DESIGN OF ELECTRON GUN AND S-BAND STRUCTURE FOR MEDICAL ELECTRON LINEAR ACCELERATOR

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Abstract

Linear accelerator technology has been widely utilized for cancer treatment in hospital. This radiotherapy utilizes an accelerated electron beam to create the x-ray beam. The idea to fabricate the prototype of medical electron linac with low cost for domestic use in Thailand was proposed and the budget has been granted. In the first phase, the electron beam energy of the machine will be 6 MeV or equivalent to x-ray energy of 6 MV. The electron gun is a diode type for the simple and low cost fabrication. The design and simulation study of diode gun will be presented together with an analysis of an electron beam in this gun. The S-Band 6 MeV side-coupled RF cavity has been designed to be the accelerating structure of the machine. The electromagnetic fields of the structure have been studied. The electron behaviour when they traverse this cavity will be studied using a particle tracking code. Progression of the project is also presented.

INTRODUCTION

Synchrotron Light Research Institute (SLRI) in Thailand has development project to build a prototype of medical linac for cancer treatment. This project has three objectives: 1) to develop prototype of medical linac by the ability of domestic people for reducing the machine import and maintenance costs, 2) to encourage researching in science and technology concerning medical application for the practical use products, and 3) to develop knowledge and expertise in accelerator and concerning technologies of medical linac. Reverse engineering approach will be employed via a donated medical linac. Suitable components and sub-systems will be procured, designed and developed to achieve such a prototype. The medical linac for cancer treatment to be developed consists of a linear accelerator structure of s-band standing wave type at 2998 MHz operating frequency, a 3.1 MW magnetron driven by a solid-state modulator, and a hot-cathode electron gun. The proposed specifications of this prototype are listed in Table 1. The sketch of prototype machine is shown in Fig. 1.

This paper is organised such that the electron gun design is discussed in the next section. The following section presents the design of accelerating structure. Thereafter the electron behaviour when they traverse the rf cavity is reported. Some concluding remarks are presented in the final section.

Table 1: Specifications of the Medical Linac

Parameters	Value
X-ray beam energy [MV]	6
X-ray dose rate [MU/min]	400-600
Field size	0x0 to 40x40 cm^2
Gantry rotation	Fix vertical
Type of accelerator	Standing Wave
Linac frequency [MHz]	2998

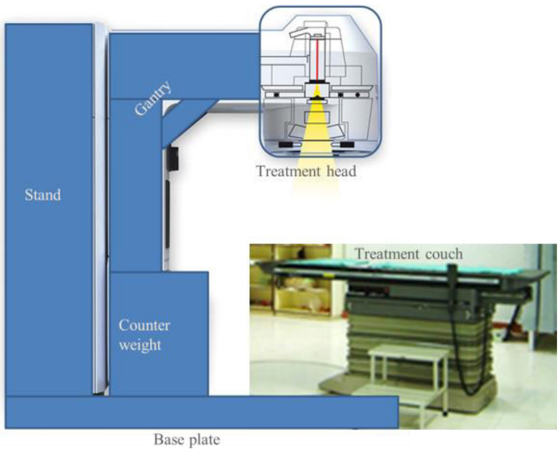

Figure 1: Sketch of prototype machine.

ELECTRON GUN

Electron gun for the prototype machine is a diode hot-cathode type. The initial shape of electron gun has been optimized for cathode voltage of -20 kV [1], but in this development the required electron energy out of electron gun is 30keV. A new optimization of electron gun shapes was performed to get higher electron energy and current. Shape dimensions of electron gun are shown in Fig. 2. CST-PS [2] was used in an optimization process to analyse the beam dynamics in three dimensions. Beam current, size, and emittance were calculated using space charge limited emission model in CST-PS. The result of particles tracking, beam cross section, and phase-space plot at the gun exit is shown in Fig. 3.

The optimized gun produces maximum electrons 823 mA with emittance of 1.07 mm mrad at -30 kV cathode voltages. Properties of an optimized gun are listed in Table 2. The emitted current of electron gun increases when a high voltage supplied to cathode increases, but emittance remains above 1 mm mrad as illustrated in Fig. 4.

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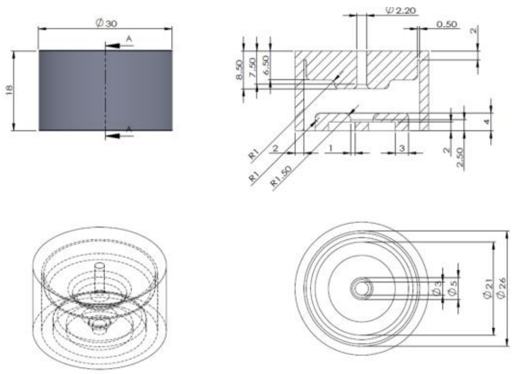

Figure 2: Shape dimensions of electron gun.

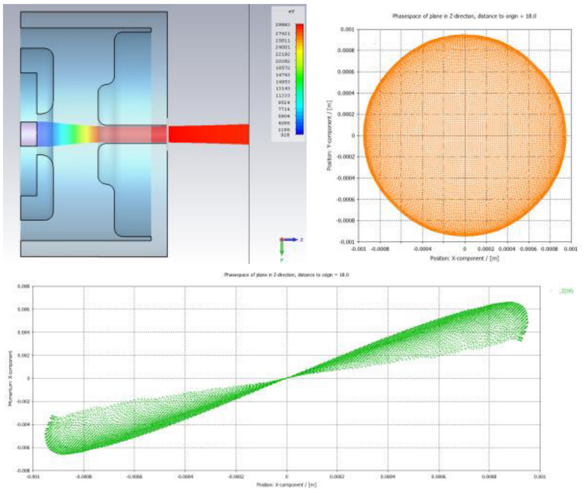

Figure 3: Electron trajectories (left), beam cross-section (right) and beam phase-space at the gun exit (bottom).

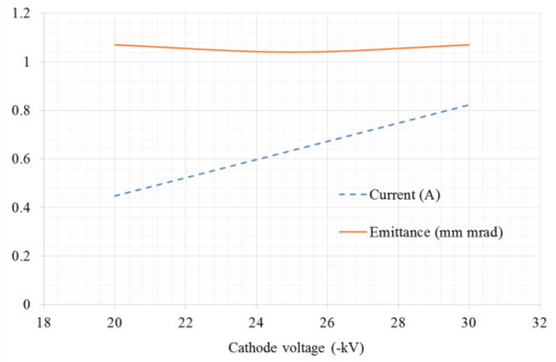

Figure 4: Emission current and emittance varied with cathode voltage.

ACCELERATING STRUCTURE

The accelerating structure in this development utilizes a side-coupled RF cavity. The sided-coupled cavity structure consists of the accelerating cavity and the couple cavity, where each couple cavity is alternately located at the side of the accelerating cavity. The coupling factor for side-coupled structures is adjusted by modifying the slot size between accelerating cavity and coupling cavity. In the side-coupled structure, the traveling ways for beam and for RF field are separated, so that both accelerating cavity and coupling cavity can be optimized independently from each other.

Table 2: Properties of the Electron Gun

Parameters	**Value**
Cathode diameter	3 mm
Cathode type	flat
Focus electrode aperture	5 mm
Anode aperture	2.2 mm
Acceleration gap	18 mm
Cathode voltage	-30 kV
Focus electrode voltage	-30 kV
Normalized RMS emittance (100%)	1.065 mm mrad
Average beam current (exit)	0.823 A
Beam diameter (exit)	1.8 mm

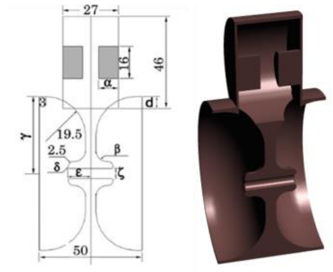

Figure 5: Sketch of cavity's cell dimensions and a 3D cut view.

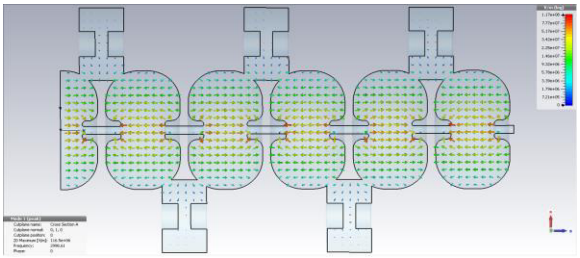

Figure 6: Electric fields distribution of resonant frequency.

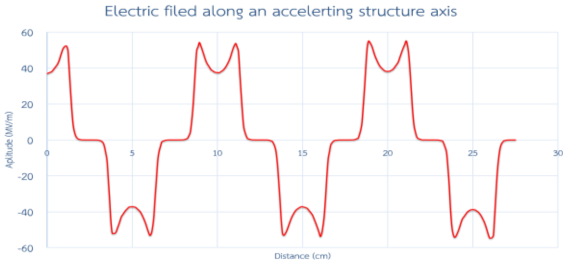

Figure 7: Longitudinal electric field amplitude along a cavity axis.

The RF cavity in this development will emulate a Varian 600C linac structure. The early work trying to emulate this cavity was published in [3 – 5]. Cell dimensions of the structure are sketched in Fig. 5 together with a 3D cut view of a cell. Dimensions indicated by Greek letters were optimized in order to get a good fields distribution at the designed resonant frequency, and all dimensions given are in mm. This cavity consists of five and a half cells with RF input port located at the 4th cell.

The resonant frequency of an optimized accelerating cell was optimized to be 3007 MHz such that when coupled to side cavities with an overlap of $d=6$ mm, the entire accelerating structure would resonate at 2998 MHz [4]. The shunt impedance of the structure is 115 MΩ/m with an unloaded quality factor of 17500. The electric fields of the resonant frequency and the amplitude of longitudinal field from CST-MWS [2] simulation are shown in Fig. 6 and Fig. 7, respectively.

BEAM DYNAMICS

Electrons properties at the exit of electron gun from CST-PS simulation were extracted and converted into a suitable data format for a particle tracking code ASTRA [6]. The electromagnetic fields of cavity were also extracted and converted into a cavity field format input of ASTRA code. The preliminary result of electron tracking through a 2D cavity's field is shown in Fig. 8. Electrons are accelerated from the initial energy of 30 keV to the final energy of 6.1 MeV with a 2D cavity's field scaled to the maximum amplitude of 55 MV/m. The beam diameter at the end of RF cavity is 1.9 mm.

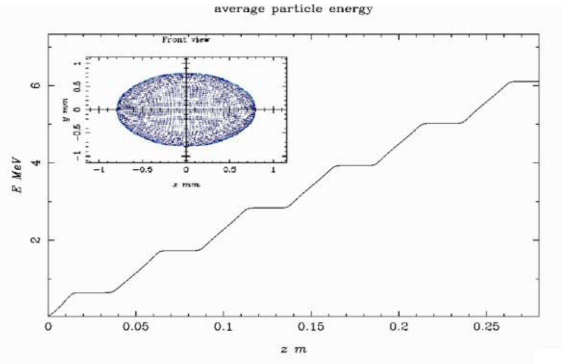

Figure 8: Electron acceleration from ASTRA tracking code.

The effects of asymmetry in electrometric field distribution caused by a side and port coupling irises were not included in the tracking code. To include that effect, 3D fields from cavity's simulation have to be extracted and input in ASTRA simulation. These are still works in progress.

CONCLUSION

The accelerating section of prototype medical linac machine has been designed with a diode electron gun and a side-coupled RF cavity. The electron gun utilizes a flat-type cathode with a nose cone anode and focusing electrode. The optimized gun produces maximum electrons 823 mA with a small beam diameter of 1.8 mm and 1.07 mm mrad emittance when -30 kV at cathode.

The RF cavity was optimized to a resonant frequency of 2998 MHz. It consists of five and a half cells with a magnetron supplied RF input at the 4th cell. Electromagnetic fields of resonant mode were extracted and converted into ASTRA input format for an electrons tracking. The preliminary result from a tracking code suggests the peak electric field amplitude to be 55 MV/m in order to accelerate electron to a final energy of 6.1 MeV.

The designs of electron gun and RF cavity have been reviewed with a manufacturer. There are comments about electron gun and cavity design. For example, electron beam occupied more than 80% of anode aperture at the exit of electron gun. This may risk the operation of a gun by accidently bombarding anode nose cone with an electron beam if there is error in fabrication process. To avoid this incident, a gun shape should be adjusted to have more focusing of electron. This will make electron occupied small area inside anode; result in a large tolerance to the fabrication errors. The tracking of electron through a cavity field should include the effects of asymmetry field of a cavity by using 3D fields. These are still works in progress.

The medical linac project is in a fabrication phase of an x-ray target and accelerating section. Corrections of electron gun and RF cavity design will be done together with manufacturer. These new design parts will be ready for testing by the end of 2017.

ACKNOWLEDGEMENT

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