ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOMS013

ELECTRON GUN SYSTEM DESIGN FOR FLASH RADIOTHERAPHY*

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Abstract

An electron gun is a device that emits electron beams used in an electron accelerator, an electron beam welder, an x-ray generator, etc. This device can be broadly divided into three components: a cathode, a grid, and an anode. A medical electron gun, which is a sub-system of an electron accelerator for FLASH radiotherapy, requires a high current. The electron gun was designed to obtain a peak current up to 15A using EIMAC Y824 cathode. We would like to introduce the structure of the electron gun and the required power supply system. In this paper, we will describe the optimization process of the electron gun structure design, the Marx-type power supply providing 200 kV pulse voltage, and the grid pulse power supply ranging from 1ns to 1.5 µs.

INTRODUCTION

Cancer treatments, in general, heavily rely on three main modalities of systemic therapy: surgery, radiation therapy, and chemotherapy. Radiation therapy (RT) is a cost-effective cancer treatment with an approximately 50% survival, when used alone or in combination with other cancer therapies [1]. A new radiation treatment maximizes the removal of a tumor while minimizing the damage to healthy tissues surrounding the tumor, thus reducing the side effects of treatment. FLASH electron beam radiation therapy is a promising treatment that delivers therapeutic doses at a high dose rate (>40 Gy/s) in less than 1 second (example:90 ms) [2-4]. Most FLASH RT studies are performed using electron beams generated from linear accelerators [5, 6] with energy of 4–6 MeV or energy-modified clinical linear accelerators. The clinical linear accelerators were modified with energy levels up to 20 MeV and successfully generated electron beams at ultra-high dose rates [7,8]. However, the inability of the beam to penetrate to the desired location remains problematic due to the limitations in the clinical energy level range (4-22 MeV). Dosimetric studies were also conducted using electron beams with energy level up to 50 MeV. The studies conducted with a 50 MeV electron beam concluded that the beam could reach deep tumors and enable FLASH radiation therapy for umors 10-15 cm deep with ultra-high dose rate electron beams [9].

With reference to the data, we are developing an electron gun system consisting of a cathode, an anode and a grid, for use in a 50 MeV FLASH electron accelerator that provides a high current. A pulse voltage of 200 kV is applied between the cathode and the anode of the electron gun to obtain a high current. The ceramic section of the electron gun is designed to be assembled with the oil tank to prevent discharge. In this paper, the beam physics design, structural design and analysis of the electron gun, and the power supply design are explained.

ELECTRON GUN DESIGN

The electron gun used in the 50 MeV FLASH electron linear accelerator is designed based on Eimac's Y-824 dispenser cathode. The characteristics of this cathode are explained in Table 1, and the external shape is shown in Fig. 1. The shape of the cathode and the anode electrodes was optimized using CST simulation program to generate a current of 15 A when 200 kV was applied to the electron gun. The shape of the node and the shape of the electron beam are shown in Fig. 2. In addition, the size of the current emitted from the electron gun and the size of the electron beam were calculated through simulation when a voltage of 150 kV was applied between the cathode and the anode. The results are shown in Table 2.

Table 1: Specification of the Cathode

Item	Specification
Model	Y824
Type	Dispenser
Cathode area	2 sq. cm
Emission	15A $@E_c = 200V$
Conflat size	2-3/4”

Figure 1: Eimac's Y-824.

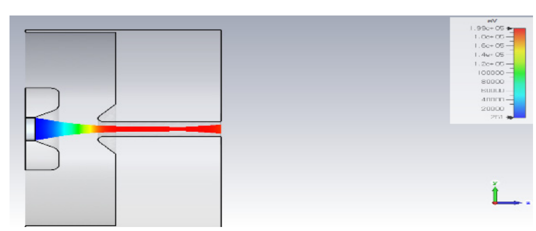

Figure 2: Simulation results with CST PS Studio.

*Work was supported by a grant of the Korea Institute of Radiological ar Sciences(KIRAMS), funded by Ministry of Science and ICT(MSIT), Rep (50572-2022)
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Table 2: Beam Data Analysis Result of CST Tracking Solver

Parameter	Result1	Result2
Beam voltage	200 kV	150 kV
Beam current	15.5 A	9.0 A
Perveance	0.173 uP	0.155 uP
Beam radius (@waist)	2.0 mm	2.0 mm

ELECTRON GUN MECHENICAL DESIGN

It is known that the length of the ceramic is generally determined according to the dielectric strength criterion of the electron gun structure, 4 kV/cm. Following the standard, our electron gun requires the ceramic with at least 50 cm in length. However, weight gain and deformation caused by increasing the ceramic length are issues that must be considered and overcome during the design and the fabrication phase. To solve the issues, the 250mm-long ceramic that is used in the existing Klystron, was designed to be assembled inside an oil tank (see Fig. 3). Thermal, structural, and vibration analysis were also performed with ANSYS on the electron gun under the condition of the maximum temperature of 826.9 ℃ (1100 K) of the cathode and the vacuum condition (torr). The thermal analysis has shown that the heat was not largely conducted to the periphery except for the cathode in a high vacuum state

The structural and thermal analysis were performed to confirm the deformation of the trophy-type structure, where the cathode located in the electron gun. The result of the analysis has shown that the total displacement occurred in the axial direction of the structure, and the total length was increased by 0.008 mm (see Fig. 4).

Mechanical vibration (mode) analysis was performed to confirm the stability against deformation during operation of the electron gun. The results are shown in Fig. 5 and Table 3. The primary vibration mode occurred at 385.3 Hz, and it was confirmed that the electron gun operates normally beyond 0-120 Hz, which is the operating range of the gun.

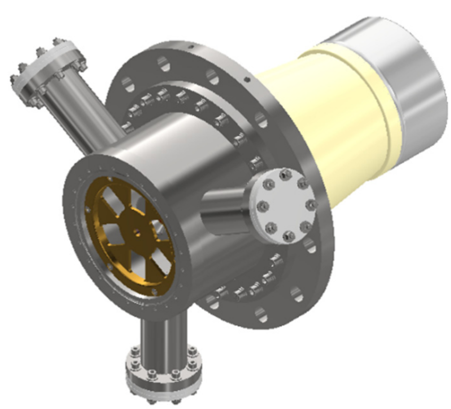

Figure 3: Electron gun outline.

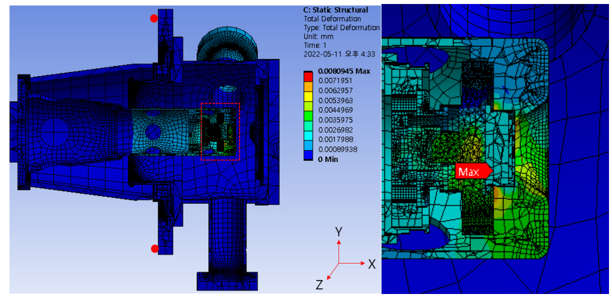

Figure 4: Structural analysis result.

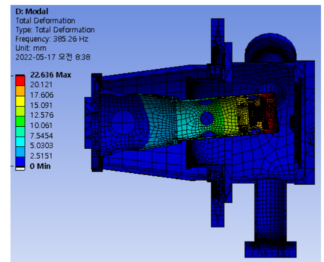

Figure 5: Vibration analysis result.

Table 3: Resonance Mode Frequency

Mode	Frequency (Hz)
1	358.3
2	394.3
3	458.1
4	474.4
5	477.6

POWER SUPPLY

In general, high-power pulse power systems are divided into two types: the line modulator method of the pulse forming network (PFN) structure using Thyratron switches, and the MARX modulator method using semiconductors and capacitors. The line modulator method requires a separate cooling system due to the heat generated during Thyratron switching. As the pulse repetition rate increases, the lifespan of the switch becomes shorter, the cooling system becomes larger, and the noise increases. Therefore, the MARX modulator method can minimize the size and noise of the entire power supply by applying semiconductor switching technology and can be used semi-permanently [10-12]. As a result, the power system of the electron gun was constructed by adopting the method using the MARK-type power supply device and an HV oil tank. The specifications of the device are shown in Table 4.

The power supply system is divided into a low voltage section and a high voltage section in terms of voltage. The power supply system is also divided into Control Rack, HV PS Rack, HV Tank, HV Deck etc in terms of components. AC220 V input power of the high voltage part is insulated from the low voltage control power through the isolation transformer. The high voltage part of -200 kV is insulated from the low voltage control power through the pulse trans-

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former. A signal transmission between devices is electrically isolated to prevent damages to the low voltage devices due to a high voltage, by applying an optical communication method.

Table 4: Power Supply Specifications

	Item	Unit	Value
Main PS	Flat top	us	1.5
	Output voltage	kV	-200
	Peak current	A	>15
	PPR	Hz	120
Heater PS	Output voltage	V	6.0/10
	Output current	A	5.2/10
Grid pulser	Output voltage	V	50-1,000
	Pulse width	ns	1-40
	Trigger	V	5
Bias PS	Output voltage	Vdc	50-500
	Output current	mA	10

CONCLUSION

The Y824 cathode was used to design the electrode shape of the cathode and anode of an electron gun that draws more than 15 A. The actual electronic structure was designed, and thermal and vibration analysis of the structure were performed. The result of the thermal analysis has confirmed that the change in distance between the anode and the cathode was about 8 µm due to the heat generated from the cathode. The minimum resonant frequency generated by a mechanical vibration was found to be 385.3 Hz. The result has confirmed the gun, to be operated without problems when the mechanical vibration occurs at a maximum of 120 Hz. Based on the analysis results, the electron gun is under fabrication. The electron gun power supply system is designed as a MARX-type with a maximum output of 4 MW, and its fabrication is being prepared.

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