Design, Fabrication & Test of Thermionic Electron Beam Emitter Assemblies

Munawar Iqbal

Associate Professor, PhD.

Centre for High Energy Physics, University of the Punjab, Lahore-Pakistan

Presented at:

High Energy Accelerator Research Organization (KEK), 1-1-OHO,Tsukuba, Ibaraki, Japan

October 11, 2016

Outline

- Preliminaries
- Thermionic DC Electron Guns
  1. Line Source/Sheet Beam EG
  2. Hairpin Source/Point Beam EG
  3. Strip Source/Sheet Beam EG
- Conclusions
- References


PAKISTANI
KASHMIR
INDIAN
KASHMIR
Islamabad
Lahore
AFGHANISTAN
PAKISTAN
IRAN
INDIA


PakWalls.com

132 of 73 are public universities and 59 are private universities

PU was Established in 1882

Have;

4 Campuses,

13 Faculties,

10 Constituent Colleges,

over 63 Departments, Centers & Institutes,

500+ affiliated colleges.

1000 permanent Faculty members

30,000 regular Students

- **CHEP started in November 1982**
- **Faculty 15, Students per Year : 180 BS (HONS) in Computational Physics, 25 Master in High Energy Physics, 10 PhD in High Energy Physics**
- **Experimental High Energy Physics (BESIII) Collaboration**
- **Theoretical High Energy Physics**
- **Accelerator Technology & Material Science**

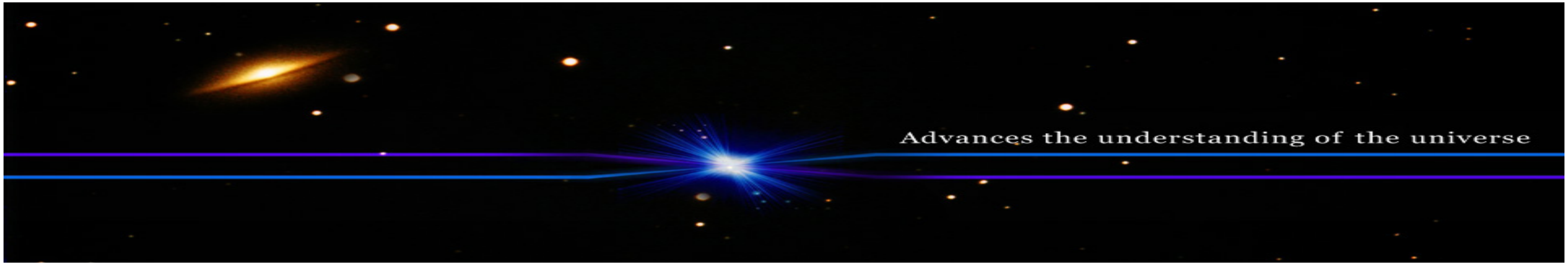
<u>Introduction</u>

- A device that generates, accelerate and to some extent focuses the beam of electrons.
- Thermionic, photo and field emissions are much popular ways for electron generation.
- Further, these emissions are temperature & space charge limited $J_{eT} = AT^2 \exp(-\phi/kT)$, $J_{eR} = 2.3 \times 10^{-6} KV^{3/2}$,

Applications

Electron beam gun is a basic part of many types of applied & fundamental Research.

- Joining, welding ,cutting, machining and modifications of refractory metals in the field of engineering sciences.
- Evaporation & coating in the field of nano- technology.
- In Electron Devices (SEM,TEM) for characterization purposes.
- **In Experimental HEP, in studying electron-positron physics, e-gun is the basic component of the Accelerator and also of Klystron.**



Thermionic DC Electron Beam Emitter Assemblies

Design Considerations of Electron Gun

For electron beam design, three parameters should carefully be taken into the considerations.

- ✓ **Firstly, a cathode should supply an adequate emission over a predetermined length of the surface with good thermal efficiency.**

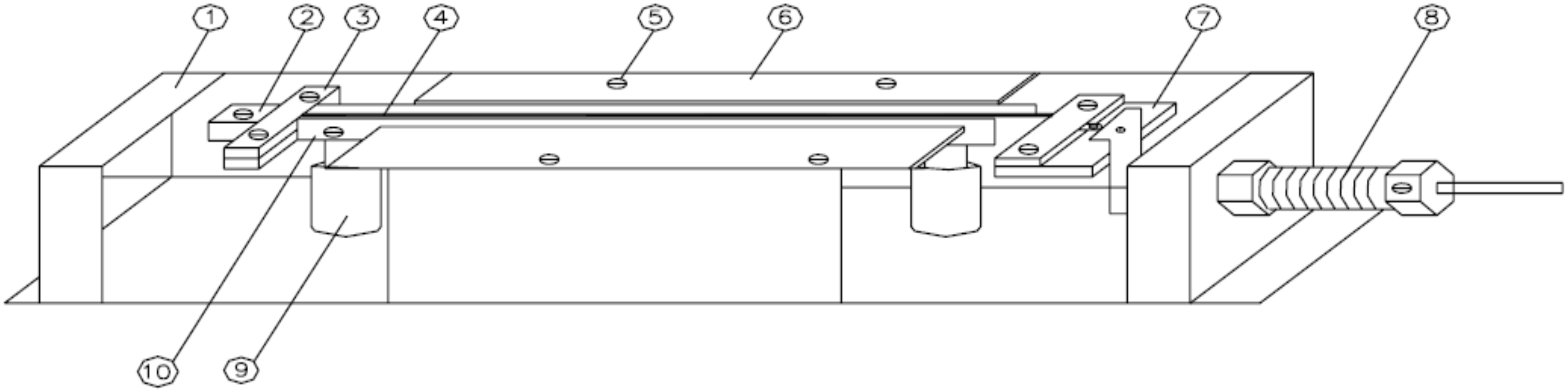
- ✓ **Secondly, the beam should have a homogenous emission across a length of several centimeters to enable large area processing of the beam.**

- ✓ **Thirdly, a uniform magnetic field is essential to provide the uniform energy density to the beam by making the trajectories parallel to each other in the field-free region to achieve a common crossover at the target.**

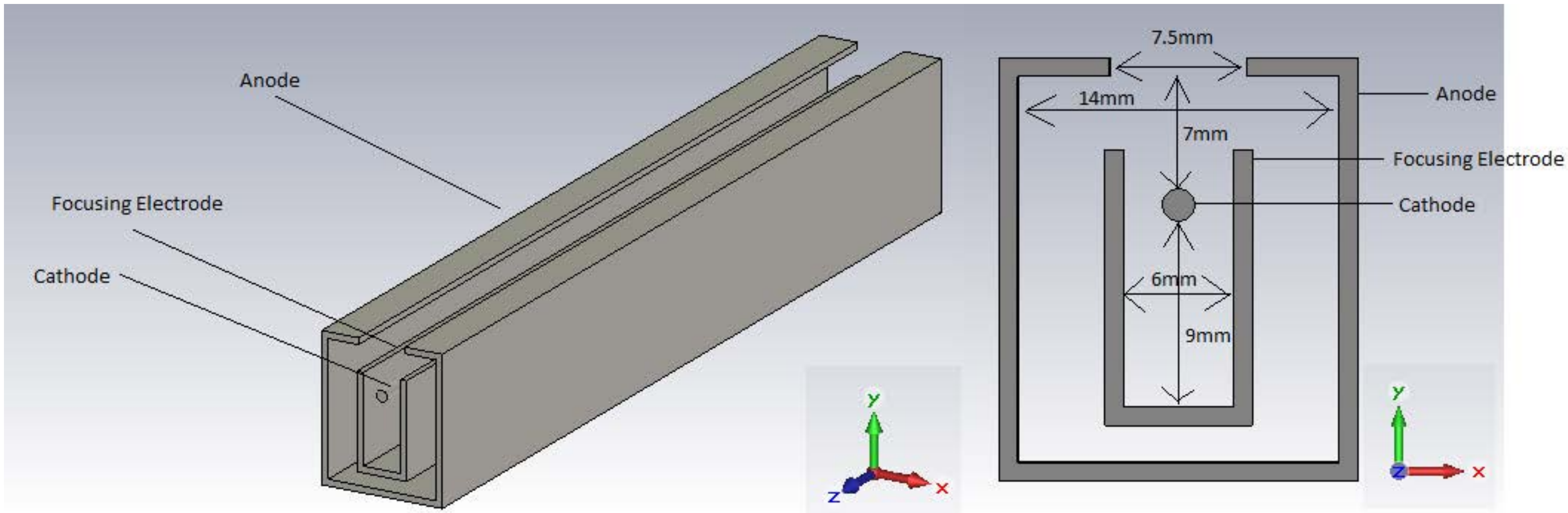
1. Line Source/Sheet Beam Electron Gun

A sheet beam electron gun with electromagnetic focusing using EGUN and CST-PS was simulated. The gun was tested up to 50 kW at 5A and10 kV, achieves power density of 33 kW/cm^2 at the target. The cathode temperature was uniform over a length of 120 mm of the cathode surface. The beam density profile strongly relates to the temperature distribution along the cathode. The gun is immersed in a uniform external magnetic field to give guidance and extra focusing to the electrons in the post-anode region. The test and simulations results are in agreement. The gun has a remarkable applications in heat treatment of large surface area and to coat large substrate surfaces at much faster evaporation and scan rates of refractory metals. **Moreover, it is a potential candidate for Klystron application.**

Design of the e-gun



1. SS Square Pipe
2. SS Mounting Bar
3. Filament Clamps
4. Cathode (Filament)
5. SS Screw
6. Anode
7. Spring Assembly
8. Spring
9. High Voltage Locating Insulators
10. Beam Former

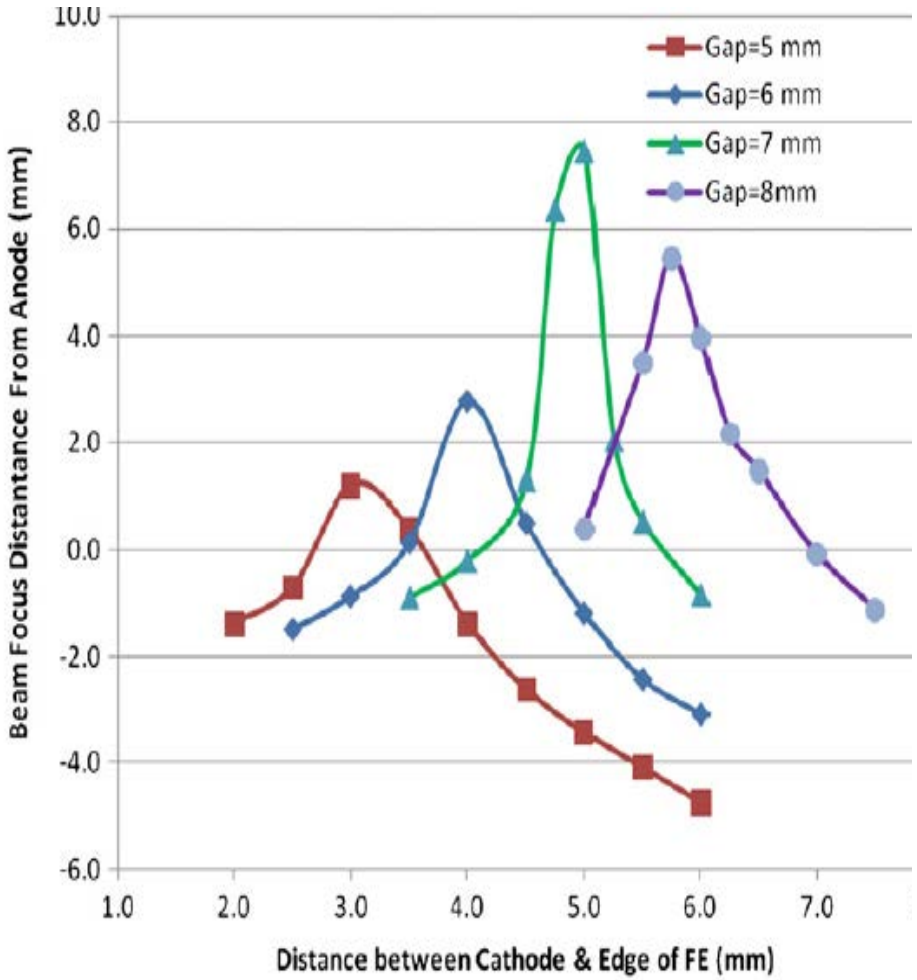


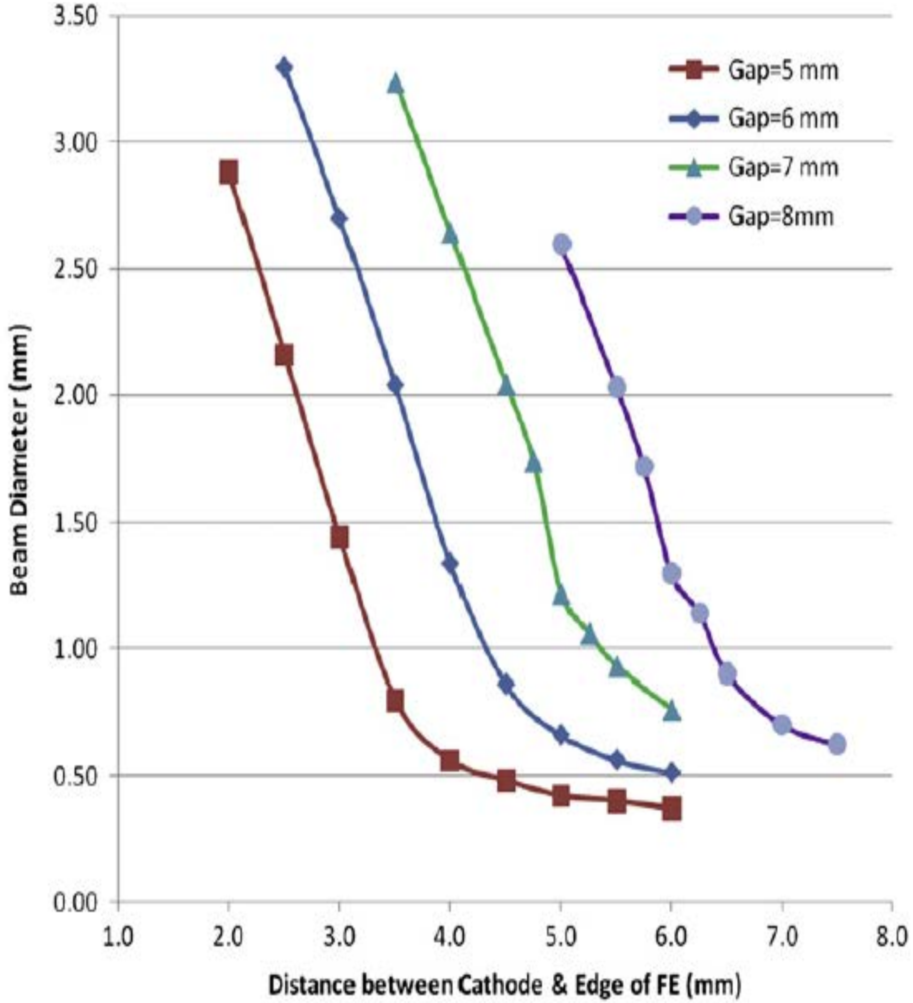
Gun Specifications

Component	Material	Dimension	Quantity
Filament	Tungsten	0.98φ×140L (120 exposed)	1
Focusing electrodes	Tantalum	16.2w×140L×1t Filament Dist. H=3.75,V= 7	2
Vertical electrodes	Tantalum	Vertical section 9h×120L×1w Horizontal section 6w×120L×1t Filament dist. H=3	2
Casing	Stainless steel	40w×40h×330L	1
Filament clamps	Molybdenum	Upper: 20w×3h×10L	2
		Lower: 20w×3h×40L	2
Insulators	Alumina	6φ×20L	2
Insulator holder	Aluminum	7.5φ×8.5L×2t	2
hearth	Copper	230w×80h×350L	1

Key: Units millimeter (mm), φ = diameter, L= length, w = width, t = thickness, h = height, H = horizontal distance, V = vertical distance

Gun optimization

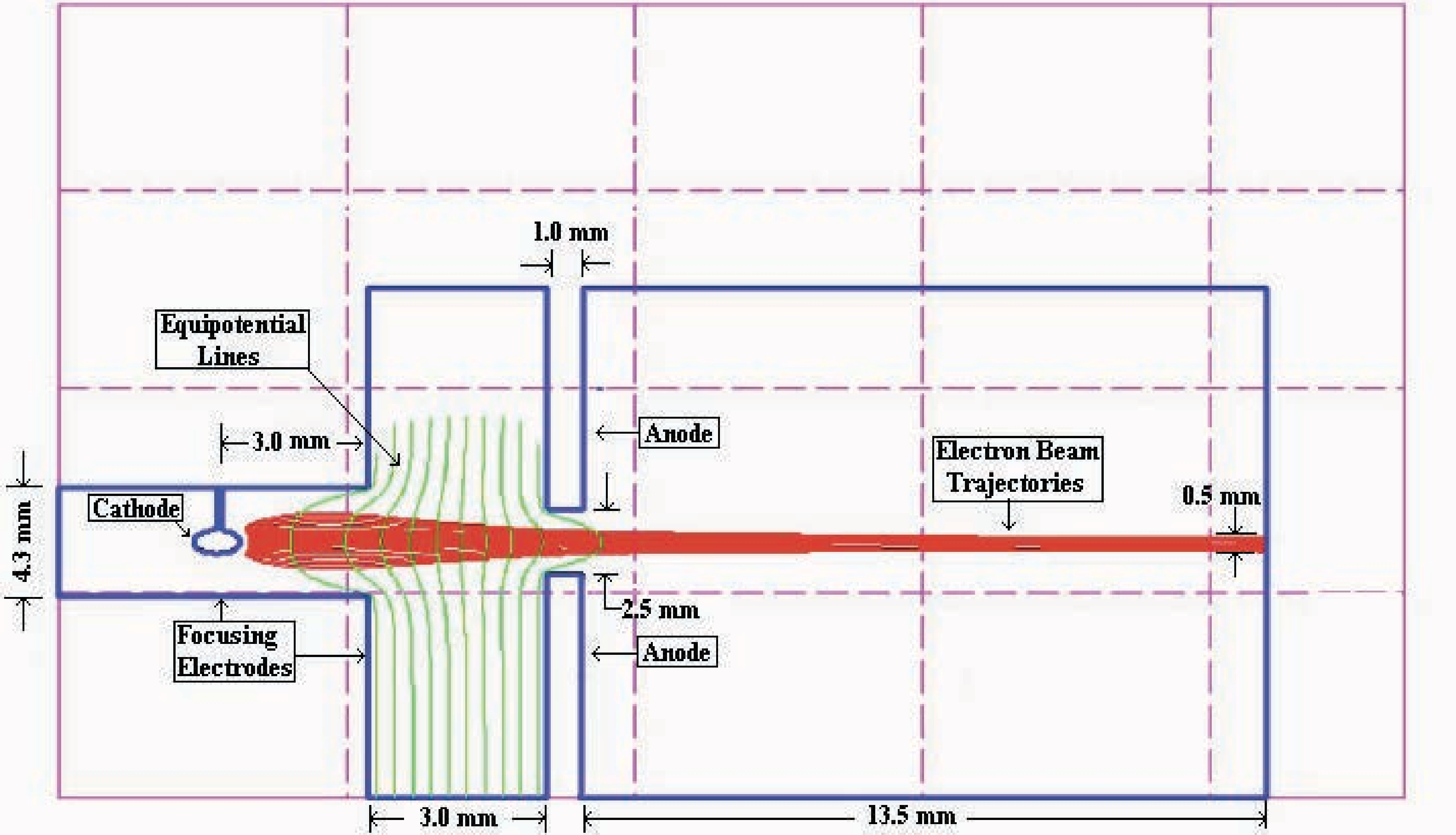




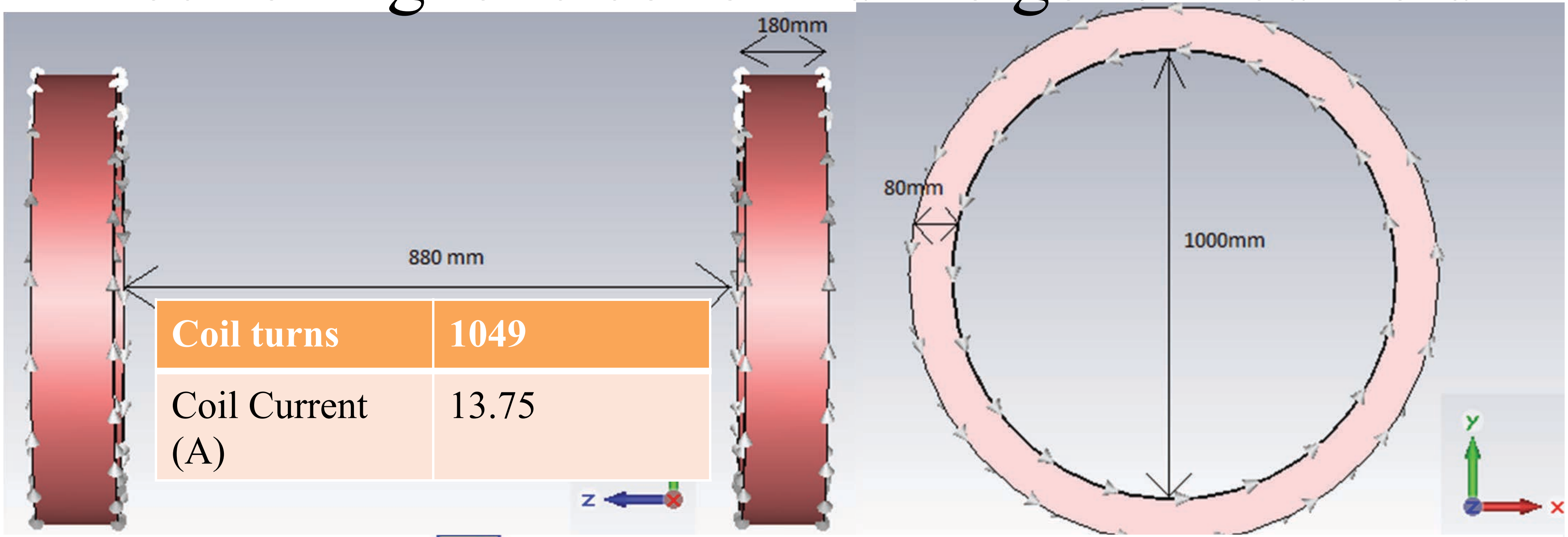
Optimization Parameters

Parameters	Optimized values
Cathode-anode distance (mm)	6
Anode slit spacing (mm)	2.5
Focusing electrode spacing (mm)	4.3
Anode-focusing electrodes distance (mm)	3
Cathode-focusing electrodes distance (mm)	3
Acceleration potential (kV)	10

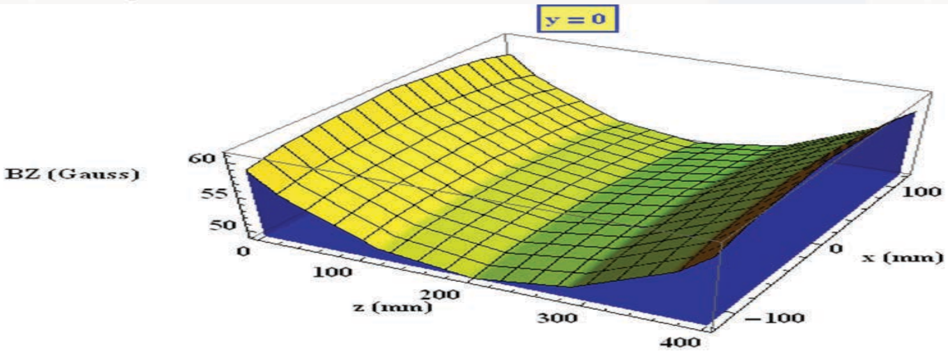
2-D EPLOT of gun with beam trajectories

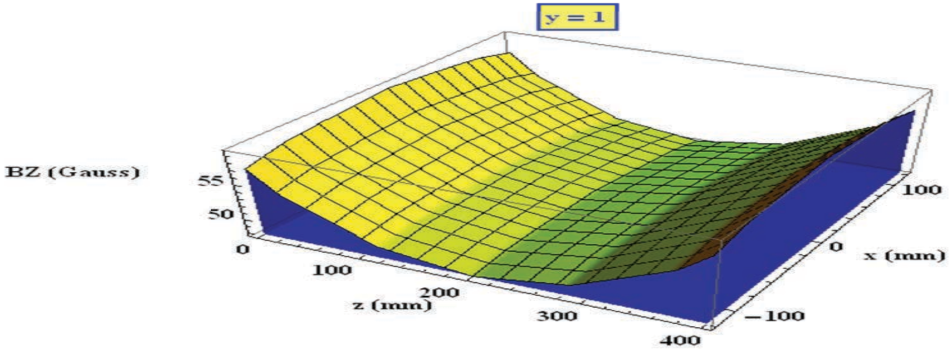


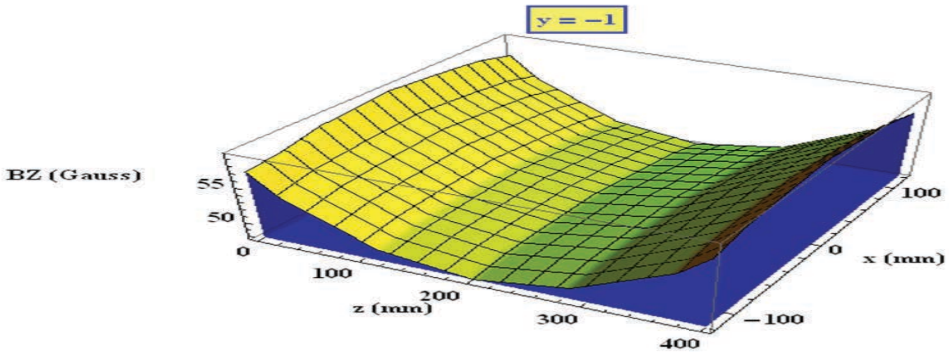
Electromagnetic coils and the generated field



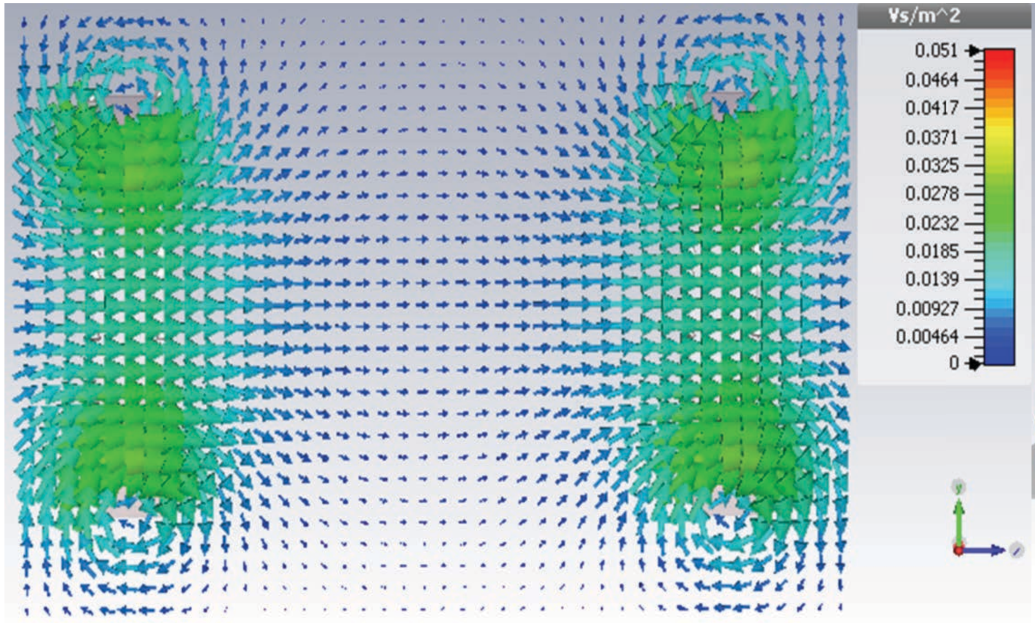
Coil turns	1049
Coil Current (A)	13.75

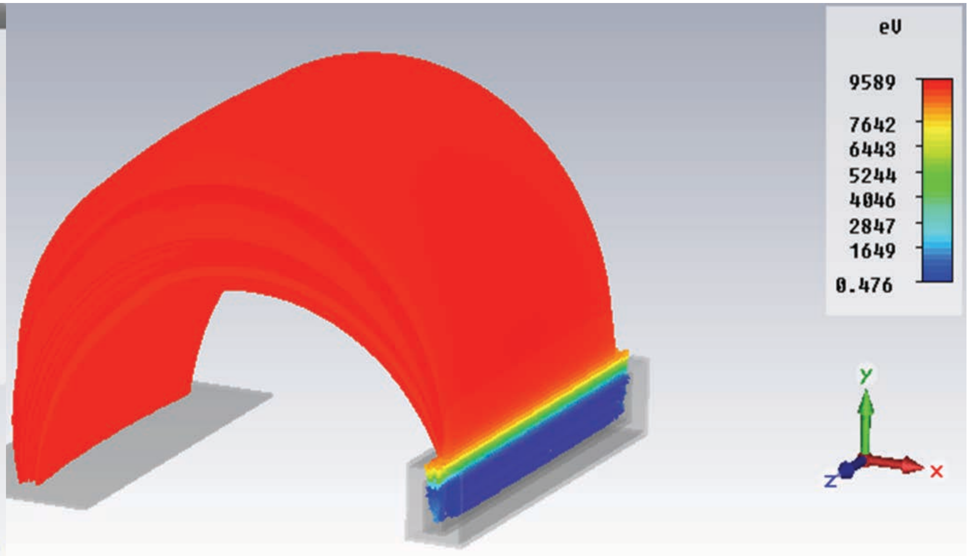


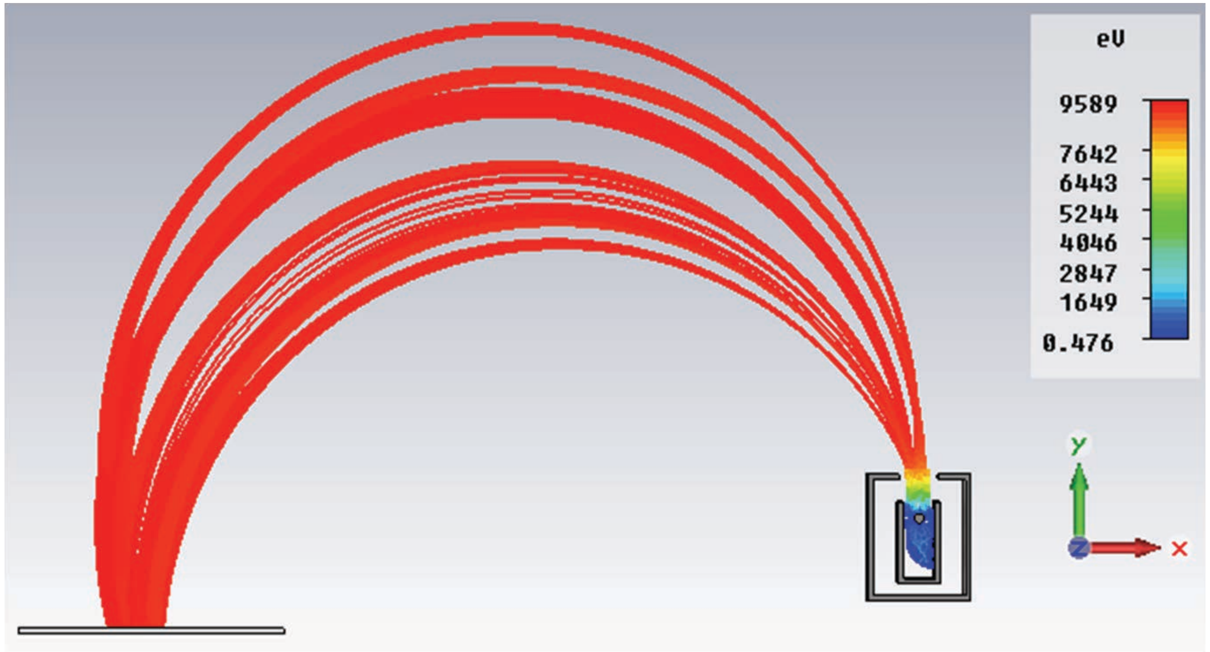




Sheet Beam in Electromagnetic Field

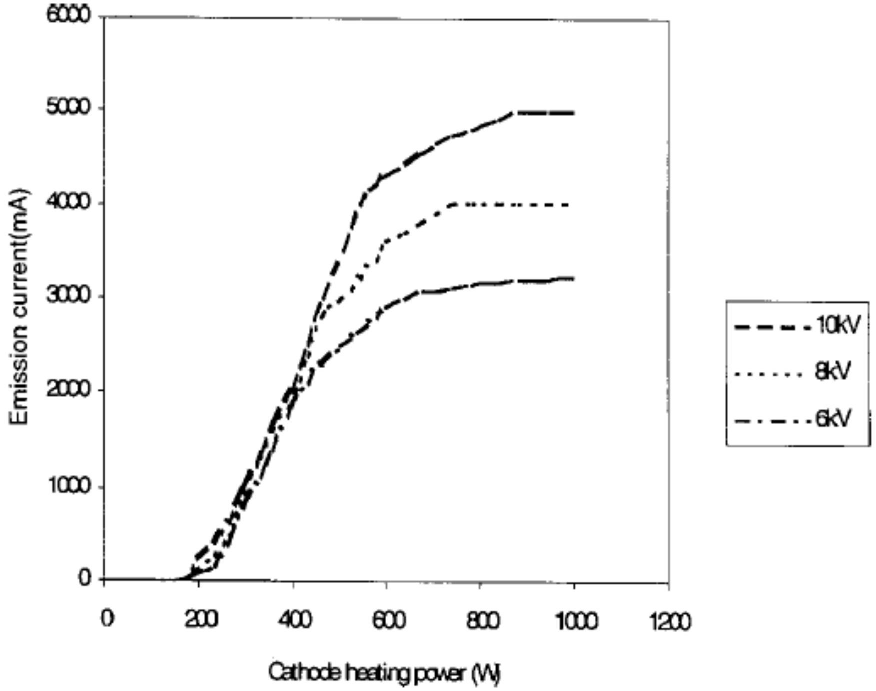


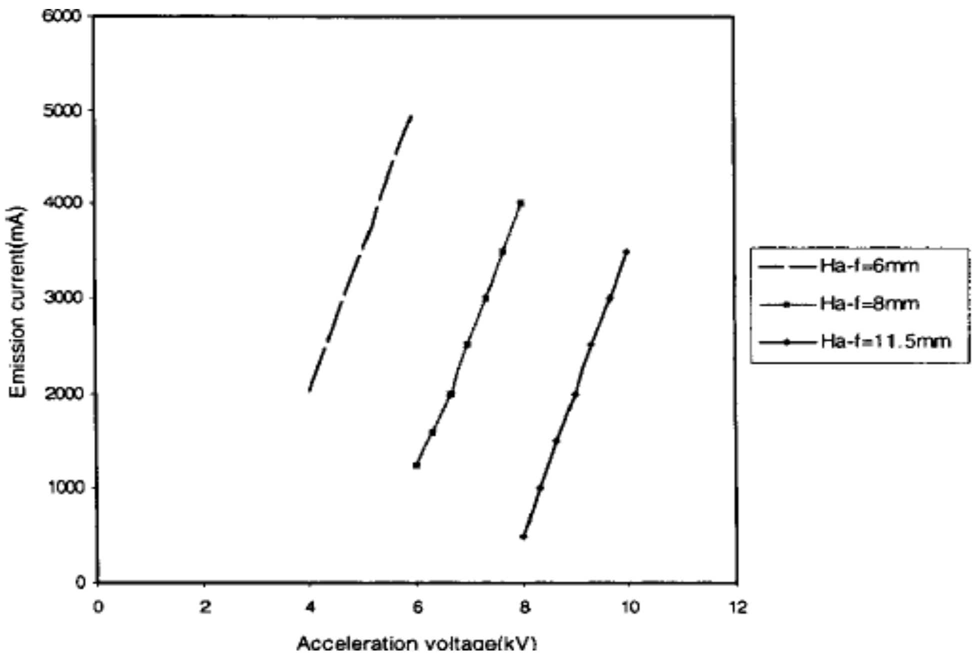


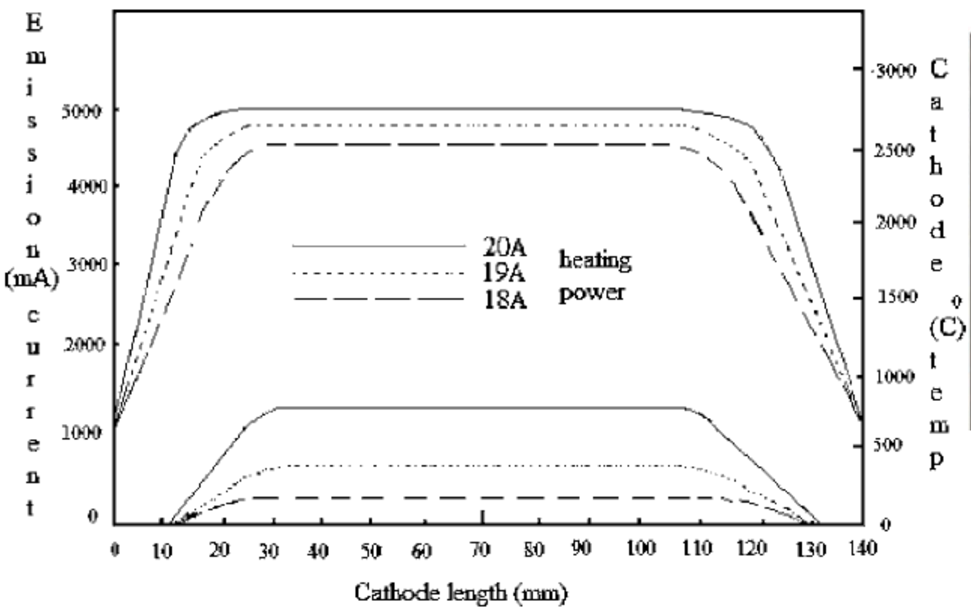


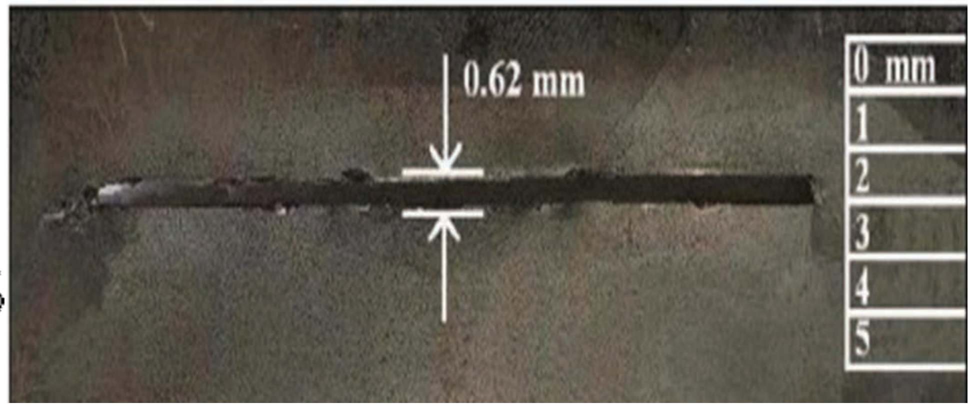
Test of the Assembly

•







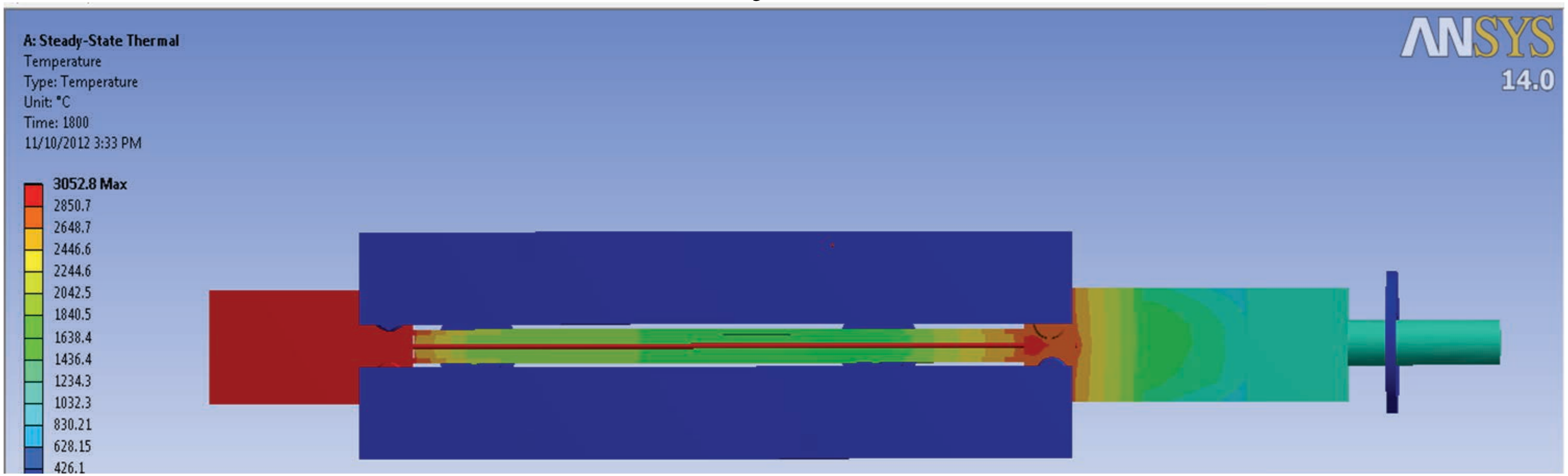


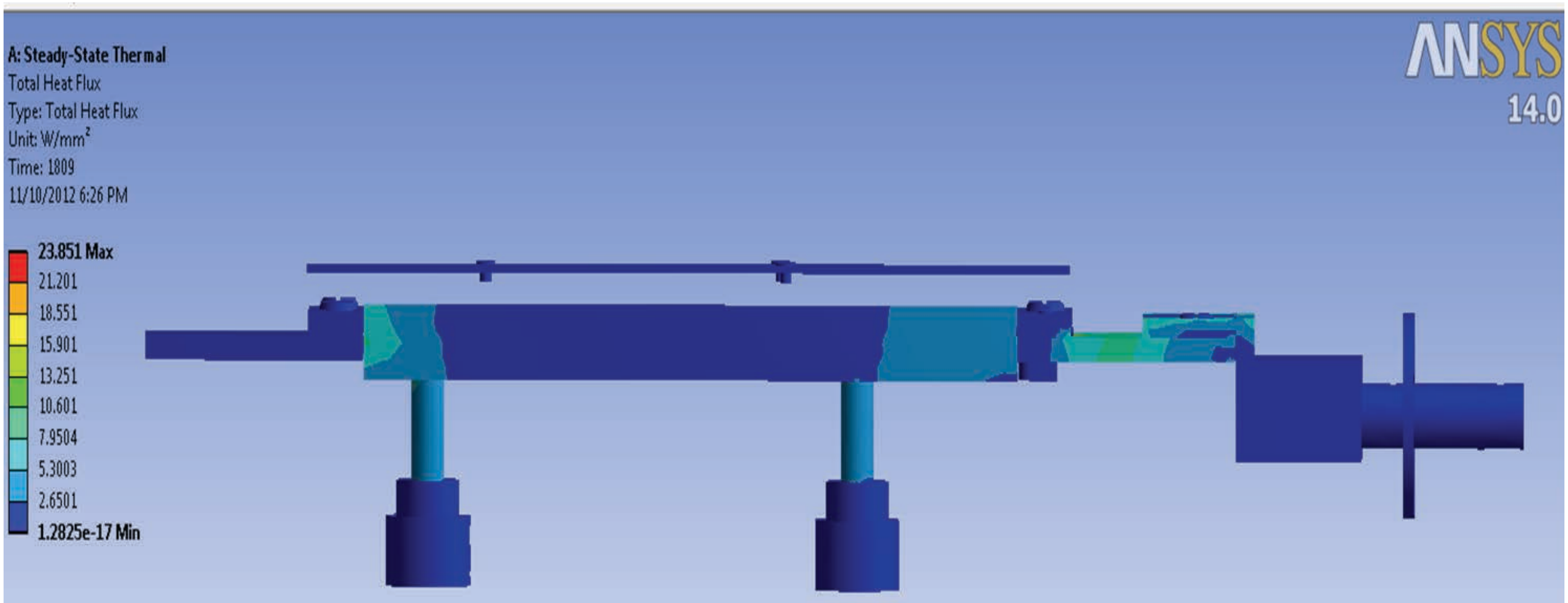
Beam profile of the electron gun at the SS target

Specifications of the Sheet Beam Electron Gun

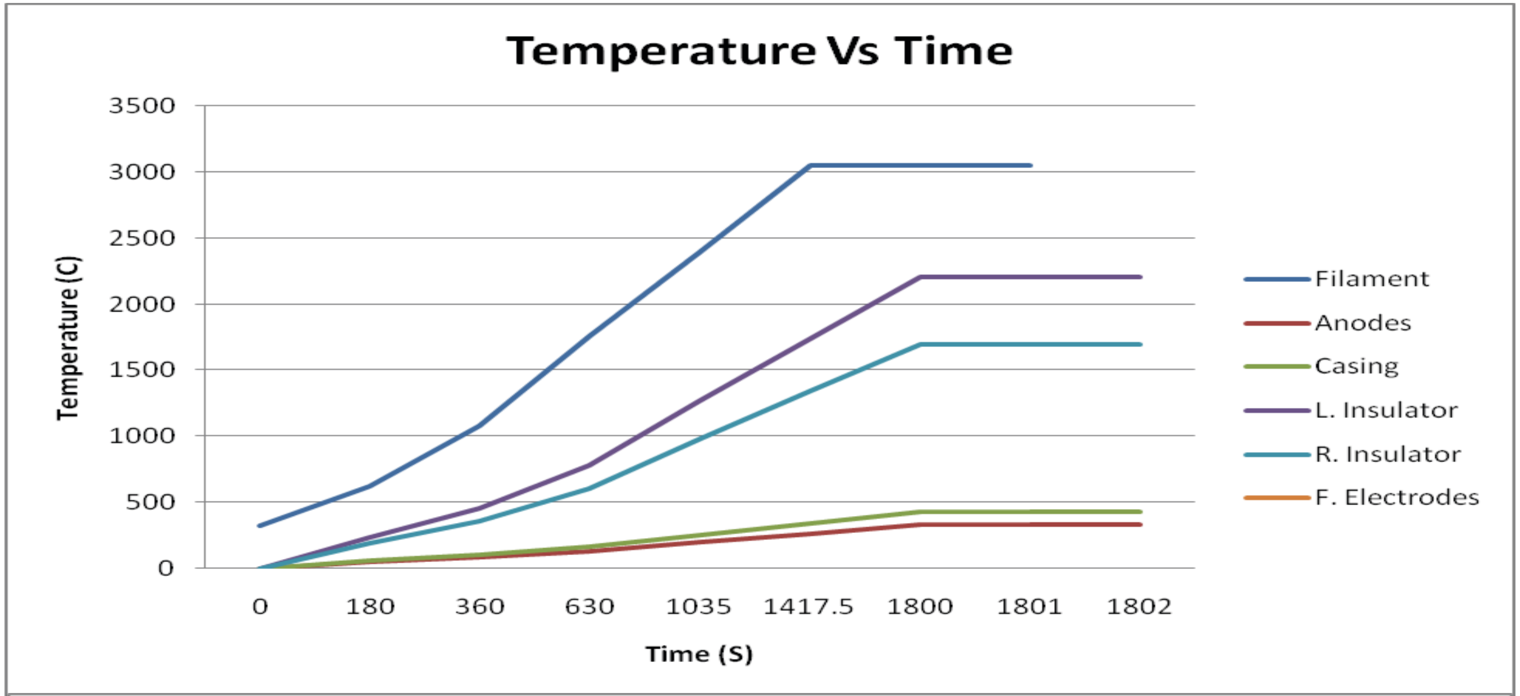
Parameters	Characteristics
Gun type	Thermionic diode gun
Cathode	Tungsten wire of 140 mm length
Filament heating power	600 W
Acceleration potential	10 kV
Beam current	5A
Emission current density	10 A/cm^2
Output power	50 kW
Power density	33 kW/cm^2
Perveance	5 $\mu A/V^{3/2}$
Pressure	5×10^{-5} Torr

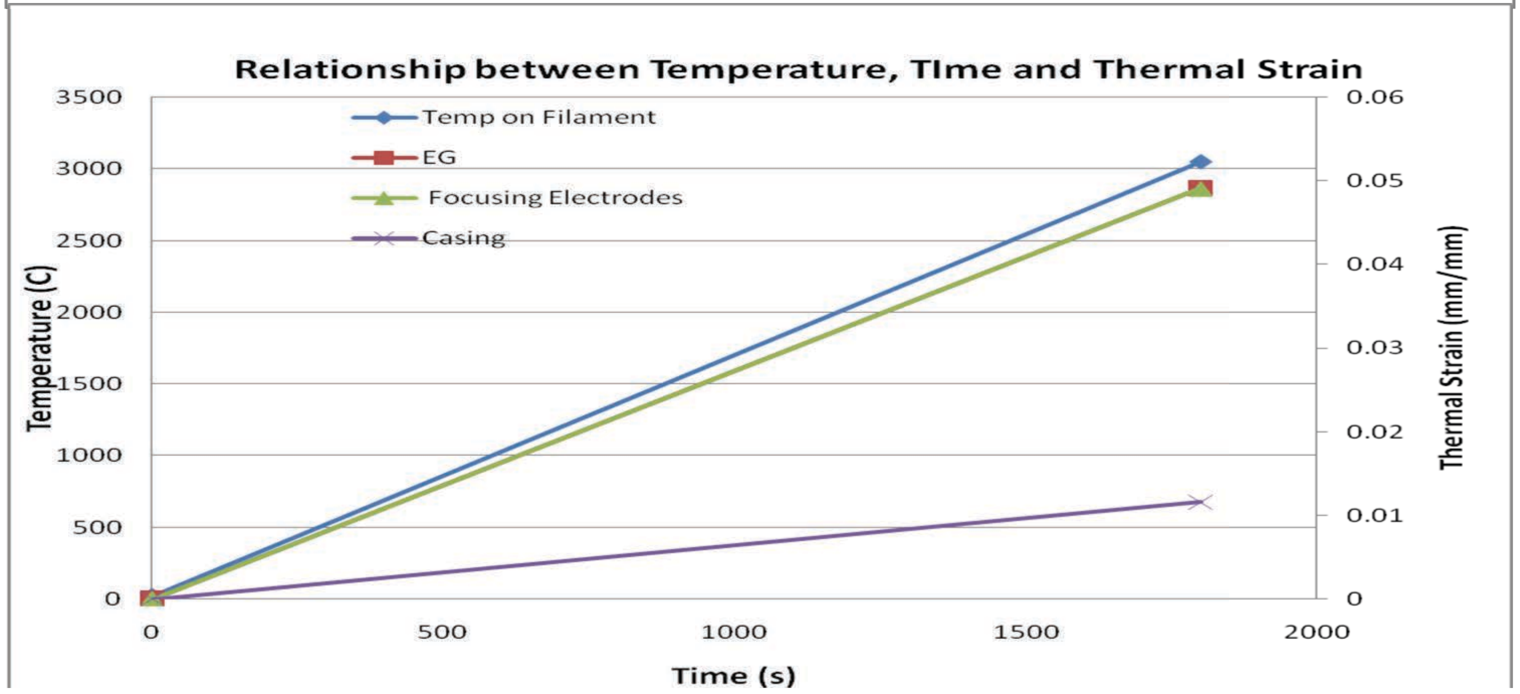
Thermal Analysis of the Gun



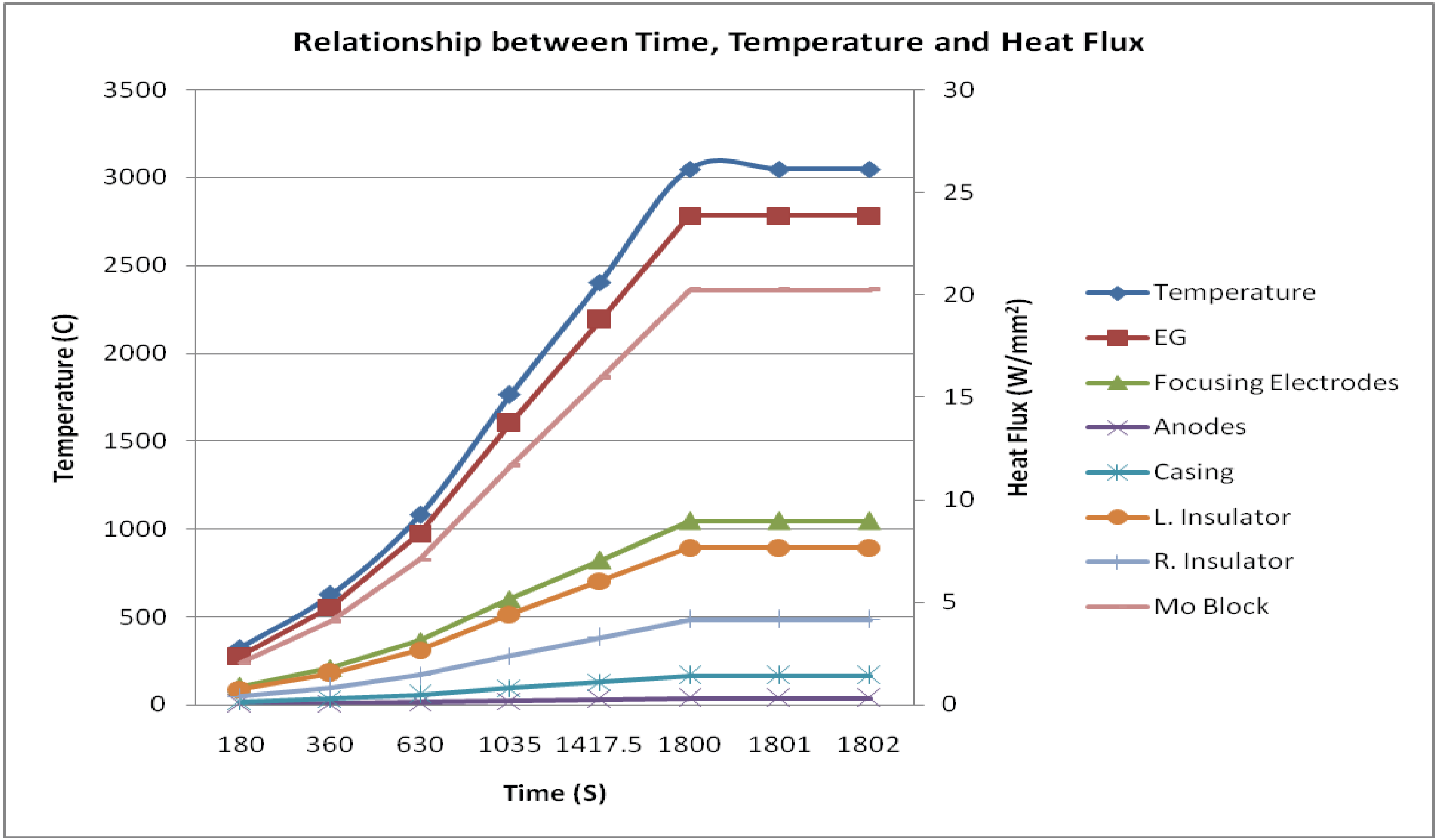


Thermal Analysis





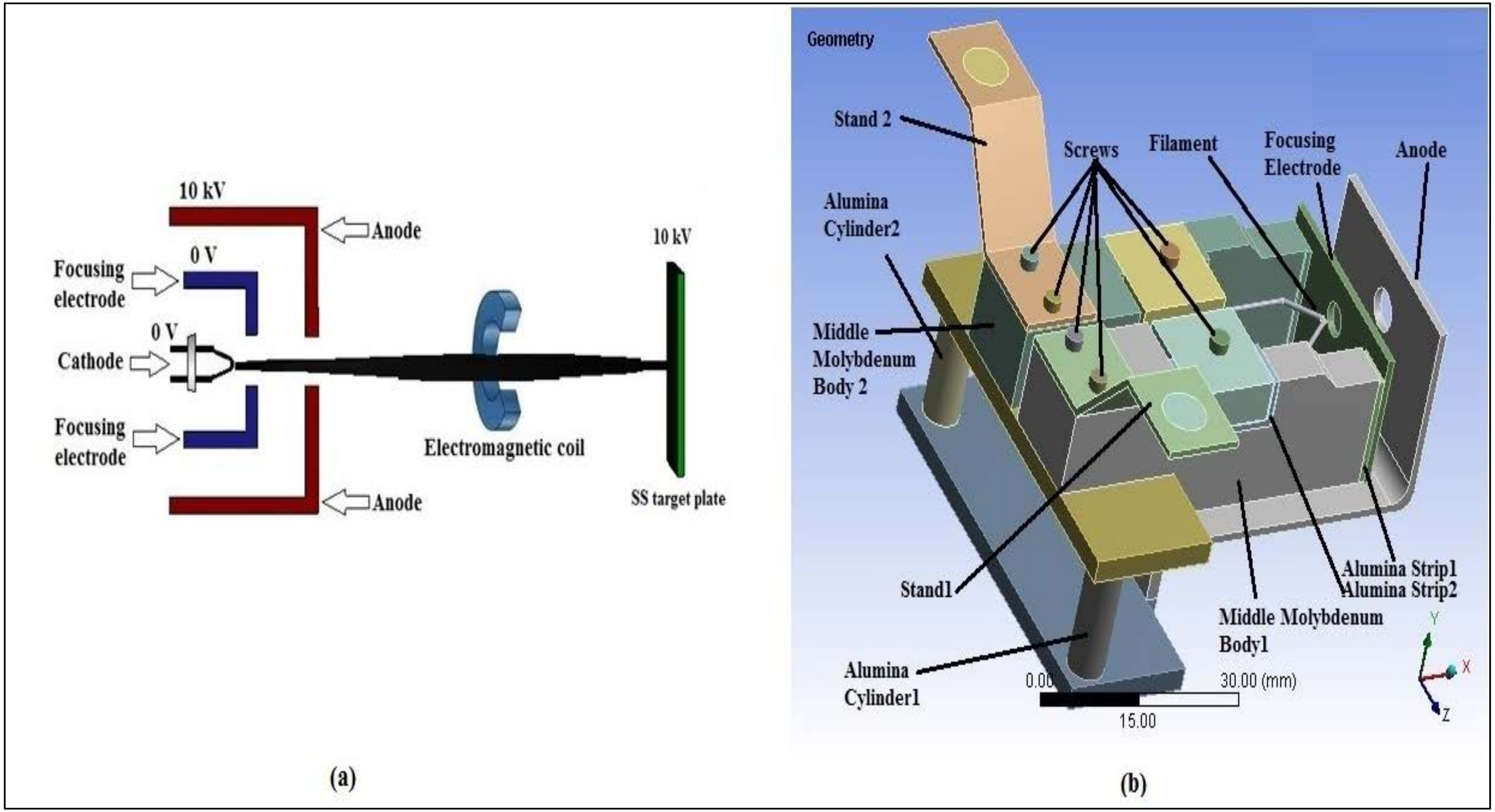
Thermal analysis



Summary of thermal analysis

Contents	Temperature C^o		*Heat Flux W/mm^2*
	Minimum	Maximum	Maximum
Electron Gun	60	3052.8	23.851
Focusing electrode	1703.4	2959.8	8.9687
Anode	313.71	330.22	0.3133
Casing	405.65	427	1.404
Alumina	426	2204.5	7.6572
Alumina Holder	358.29	450	0.38761
Molybdenum block and Clamp	1367.2	3048.6	20.235
Alumina insulation strip on tight clamp	694.58	2712.3	1.0862

2. Hairpin Source/Point Beam Electron Gun

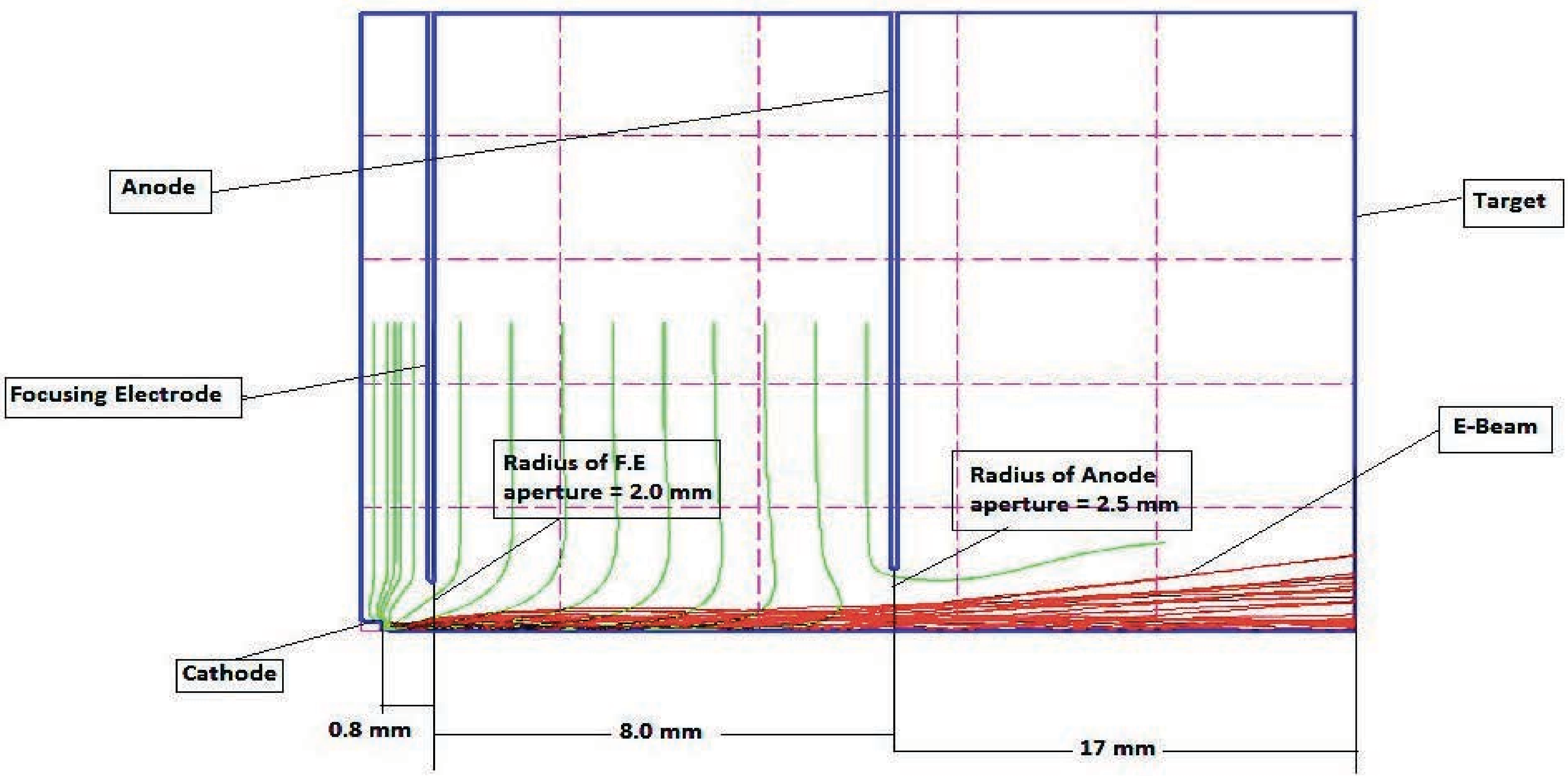


(a) Two dimensional schematic view of the gun with electromagnetic coil and target, and (b) Three dimensional model of the gun.

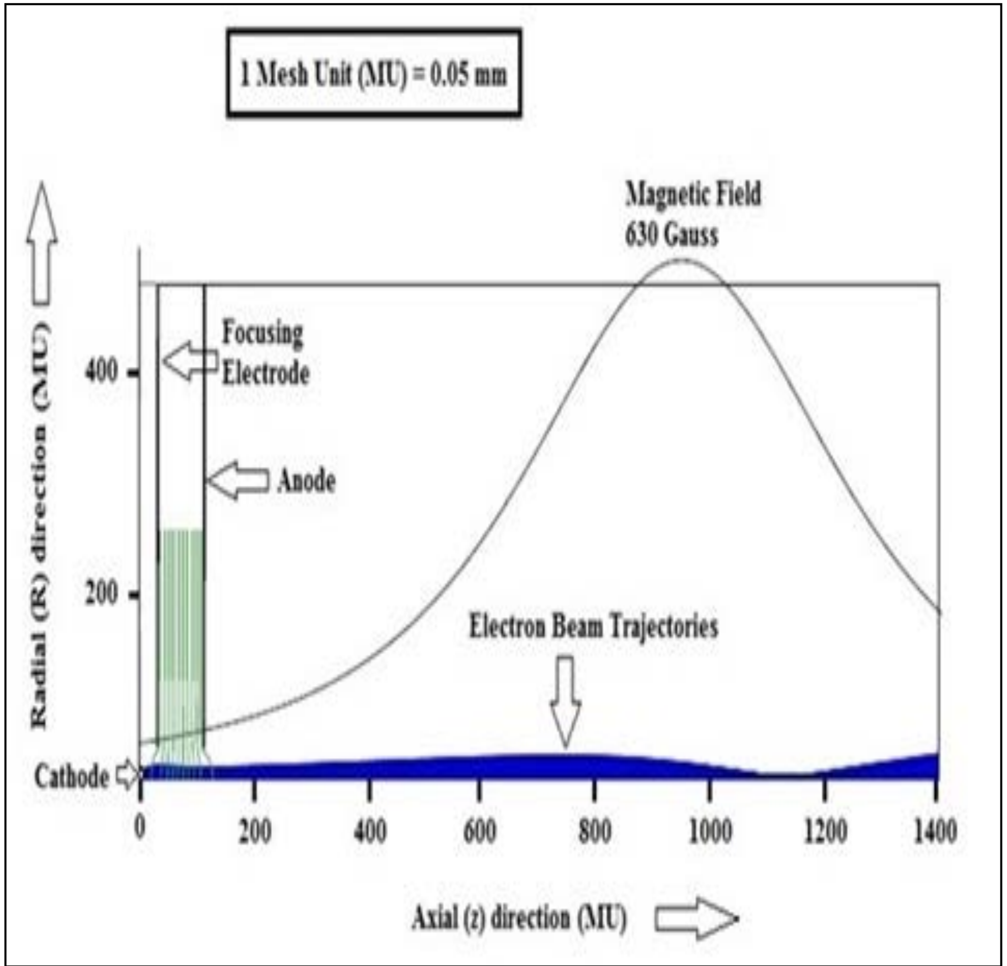
Parameters for beam optimization

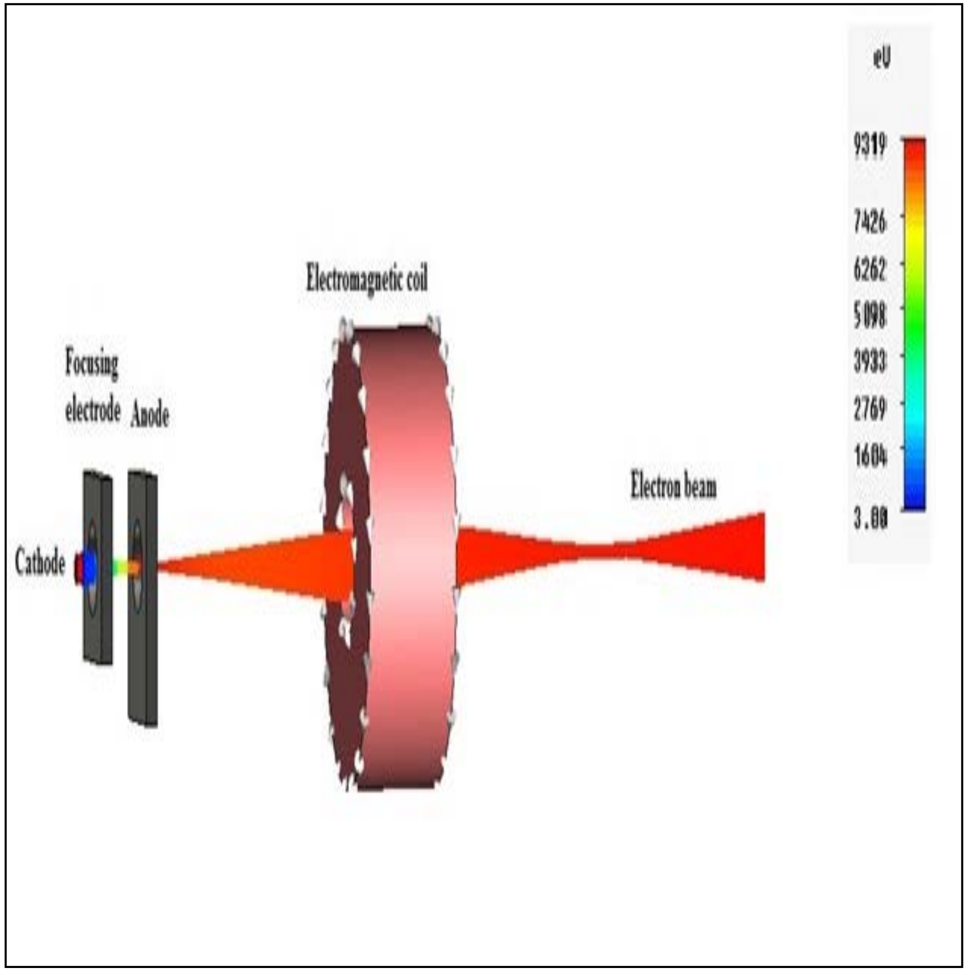
Parameters	Values
Cathode potential (V)	0
Focusing electrode potential (V)	0
Anode (kV)	10
Cathode- anode spacing (mm)	5.1
Cathode - focusing electrode spacing (mm)	1.0
Anode hole diameter (mm)	3.1
Focusing electrode hole diameter (mm)	3.2
Magnetic field (Gauss)	630

EGUN Simulation of the Gun



Beam trajectories in the Magnetic Field

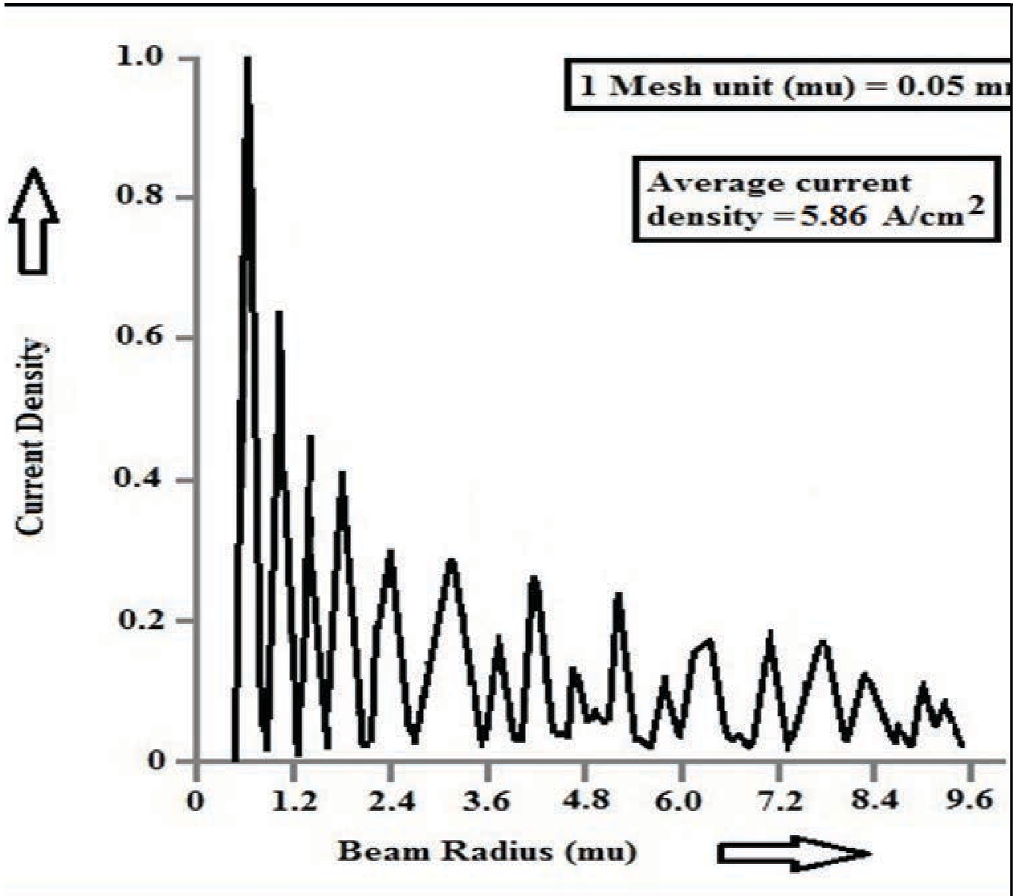


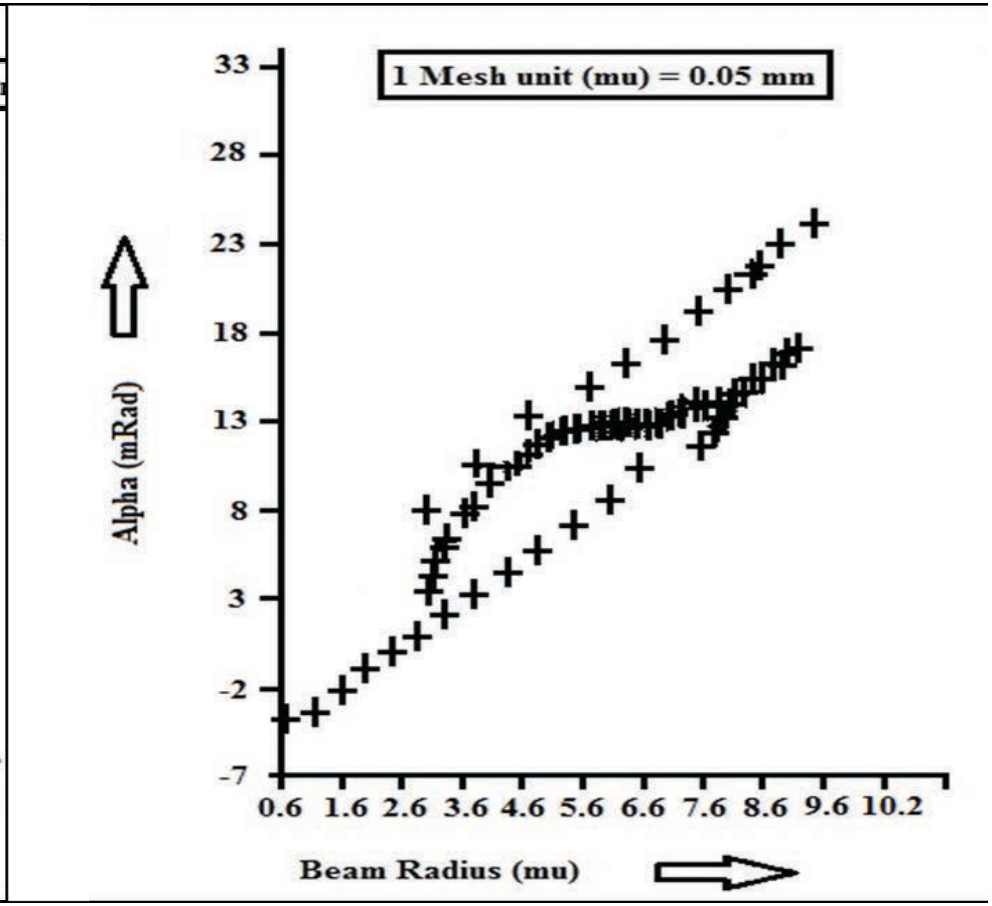


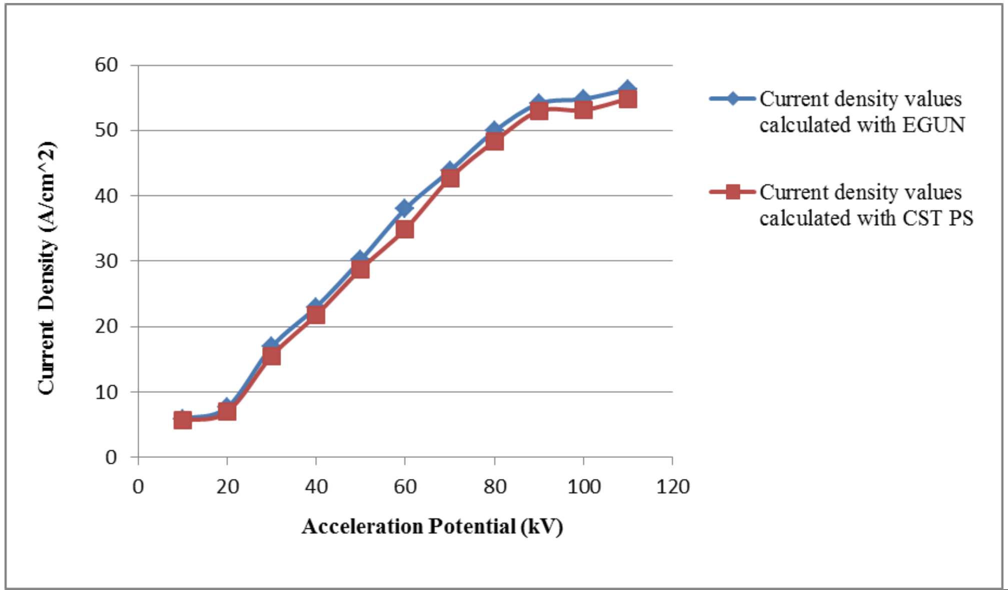
Two dimensional (2-D) Plot of beam trajectories.

Three dimensional (3-D) schematic of the gun and its convergence with the coil.

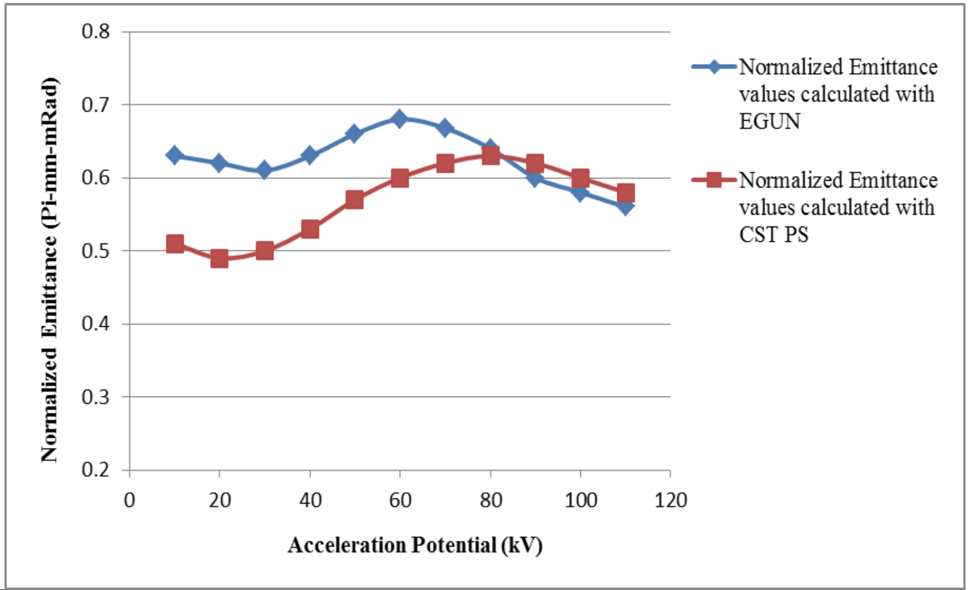
Emission Characteristics of the Assembly



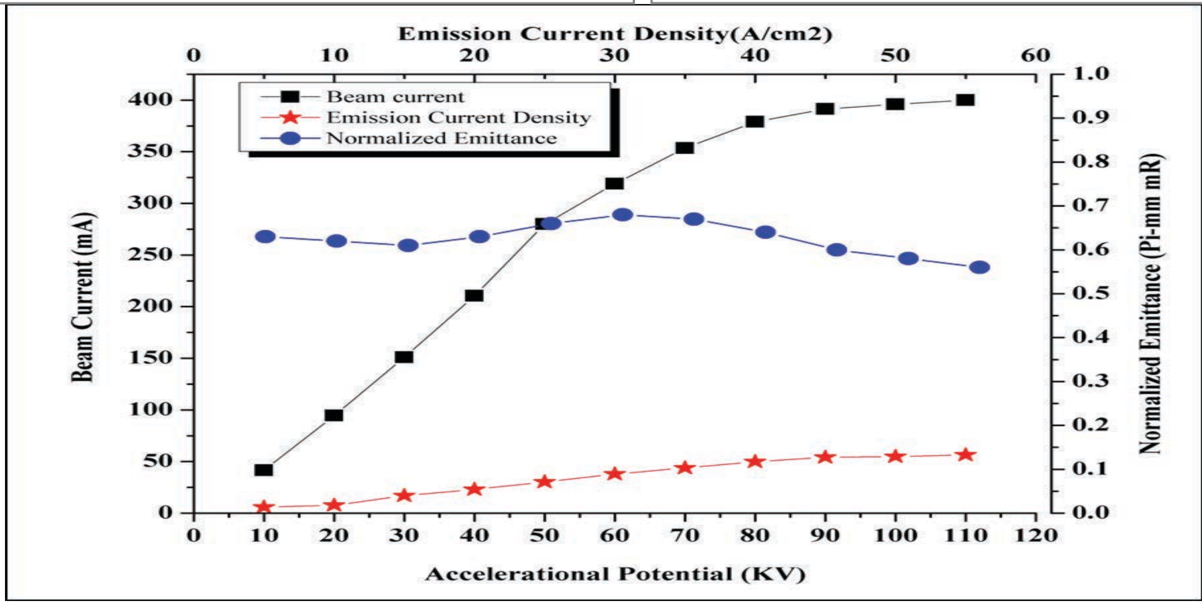




Current Density (A/cm^2)
0
10
20
30
40
50
60
0
20
40
60
80
100
120
Acceleration Potential (kV)
Current density values calculated with EGUN
Current density values calculated with CST PS



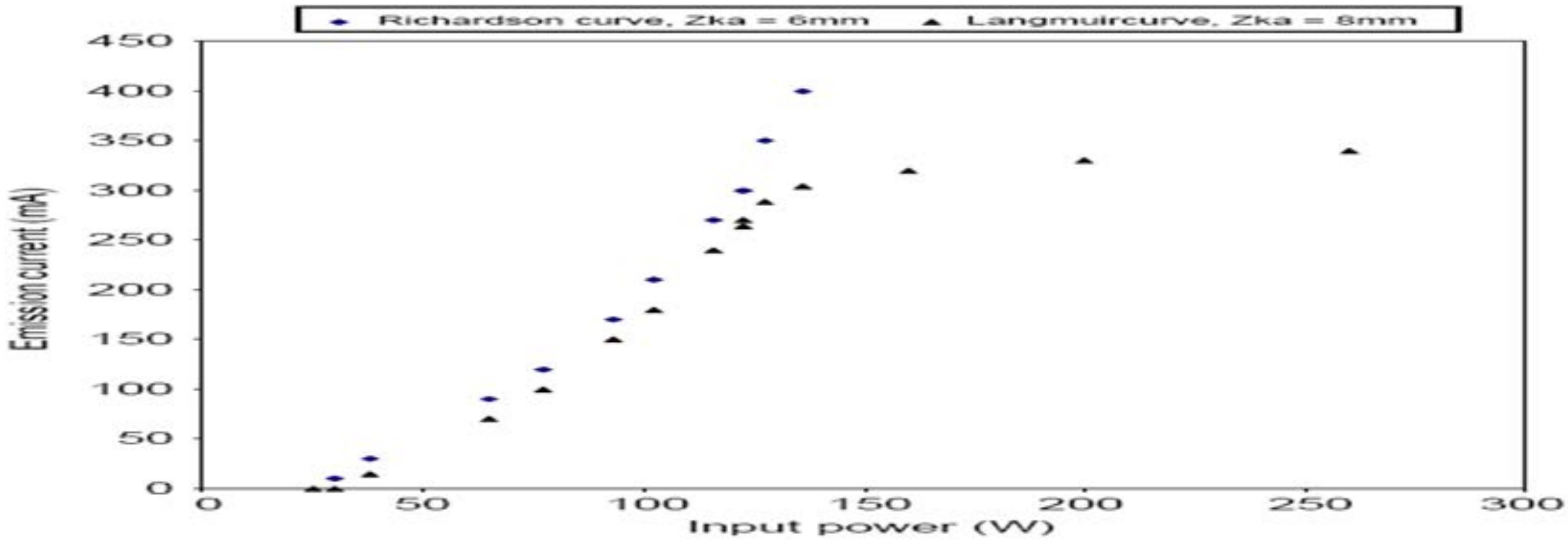
Normalized Emittance (Pi-mm-mRad)
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
20
40
60
80
100
120
Acceleration Potential (kV)
Normalized Emittance values calculated with EGUN
Normalized Emittance values calculated with CST PS



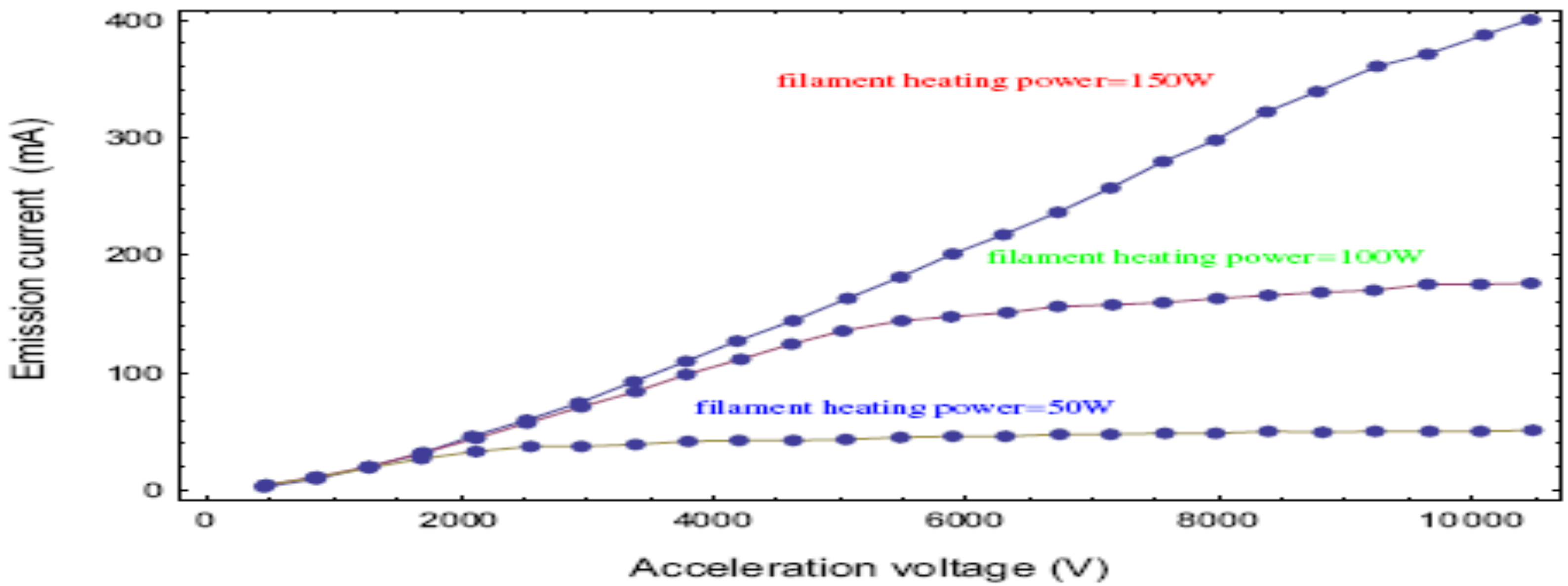
Emission Current Density(A/cm2)
0
10
20
30
40
50
60
Beam current
Emission Current Density
Normalized Emittance
Beam Current (mA)
0
50
100
150
200
250
300
350
400
Normalized Emittance (Pi-mm mR)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
10
20
30
40
50
60
70
80
90
100
110
120
Accelerational Potential (KV)

Test Results of Hairpin source EG

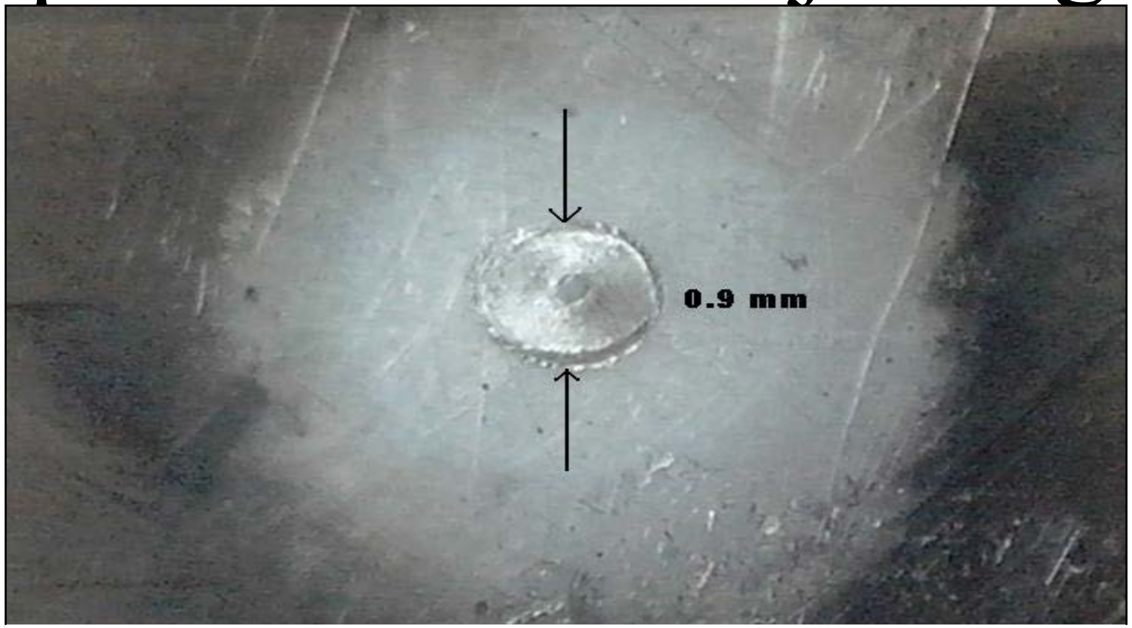
- **Emission Characteristics**

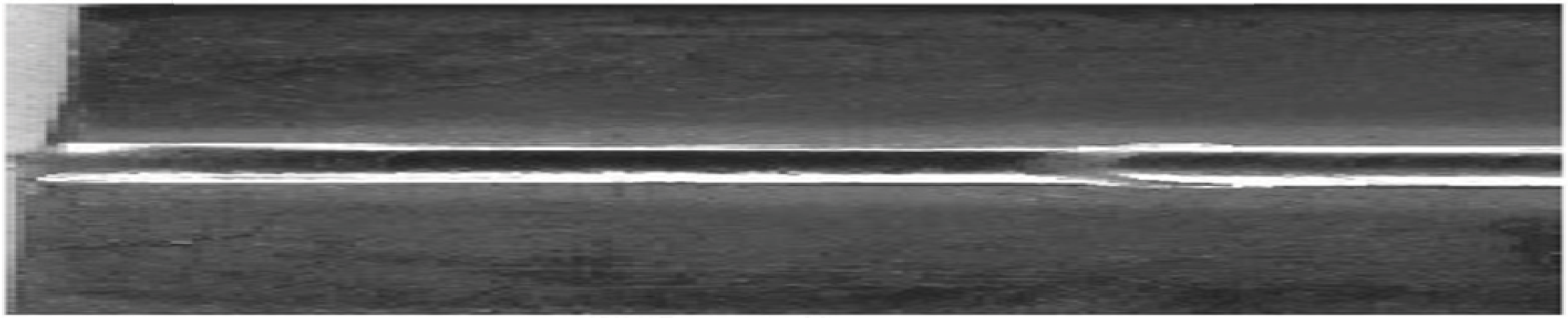


Behavior of Electron Gun at different anode to filament heights.

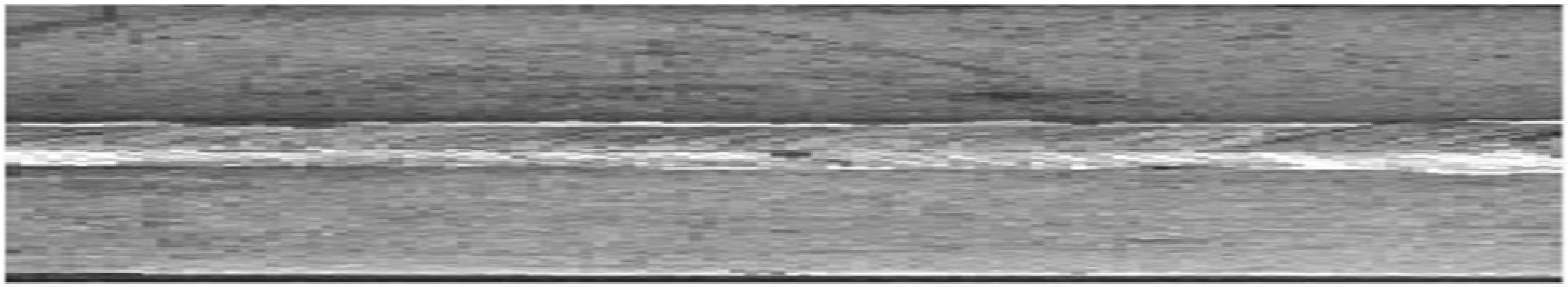


Beam profile at SS and joining of metals





SS welding



Al Welding

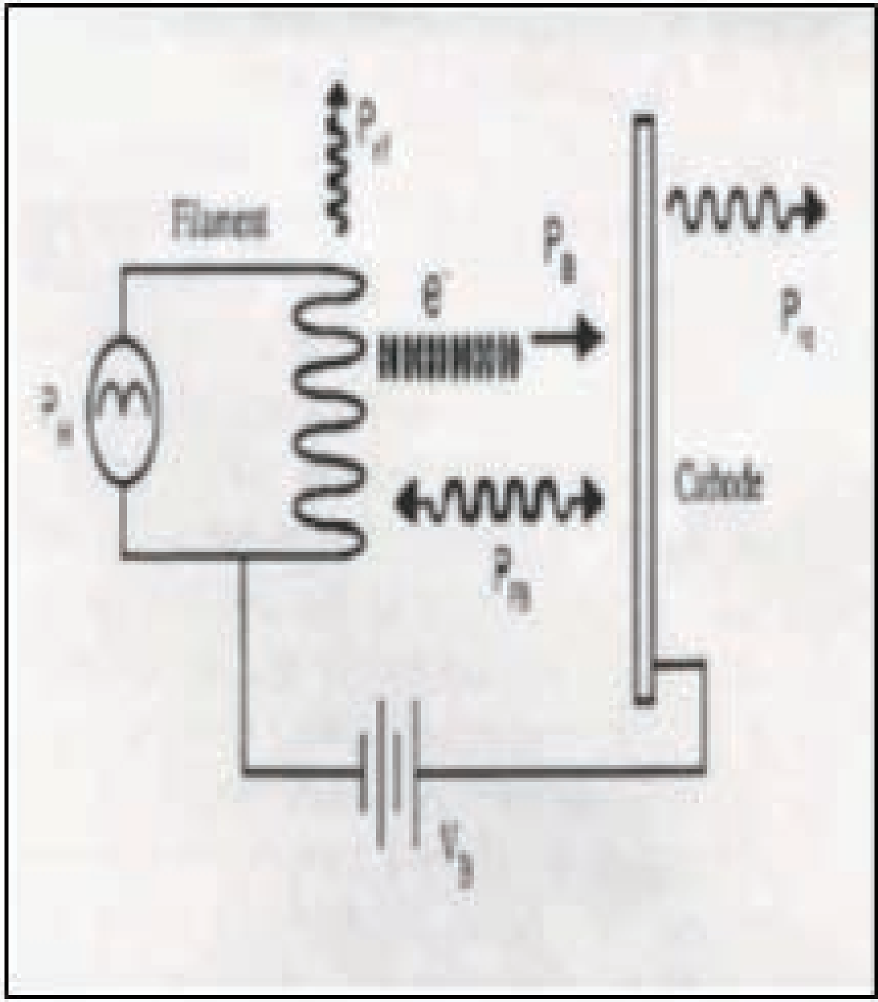
Results

Parameters	Simulated values EGUN	Simulated values CST	Measured values
Beam diameter (mm)	0.85	0.96	0.90
Beam convergence distance (mm)	60	60	60
Beam current (mA)	41.5	41.5	42
Current density (A/cm^2)	5.86	5.60	5.35
Power density (W/cm^2)	5.86×10^4	5.6×10^4	5.35×10^4

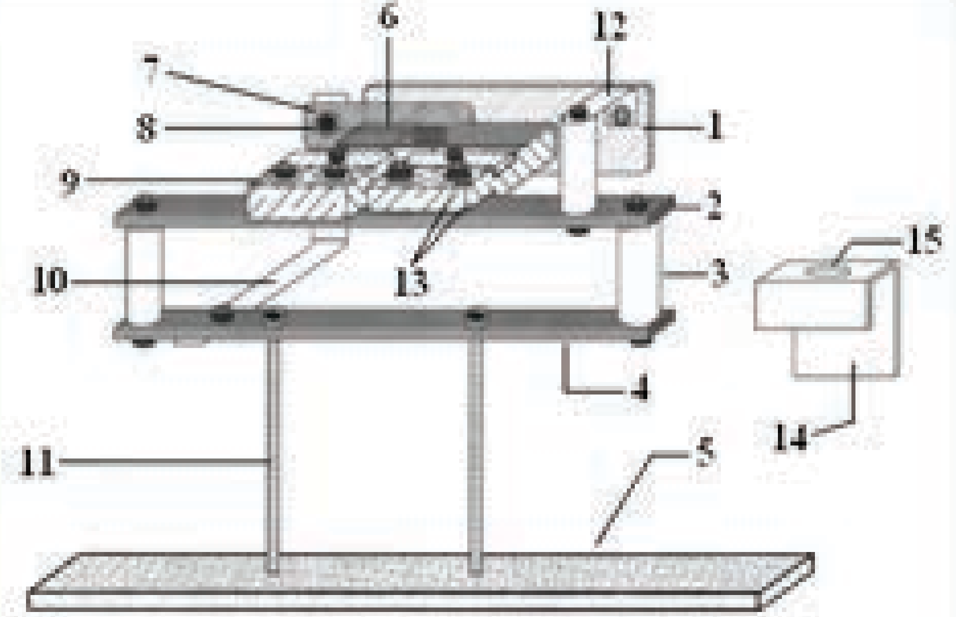
Specifications of Hairpin Source Electron Gun

Parameters	Characteristics
Gun type	Thermionic hairpin
Cathode	Tungsten wire of 0.7 mm diameter
Acceleration potential	10 kV
Beam current	42 mA
Emission current density	32.96 A/cm^2
Power density	$5x\ 10^5$ W/cm^2
Beam emittance	1.1 Pi mm-mRad
Perveance	10^{-5} $A/V^{3/2}$

3. Strip source electron beam gun



Schematic view of an indirectly heated cathode model



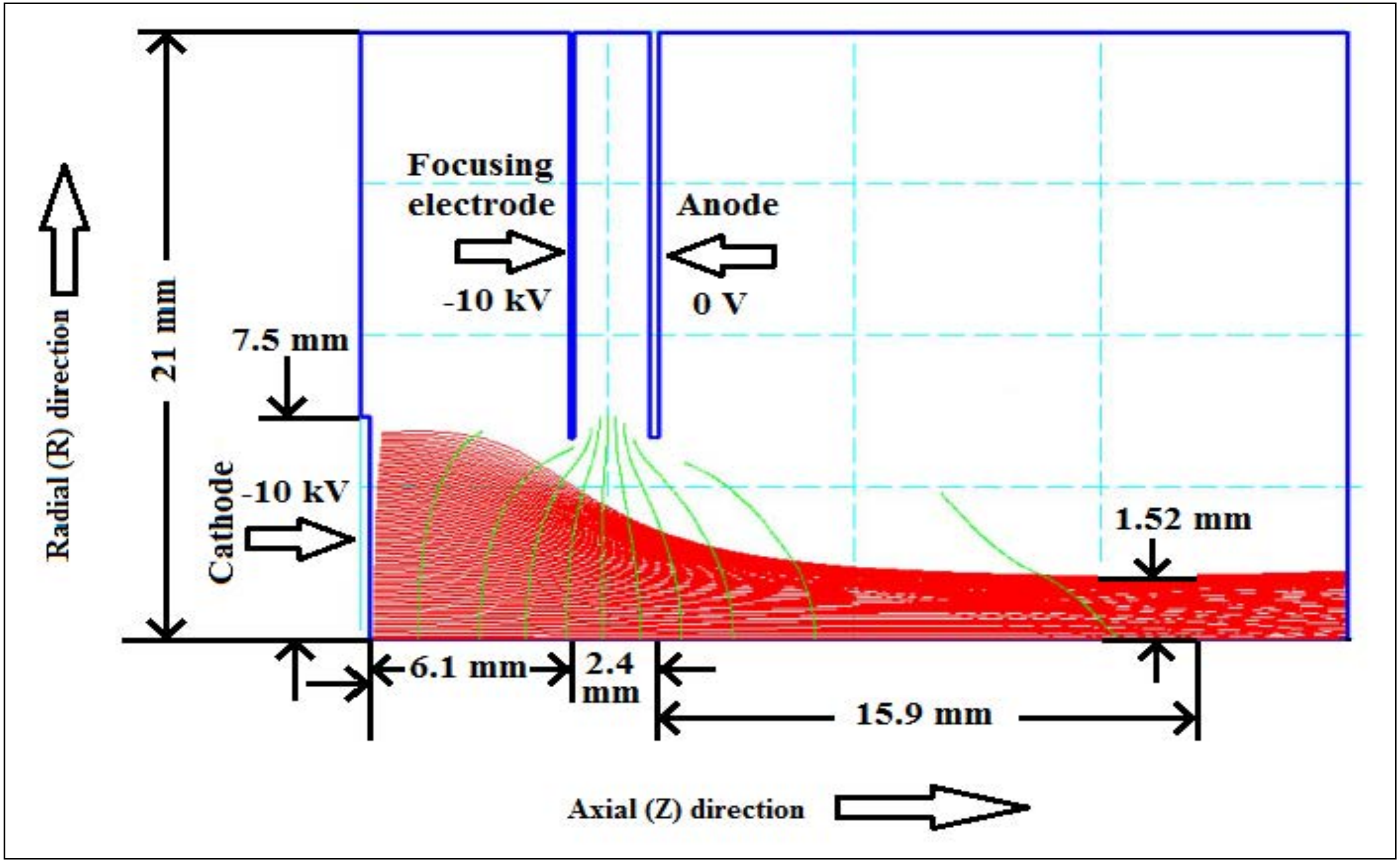
(1) Anode (2) Mounting Bar (3) Locating Insulator (4) Support Bar (5) Base Plate (6) Focusing Electrode (7) Cathode (8) Auxilary Cathode (9) Blocks (10) (10) Cathode Support (11) Screws (12) Anode Support (13) Flanged Insulators (14) Projected view of focusing electrode (15) Slit

Schematic view of the strip source electron gun

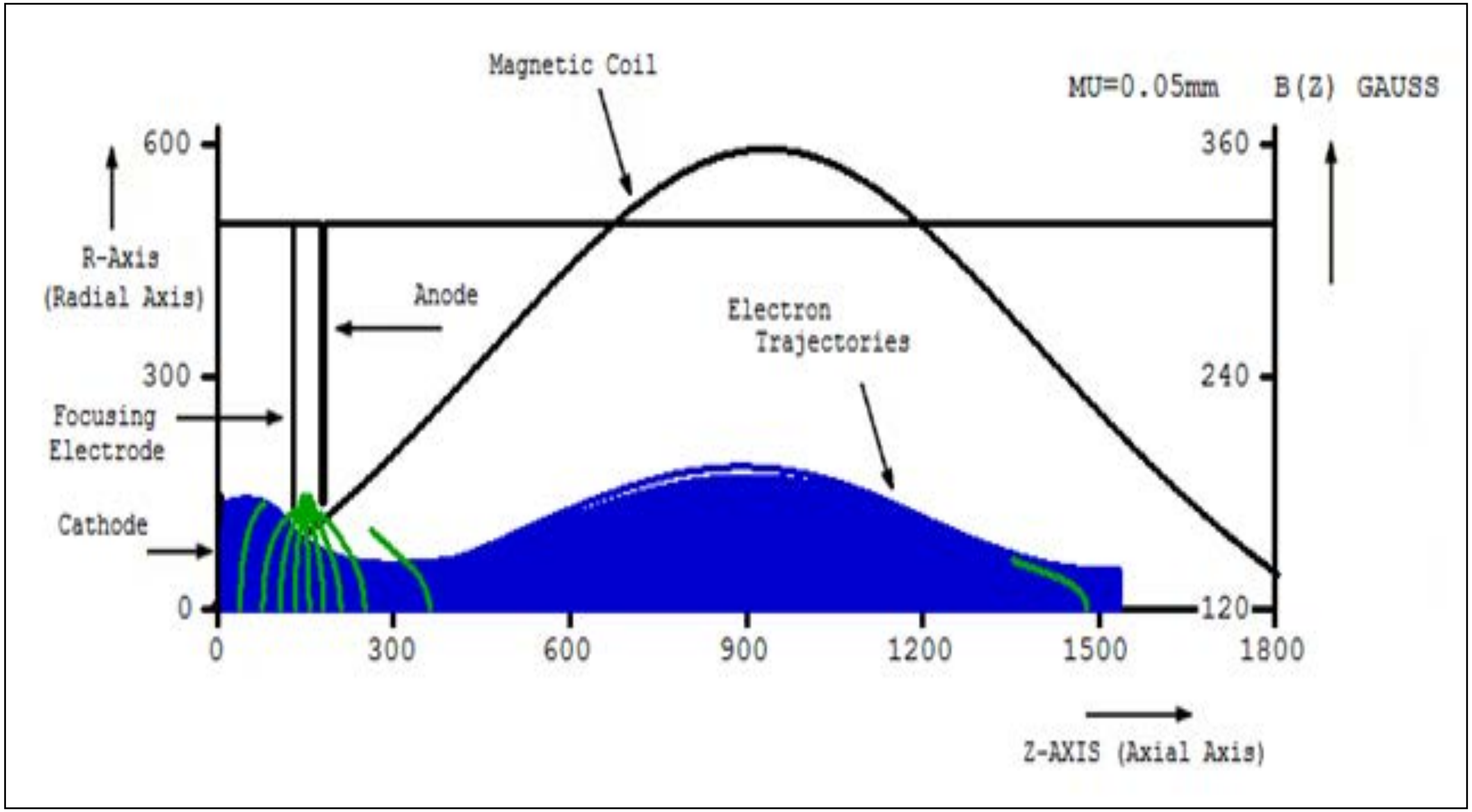
Parameters fixed for beam optimization

Parameters	Optimized gun configuration
Cathode to focusing electrode distance (mm)	6.1
Cathode to anode distance (mm)	8.5
Focusing electrode to anode distance (mm)	2.4
Focusing electrode slit spacing (mm)	13.35
Anode hole diameter (mm)	13.4
Acceleration potential (kV)	10

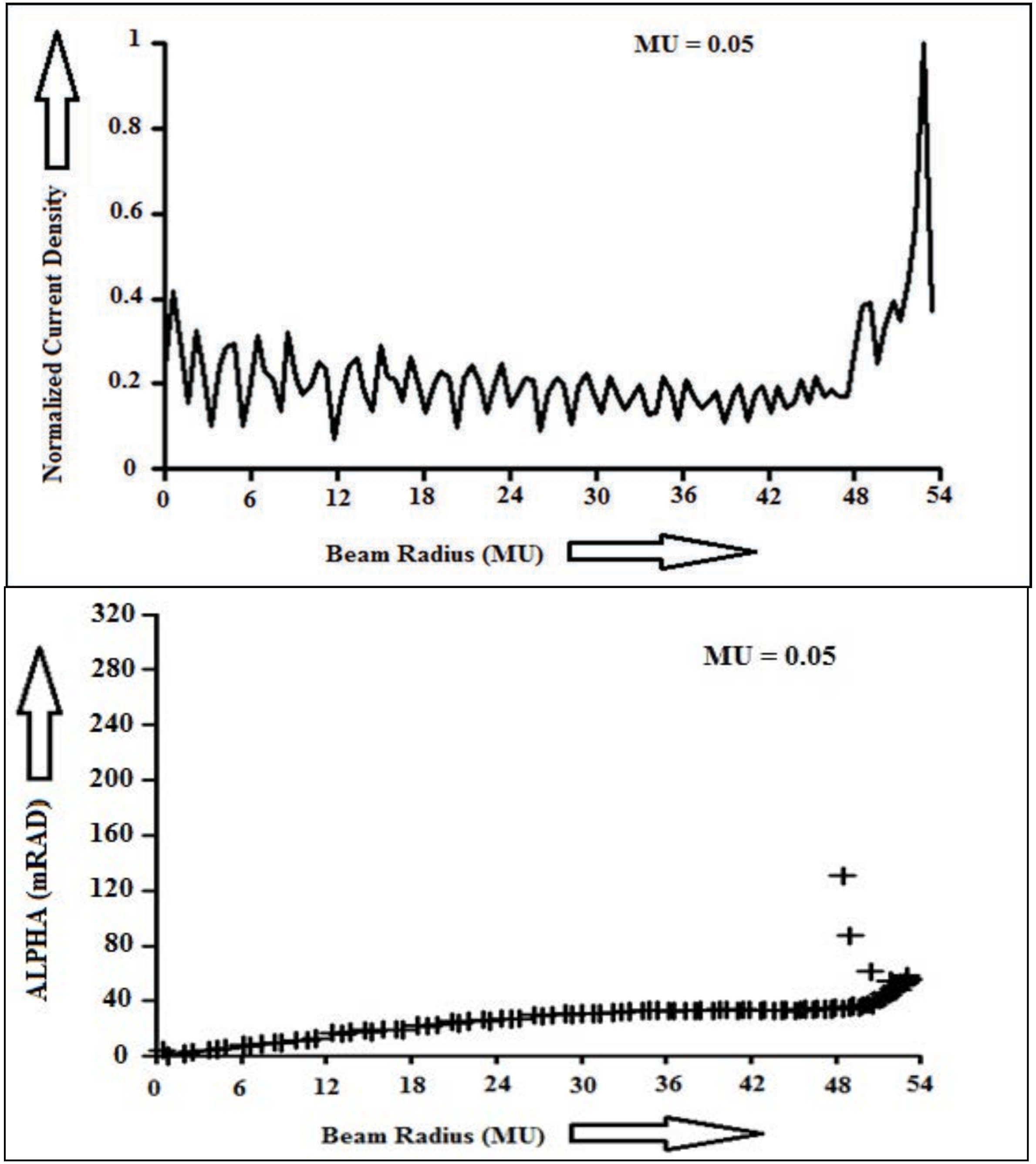
Designing and simulation of the gun



Electromagnetic focusing of the Beam



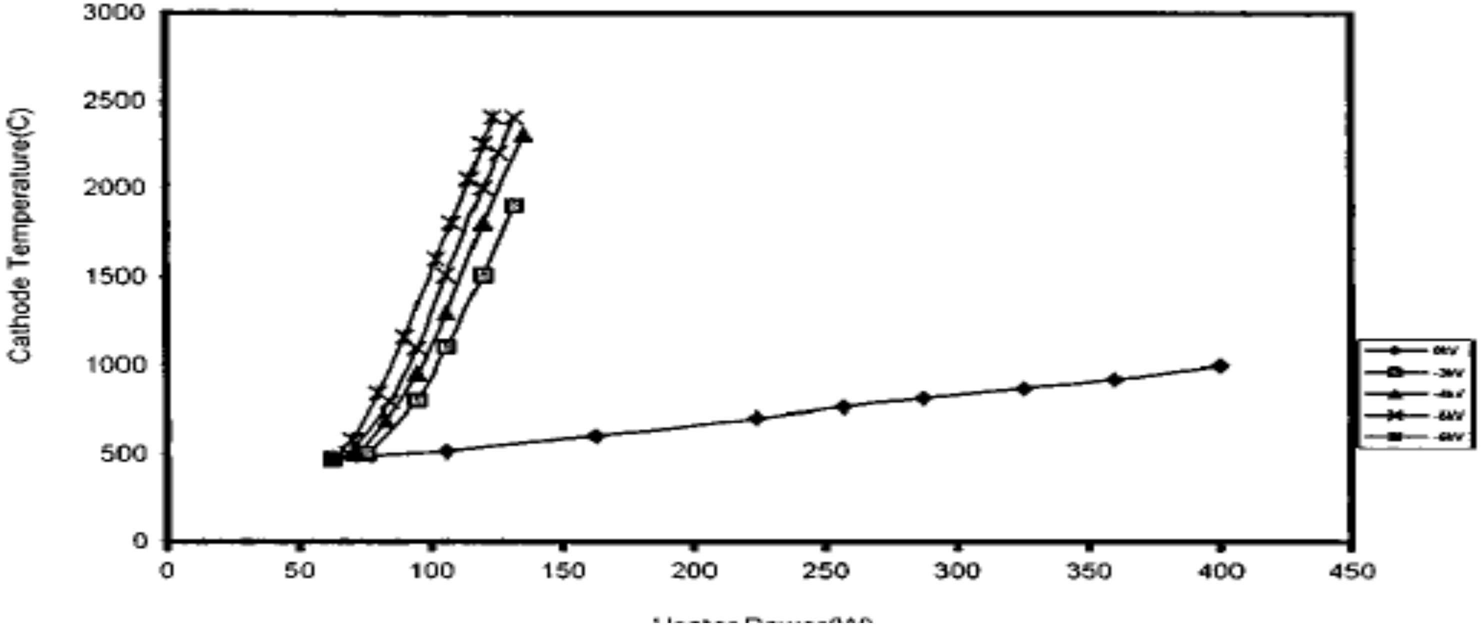
Emission Parameters of the Gun

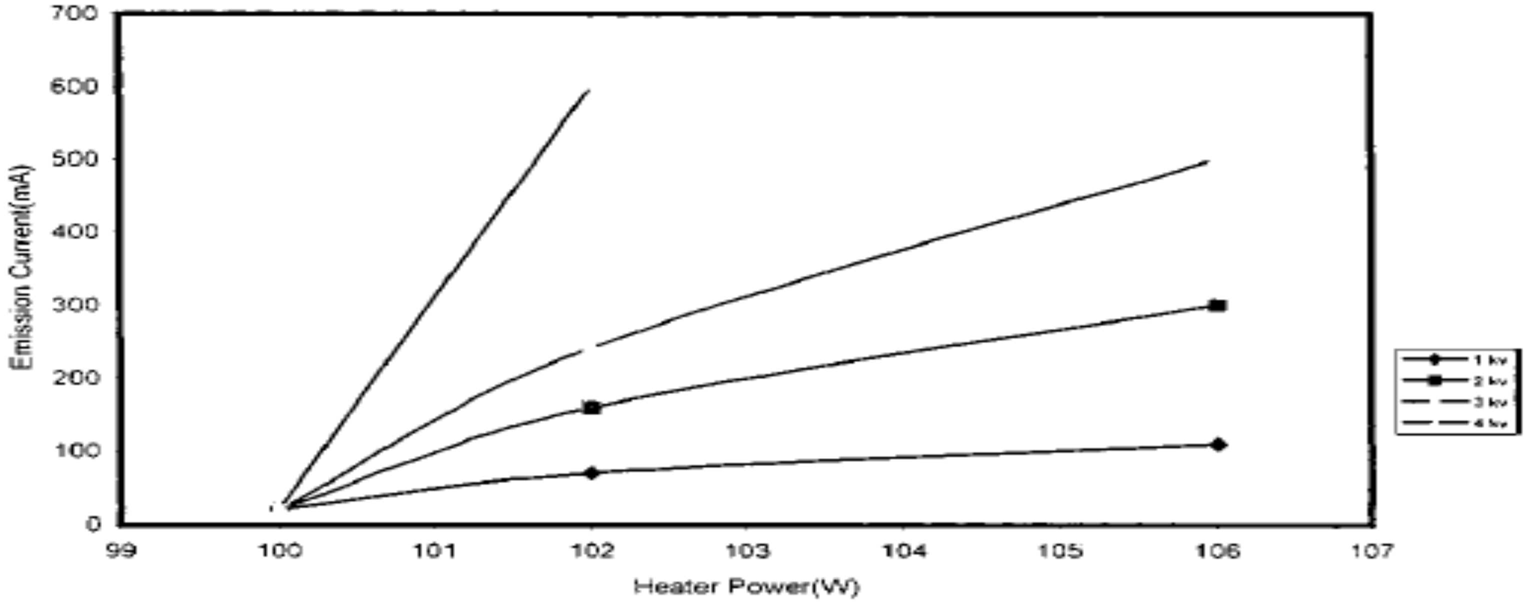


Emission parameters of focusing results with experimental results.

Parameters	Electrostatic focusing results	Experimental results	Electromagnetic focusing results
Magnetic Field (Gauss)	-	-	350
Beam Focusing Distance from Anode (mm)	15.9	15.9	68
Beam Waist diameter at beam focusing distance (mm)	3.04	3.15	4.0
Beam Current (Ampere)	1.12	1.12	1.12
Average Current Density (A/cm^2)	1.15	1.02	5.04
Power Density (A/cm^2)	1.15×10^4	1.02×10^4	5.04×10^4
Total Emittance (π mm mRad)	208.8	-	162.3
Normalized Emittance (π mm mRad)	41.5	-	31.72

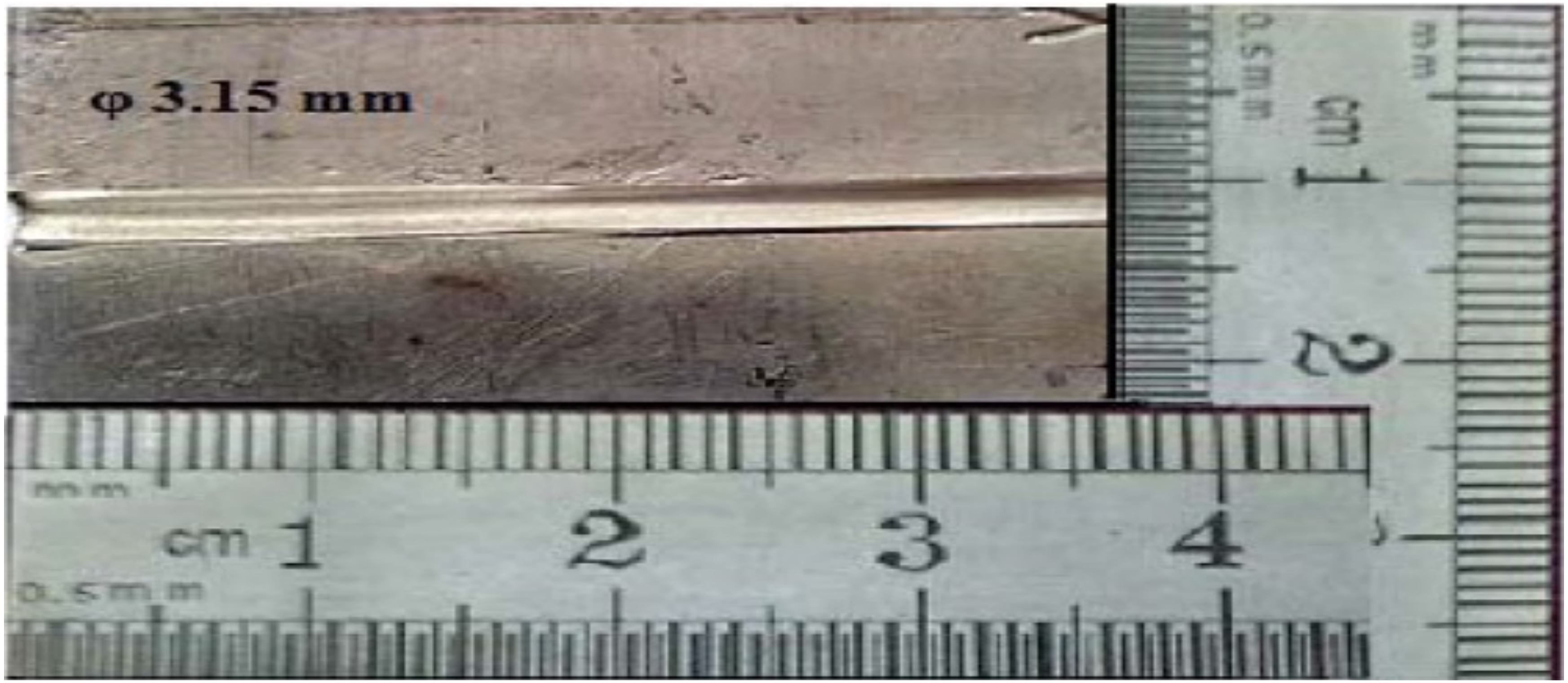
Test Results of the Assembly





Vacuum 85 (2011) 654–656

Experimental validation



Conclusions

- The guns are without any biasing and have flat geometry of the electrodes. Thermionic electron gun is economical, easy and simple to produce electron beams.

- EGUN & CST soft wares are comprehensive and user friendly software to optimize the electron beam trajectories both for electrostatic & magnetic fields.

- ANSYS software is good for modeling and then thermal analysis of E-gun to keep each gun component under permissible temperature limit for long duty cycle.

References

Vacuum 101 (2014) 157–162

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Optimization of the hairpin-source electron gun using EGUN

Munawar Iqbal [a,*], Ghalib ul Islam [a], Safa Saleem [a], W.B. Herrmannsfeldt [b]

[a] *Centre for High Energy Physics, University of the Punjab, Lahore, Pakistan*
[b] *Stanford Linear Accelerator Center, Stanford University, Palo Alto, CA, USA*

ARTICLE INFO

Article history:
Received 30 March 2013
Received in revised form
25 July 2013
Accepted 8 August 2013

Keywords:
Emission density
Power density
Beam convergence
EGUN

ABSTRACT

We present a comparison of the experimental and simulated results of the thermionic hairpin-source, electron beam assembly using the SLAC electron beam trajectory program (EGUN). The gun was optimized for maximum emission current density and beam convergence in the post anode region. Therefore, by optimizing different parameters, an emission current density of 32 A/cm^2 with maximum beam convergence of 0.9 mm was obtained. This corresponds to a power density of 3.29×10^5 W/cm^2 at the focus point. As this was accomplished without the aid of magnetic focusing, the assembly was much simplified. The gun can now be used for electron devices and accelerator technology which require high current and power densities.

REVIEW OF SCIENTIFIC INSTRUMENTS **85**, 066106 (2014)

Simulation and test of a strip source electron gun

Munawar Iqbal,[1,2,a)] G. U. Islam,[1] I. Misbah,[1] O. Iqbal,[1] and Z. Zhou[2]
[1]*Centre for High Energy Physics, University of the Punjab, Lahore 45590, Pakistan*
[2]*Institute of High Energy Physics, Chinese Acedemy of Sciences, Beijing 100049, China*

(Received 2 December 2013; accepted 1 June 2014; published online 11 June 2014)

We present simulation and test of an indirectly heated strip source electron beam gun assembly using Stanford Linear Accelerator Center (SLAC) electron beam trajectory program. The beam is now sharply focused with 3.04 mm diameter in the post anode region at 15.9 mm. The measured emission current and emission density were 1.12 A and 1.15 A/cm^2, respectively, that corresponds to power density of 11.5 kW/cm^2, at 10 kV acceleration potential. The simulated results were compared with then and now experiments and found in agreement. The gun is without any biasing, electrostatic and magnetic fields; hence simple and inexpensive. Moreover, it is now more powerful and is useful for accelerators technology due to high emission and low emittance parameters. [http://dx.doi.org/10.1063/1.4883175]

Nuclear Instruments and Methods in Physics Research A 641 (2011) 1–4

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Electrostatic focusing of directly heated linear filament gun using EGUN

Munawar Iqbal [a,*], M.A.K. Lodhi [a], Zahid Majeed [b], Dimitri Batani [c]

[a] Department of Physics, Texas Tech University, Lubbock, TX 79409, USA
[b] National Engineering and Science Commission, Islamabad, Pakistan
[c] Dipartimento di Fisica, Università degli Studi di Milano Bicocca, Italy

ARTICLE INFO

Article history:
Received 29 November 2010
Received in revised form
17 February 2011
Accepted 19 February 2011
Available online 29 March 2011

Keywords:
Line source
EGUN
Minimum beam spread
Axial focusing distance

ABSTRACT

This paper presents the optimization of a line source rectangular electron gun using electrostatic focusing. We optimized the gun by shaping the configuration of its electrodes in order to achieve the desired focusing characteristics, namely maximum focusing distance and minimum beam spread. The optimization has been carried out using the software EGUN. We have also simplified the gun design using only one focusing electrode at the same potential as that of the cathode and by avoiding magnetic focusing field, separate focusing electrodes and additional power supply, thus minimizing the cost without any loss in its accuracy and efficient performance. This gun with the optimum configuration was used in actual experiment and the results of the simulation were compared with the experimental measurements.

Optik 127 (2016) 1905–1908

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Simulation and test of a thermioic hairpin source DC electron beam gun

Ghalib ul Islam[a], Abdul Rehman[a], Munawar Iqbal[a,b,*], Z. Zhou[b]

[a] Centre for High Energy Physics, University of the Punjab, Lahore 54590, Pakistan
[b] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 13 May 2015
Accepted 17 November 2015

Keywords:
Electron gun
Acceleration potential
Current density
Emittance
EGUN

ABSTRACT

A hairpin source electron gun was simulated and tested for its emission characteristics. We calculated beam emittance 4.3 π-mm-mR and average current density 5.80 A/cm^2 which corresponds to power density 5.80×10^4 W/cm^2 with 0.9 mm of beam waist diameter at 113 mm in the post anode region. The simulation and test results were found in agreement at 10 kV of acceleration potential. We also calculated the variation of current density and emittance with acceleration potential up to the saturation limit of the gun (100 kV). The gun is useful for electron optical devices, electron accelerators and deep weld joints of refractory metals.

REVIEW OF SCIENTIFIC INSTRUMENTS **84**, 056113 (2013)

: Thermal analysis of the long line source electron gun

M. Iqbal,[1,a)] A. Wasy,[2] and M. A. K. Lodhi[3]
[1]*Centre for High Energy Physics, University of the Punjab, Lahore 45590, Pakistan*
[2]*Department of Mechanical Engineering, Changwon National University, Changwon 641-773, South Korea*
[3]*Department of Physics, Texas Tech University, Lubbock, Texas 79409, USA and University of Management and Technology, Lahore, Pakistan*

(Received 8 April 2013; accepted 20 May 2013; published online 29 May 2013)

We performed thermal analysis for our previously reported [M. Iqbal, K. Masood, M. Rafiq, M. A. Chaudhry, and F. Aleem, Rev. Sci. Instrum. **74**, 4616 (2003)], long linear filament electron gun assembly using ANSYS software. The source was set under a thermal load of 3000 °C, to evaluate temperature distribution, thermal strain, and heat flux at various components of the gun. We calculated the maximum heat flux (9.0 W/mm^2) that produced a thermal strain of 0.05 at the focusing electrodes. However, the minimum value of the heat flux (0.3 W/mm^2) was at the anode electrodes which correspond to a negligible thermal strain. The gun was validated experimentally showing a uniform cross section of the beam at the molybdenum work plate comparable to the size of the filament. Our experimental and theoretical results are in agreement. The gun had been in continuous operation for several hours at high temperatures without any thermal run-out. *© 2013 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4808331]

Thanks for your Patience