Design of a 200keV high pulse current electron beam facility

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DESIGN OF A 200KEV HIGH PULSE CURRENT ELECTRON BEAM FACILITY *

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Abstract

In the paper, design of a 200keV high pulse current electron beam facility is introduced. Physical parameters of the beam have been selected to satisfy the plasma experiment's need. LaB_6 has been used as cathode material for its desirable qualities. Temperature distribution simulation in vacuum chamber has been finished. Because the maximum working temperature in the system is about 2400^o C, grid is made of Molybdenum which is heat-resistant. In order to get high pulse current and line shaping electron beam, shape of electrodes has been optimized. Electric field distribution and process of electron beam emission have been simulated with considering space charge effects. Ceramic flange's electrics and mechanics properties have also been analyzed. Exit window is made of titanium with 40μm thickness. During passing through the window, relationship between initial energy and energy loss of the electron beam has been obtained by MC simulation. Assembling of the facility has been finished and some parameters have been measured in testing experiments.

INTRODUCTION

As we know, plasma is by far the most common form of matter, which consists of a collection of free moving electrons and ions. Energy is needed to strip electrons from atoms to make plasma. The energy can be of various origins: thermal, electrical, high energy charged particle beam, laser, etc. In order to make some study about plasma applications in industry, A 200keV High current line shaping electron beam facility has been designed as part of a plasma generator. Fundamental parameters of electron beam are summarized in table 1. Basic scheme of the electron beam facility is shown in Fig. 1. This girded electron gun mainly consists of cathode-grid assembly, anode with rectangular foil window, and so on. For the high voltage power supply of the facility, cascade voltage multiplier has been used.

CATHODE-GRID ASSEMBLY DESIGN

In the facility, cathode with high emission current density is required. Lanthanum hexaboride has been selected as cathode material after comparing the electron emission current density as a function of temperature for LaMo, BaO, tungsten, tantalum, and LaB_6[1]. LaB_6 has many desirable cathode qualities such as high current densities at relatively low temperature, low evaporation rate, long lifetime, and resistance to chemical poisoning in vacuum accidents. Experiments [2] showed that LaB_6 cathode emits over 600A of electrons at an average of $20A/cm^2$ continuously with no observable lifetime limits after about 400h of operation.

Table 1: Design Parameters of Electron Beam Facility

Beam energy	~200keV
Peak current	~15A
Average current	~50mA
Beam power (peak)	~3MW
Beam power (average)	~10kW
Beam cross section (at exit window)	$40\times600mm^2$
Micropulse length	4~10μs
Micropulse periods	4~10ms

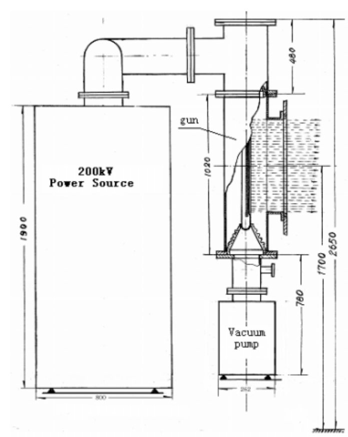

Figure 1: Layout of the Electron Beam Facility.

The cathode is 600mm long, 5mm wide, and it's thickness is 2mm. Large area cathode must be heated indirectly by radiation or electron bombardment because resistance of LaB_6 is too low for direct heating[3]. In the facility, cathode is heated by radiation from heater. The cathode heater consist of two 1mm diameter tungsten filaments clamped in parallel into the connector. When working temperature of tungsten filament is under 2400℃, the heater can work stable and has a long lifetime. Because large area LaB_6 is very brittle, refractory material molybdenum and BN are used to support the cathode.

Since the cathode must operate at temperature around 1300℃ to obtain the desired current density, the facility has been designed to maximize the thermal insulation of

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the cathode. As Fig.2 Shows, one layer of thin molybdenum foil are placed around the whole assembly to act as heat shielding and give a uniform distribution of temperature.

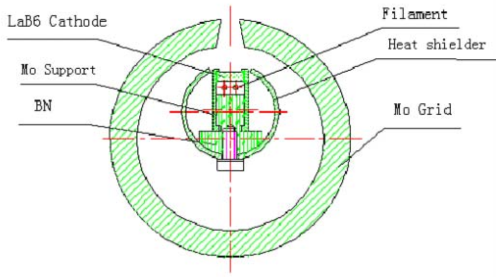

Figure 2: Cross Section of the Cathode-grid Assembly.

Molybdenum has been selected as grid because of it's high melting point 2650 ℃. Considering the stress intensity factor, anode is made of stainless steel[4].

Temperature distribution calculation in the vacuum chamber has been finished using I-DEAS code. Solution shows that when the filaments temperature is about 2350 ℃, temperature of the cathode can reach 1355℃, and the heat shielding 1320℃. In addition, water cooling system is needed because maximum surrounding temperature in the vacuum chamber is about 395℃.

The anode's inside diameter is 244mm, and it's thickness 4mm. The thickness of molybdenum grid is selected 6mm for machining easy.

Because the electron beam cross section $40\times600mm^2$ is needed at the exit window, OPERA-3d code has been used to optimize the beam forming electrodes design. Solution shows that when the grid voltage related to cathode is -50V, Beam emission can be restrained. Electric field distribution in accelerating chamber has been obtained when grid voltage is 200V. The maximum electric field is about 5.4MV/m and average field 2.1MV/m. When the cathode working temperature is 1355℃, Beam emission process has been simulated with considering space charge effects[5]. As Fig.3 shows, about 42mm width beam can be gotten at the metal foil window. Current density distribution is shown in Fig.4. Solution indicates that about 14.95A beam current can be obtained under this condition. The simulation also shows that higher beam current can be gotten by adjusting the grid voltage.

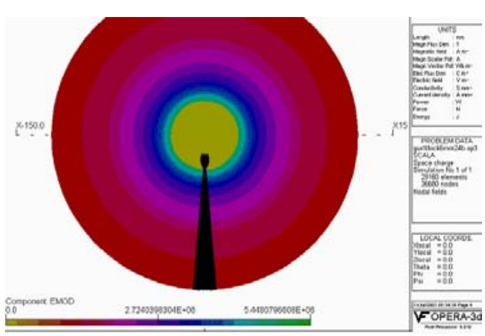

Figure 3: Simulation of Electron Beam Emission.

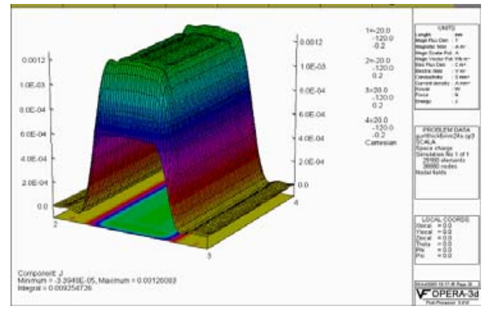

Figure 4: Current Density Distribution at Exit Window.

CERAMIC FLANGE DESIGN

Al_2O_3 ceramic has been chosen as flange material, Which is located between anode and grid. One side of the flange is in vacuum and another is in insulation oil.

One side of the ceramic flange is designed as wave shaping and another is smooth to avoid electric field breakdown along the surface of flange (see Fig. 5). Electric properties has been studied by making a model using OPERA-3d. Solution indicates that average electric field along the flange is 0.85MV/m in vacuum chamber, and 0.78MV/m in the oil. Mechanics properties of the flange has also been studied with ANSYS code. In vacuum chamber a pressure less than 5×10^{-5} Pa has been obtained. Simulation shows that maximum deformation variable of the flange is about 0.18 μm, and the maximum stress that the flange withstands is 1.5Mpa. All of these indicates that the structure of flange can satisfy design demand.

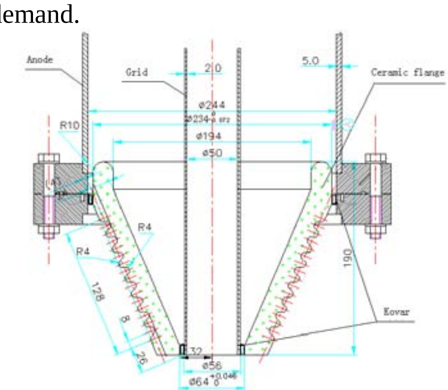

Figure 5: Sketch of Ceramic Flange.

METAL FOIL WINDOW DESIGN

Titanium has been selected as the foil window material[6,7]. Maximum stress that the window withstands has been calculated using ANSYS code. Table 2 shows the stress with different foil thickness. After comparison, 40 μm thickness foil widow has been used in the facility.

Energy losing process has been simulated using EGS4 code for different initial energy beam during passing through the window. Fig.6 shows the energy distribution of the electron beam after passing through the window. It shows that when initial energy is 200keV, losing energy is about 65keV. When the initial energy is 240keV, losing energy will be 13keV. In order to get higher output beam

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energy, voltage of the power supply can be increased properly.

Table 2: Maximum Stress the Foil Windows Withstands

Dimension	Stress
30μm×40mm×600mm	0.94GPa
40μm×40mm×600mm	0.59GPa
50μm×40mm×600mm	0.46GPa

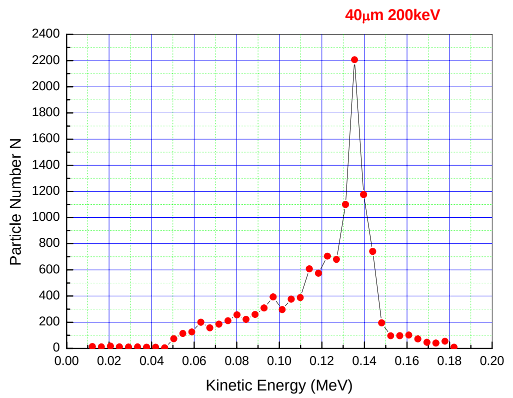

Figure 6: Energy Distribution of Electron Beam after Passing Through the Foil Window.

INTRODUCTION OF THE FACILITY

Machining of all elements has been finished. The electron beam facility is shown in Fig.7, from which one can see the ceramic flange, grid, and LaB_6 cathode, etc.

Some parameters has already been measured. In order to get the relationship between filament current and the cathode temperature, a structure with three watching windows has been used. Fig.8 shows that the cathode becomes incandescent when it is at a high temperature. Fig.9 gives the cathode temperature varying with filament current increasing. The high voltage power supply is being tested now for beam emission experiments.

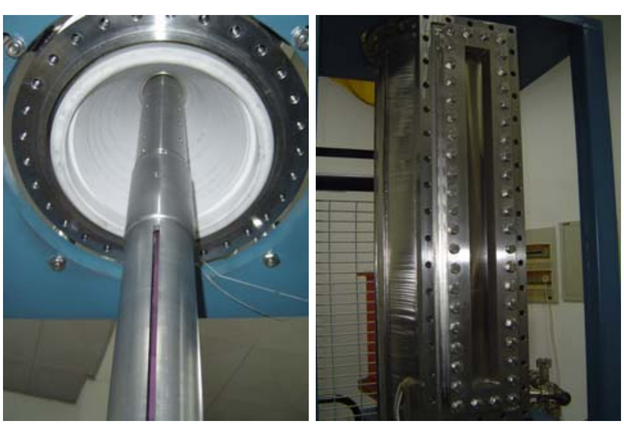

Figure 7: Photo of the electron beam facility.

SUMMARY

Design of a 200keV high pulse current electron beam facility has been introduced. From numerical calculations and simulations, the facility may generate line shaping electron beam with 15A peak current. Assembling of the facility has been finished and some parameters have been measured. Preparing for beam emission, testing experiments are being done now.

Figure 8: Cathode becoming incandescent.

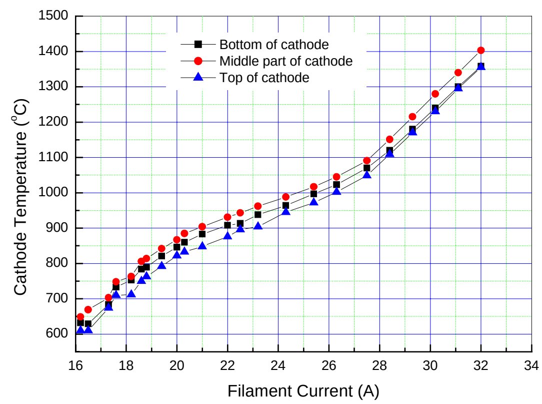

Figure 9: Relationship between Cathode Temperature and Filament Current, Measured from Three Watching Windows.

REFERENCES

[1] M. E. Herniter, W. D. Getty,"Development of High-current-density LaB_6 thermionic emitters for A space charge limited electron gun", PAC 1987, P292-294

[2] M.E. Herniter, W. D. Getty, "High current density results from a LaB_6 thermionic cathode electron gun", IEEE Transactions on plasma science, 1990, Vol.18, No.6: 992-1001

[3] D.M. Goebel, Y. Hirooka, T. A. Sketchley, "Large-area lanthanum hexaboride electron emitter", Rev.Sci.Instrum, 1985, 56(9):1717-1722

[4] Z. Bichen, Handbook of Metal Material, Metallurgic Industrial Publishing Company, 1978

[5] John David Jackson, Classical Electrodynamics (Third Edition), Published by JOHN WILEY & SONS, INC.

[6] Frauman , "Titanium-Properties and Applications for the Chemical process Industrics", Reprinted from, Encyclopedia of Chemical Processing and Design, New York, Vol. 58, pp.123-147.

[7] R.W. Schutz,"Performance and Application of Titanium Alloys in Geothermal Brine Service", Paper 139, Corrosion 84, New Orleans.

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