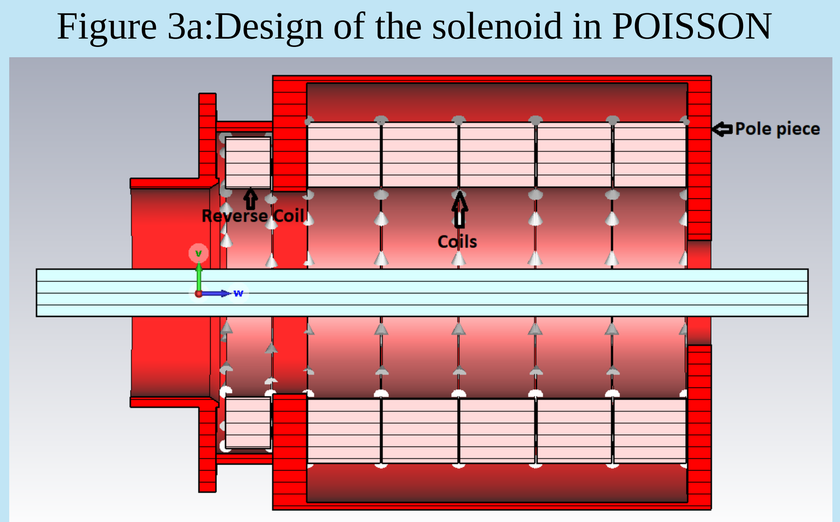

Figure 3b:Design of the solenoid in CST

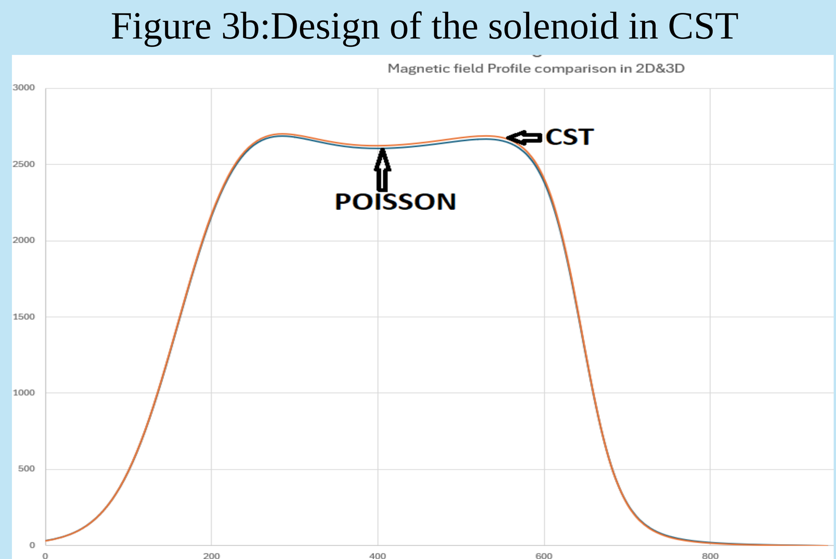

Figure 4:Axial Magnetic field profile Comparison of the Magnet(CST&POISSON)

Beam Optics Simulation

Table 2. Simulation parameters

Parameter	Units	Values
Cathode voltage	kV	0
Anode voltage	kV	425
Magnetic field	Gauss	2687

The gun was then simulated in DGUN and CST Codes for the beam optics analysis. To get the maximum beam convergence, high emission density and low perveance in the field free region we used the parameters as listed in table2.

We obtained an electron beam of average radius of 5.55 mm in DGUN and 5.73 mm in CST. The electron beam trajectories are shown in figure 5(a , b).

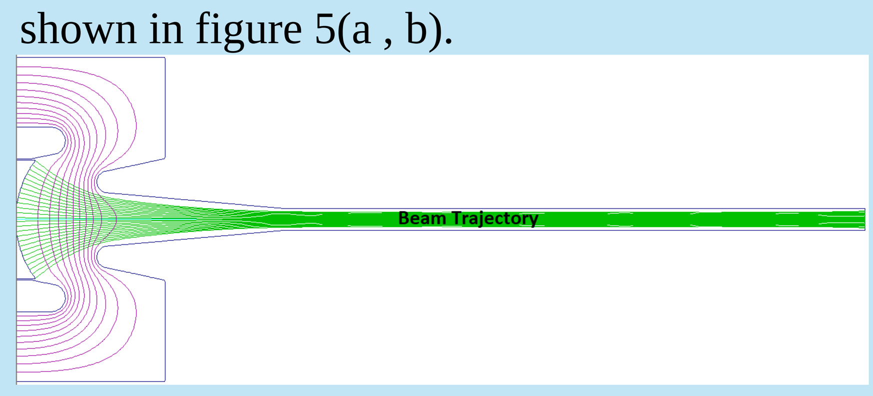

Figure 5(a): Beam trajectories of Klystron electron beam gun under magnetic field in DGUN

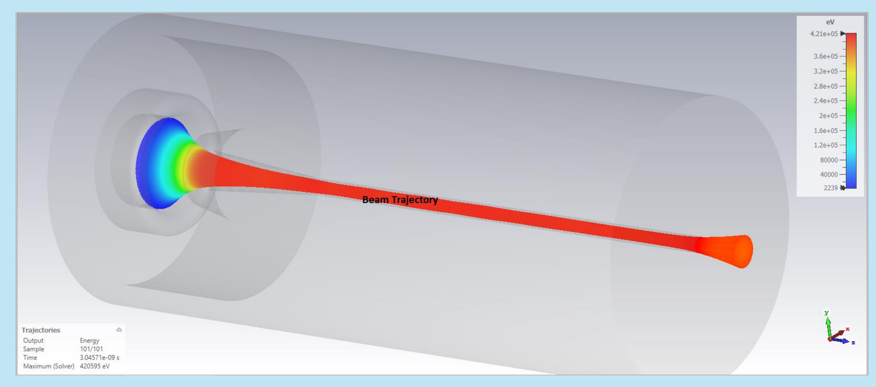

Figure 5(b): Beam trajectories of Klystron electron beam gun under magnetic field in CST

Gun Ceramic

We used POISSON and CST code to design Gun envelope and calculate its electric field as shown below.

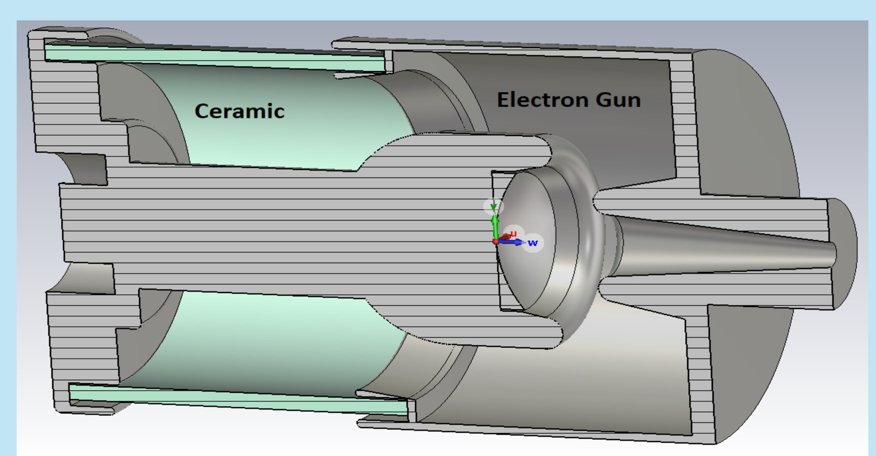

Figure 6: Design of the gun and ceramic in CST

Results and Discussions

A maximum electric field value of 22.7 kV/mm at the focusing electrode is obtained as the potential lines are spaced very close to each other as can be seen in the Figure 5(a). A space charge current of 418A is obtained as can be seen in the Figure 7. The perveance is calculated to be 1.5 μP.

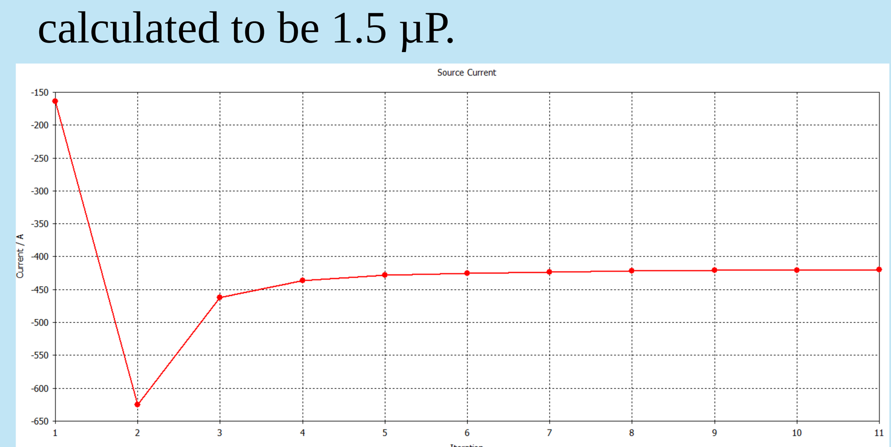

Figure 7: Space charge beam current

The values of the maximum & minimum beam size under the magnetic field is also shown in Figure 8. Transmission of the beam in the downstream is given in Figure 8 which shows the size and the ripple of the beam. The beam is laminar with reduced size under the obtained magnetic field.

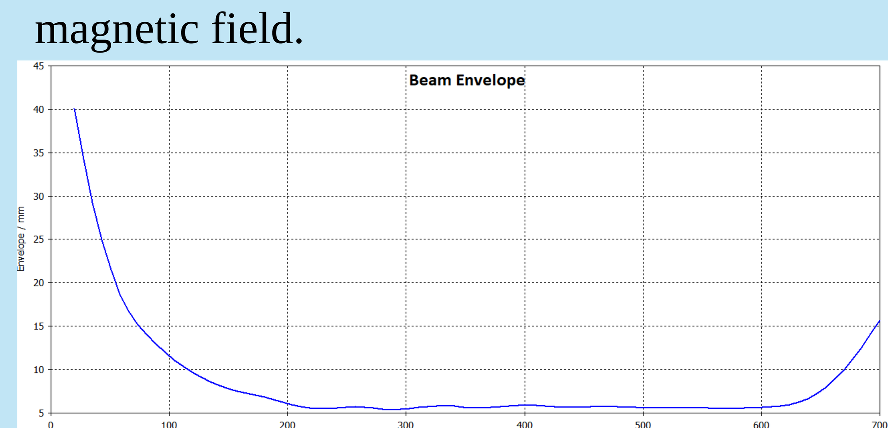

Figure 8: Envelope vs. plane position

Figure 9 represents the dotted line which shows the current density on cathode. The current density value almost uniform, and it drops at the edges of the cathode due to lower heating. The maximum value obtained is around 8.8 A/cm^2.

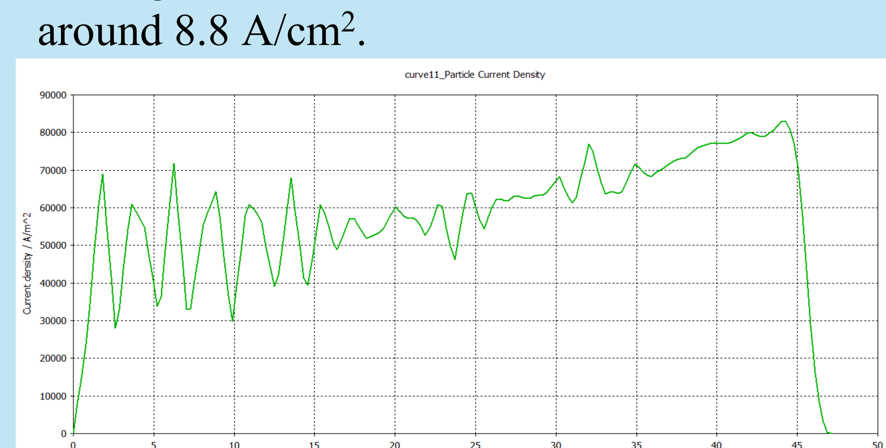

Figure 9: Current density vs. cathode radius

Summary

A thermionic high-power diode electron gun in a simple structure is designed (modeled), simulated and analyzed. Simulation values verified from the two codes, DGUN and CST agree. High emission current, low perveance of the source have been obtained.. Close agreement of simulated results depicts that the DGUN and CST are best suited software's for complete design and analyses of electron beam guns of klystron for linear accelerators applications. Magnetic field of strength 2687 Gauss is used to focus the beam at the target The electron beam is focused on the target with the desired size of the radius of the beam. The percentage current error between DGUN and CST results was about 0.83 %. A summary of the calculated parameters are given in table 3.

Table 3: Emission Characteristics of the Gun

Parameters	Units	CST	DGUN	POISSON
Acceleration voltage	kV	420.7	425	425
Current	A	418	425.1	NA
Maximum Cathode current density	A/cm^2	8.8	8.8	NA
Perveance	μP	1.5	1.5	NA
Maximum radius	mm	6.04	5.86	NA
Minimum radius	mm	5.3	5.239	NA
Average radius	mm	5.67	5.54	NA
Ripple rate	%	6.5%	5.6%	NA
Electric field @ focusing electrode	kV/mm	22.7	19.3	22.7
Electric Field @ ceramic	kV/mm	4.7	NA	4.7
Maximum Magnetic field @ drift tube	Gs	2687	2687	2687

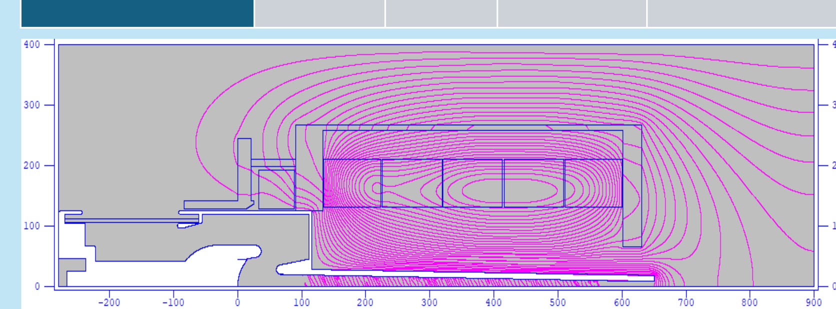

Figure 10a:Design of the Gun, solenoid and ceramic seal in POISSON

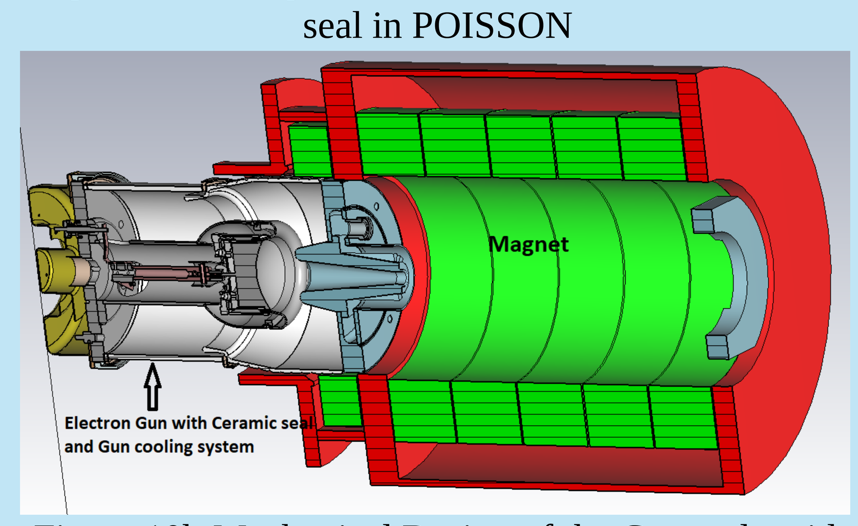

Figure 10b:Mechanical Design of the Gun, solenoid and ceramic seal in CST

Figure 10(a , b) shows the Mechanical Design of the Gun, solenoid and ceramic seal in POISSON and CST software.

The gun, magnet and the ceramic are designed for 80MW klystron and now under fabrication in the Chinese company.

References

1- A Microwave Source of Surprising Range and Endurance* George Caryotakis Stanford Linear Accelerator Center, Stanford University, Stanford CA 94309.

2- A. Larionov, K. Ouglekov, DGUN-code for simulation of intensive axial-symmetric electron beams, in: Proceedings of 6th ICAP, Darmstadt, Germany, 2000, p. 172.

3- POISSON Code, Los Alamos National Laboratory Report, 1987, LA-UR-87-126.

4- User Manual, CST-Particle Studio, Darmstadt, Germany, 2020.

5- Gao, J. CEPC Technical Design Report: Accelerator. Radiat Detect Technol Methods 8, 1–1105 (2024)

* Work supported by Yifang Wang's Science Studio of the Thousand Talents Project