# DESIGN OF A RADIOTHERAPY MACHINE USING THE 6 MeV C-BAND STANDING-WAVE ACCELERATOR*

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## *Abstract*

The majority of the radiotherapy are performed with linacs producing a uniformly intense electron-beam or X-ray beam of different energies. The linacs have the strong attraction of compactness, efficiency, reliability, moderate cost, and well-known technology. We developed and constructed the 6 MeV C-band linac which consists of a thermionic electron gun, a standing-wave accelerating column with the length of 450 mm, a 2.5 MW magnetron, a beam transport system, a beam collimation and monitoring system, and auxiliary systems of vacuum system, water cooling system etc. For the medical application, the gantry system is required to be rotated around the patient and to deliver the beam to the tumor from the linac. We design the gantry mounting our developed C-band linac isocentrically. In addition, the beam bending system and beam collimation are discussed to optimize the gantry space and to improve the beam performance. In this paper, we describe the designed radiotherapy machine including the gantry, a treatment couch and a control console, and present the study results.

## INTRODUCTION

The electron and X-ray beams with megavoltage energy from linacs are dominantly used for the cancer treatment. The linac for medical application is aiming to produce a stable mono-energetic and high current electron beam and to produce a focussed X-ray beam which is generated onto a small focal spot by the concentrated electron beam. These beams are modulated and irradiates the target object following the specific purpose.

The 6 MeV C-band linac with a standing wave accelerating column was developed to produce the electron beam and X-ray beam for the medical and industrial application (Figure 1) [1,2]. Especially, the radiation head was designed and constructed to generates the X-ray beams and shape the beam profile corresponding to the patient's tumor with the collimators. And the control system and the monitor chamber are also developed to be specialized in the medical linac [3]. The preclinical study using human cancer cell lines was performed with this linac beam and verified the biological effectiveness with the cell survival ratios.

We propose a radiotherapy machine including a gantry based on the 6 MeV C-band linac, a rotatable couch for treatment, and a control console. In this paper, we describe the design of the radiotherapy machine. The issues raised in design and the future plan are discussed.

## ADOPTION OF 6 MeV C-BAND LINAC

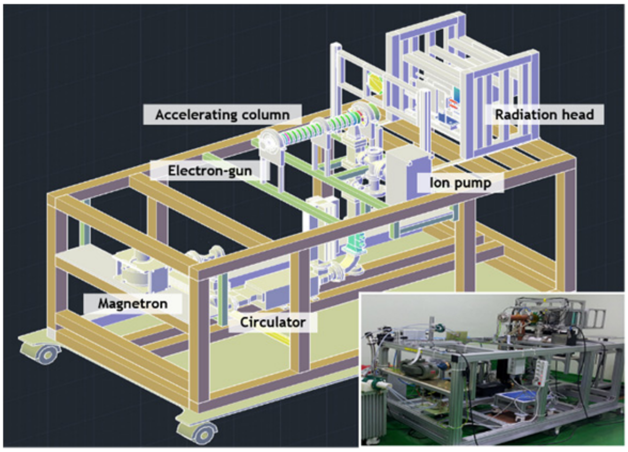

Figure 1: Design and construction of the 6 MeV C-band linac.

In order to adopt the 6 MeV C-band linac to the gantry design, the issues of beam bending, the integration of beam transport components, and the beam collimation should be considered.

This linac consists of a thermionic electron gun, a standing-wave accelerating column with the length of 450 mm, a 2.5 MW magnetron, a beam transport system, a beam collimation and monitoring system, and auxiliary systems of a vacuum system, a water cooling system, a pulse modulator, etc. As shown in Figure 1, the accelerating column is located coaxially with the radiation head and then parallel with the radiation beam irradiating a sample horizontally. Due to the patient position and the limitation of gantry size, it is necessary to bend the electron beam at an angle of approximately 90° or 270°.

The beam transport system from the magnetron to the accelerating column is composed of the WR187 waveguide components. There are two arc detectors for RF breakdown, a circulator for the protection of the reflected RF power, a loop coupler for monitoring the incident/reflected RF power, a RF ceramic window for separating the accelerator vacuum side from the $SF_6$ gas-pressured RF system side, and several waveguide bends and twists to change the RF direction. The compact transport system is required to be integrated in the limited gantry space.

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The radiation head produces the electron-beam and X-ray beam by selecting the target. It can be managed by the control system remotely. The electron beam is spread by the scattering foils to the required irradiated area and the X-ray beam by the flattening filter. The beam field size is controlled by the collimator. We verified the X-ray field size of 40x40 $cm^2$ at the source-to-axis distance (SAD) of 100 cm using this collimator, satisfied with IEC/TR 60977 report. The collimator providing the fixed shape of beam is used in this design.

## RADIOTHERAPY MACHINE

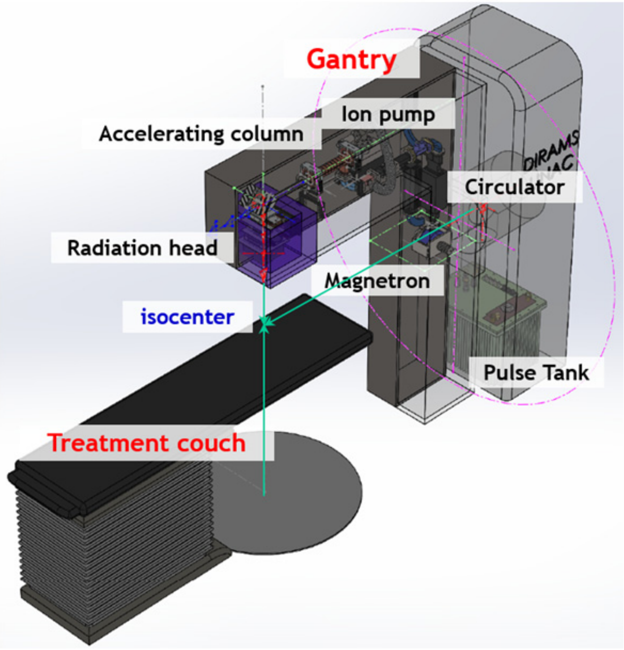

Figure 2: Design of a radiotherapy machine including the gantry isocentrically mounted on a support stand and a treatment couch.

### *Design with Isocenter*

Since patients should be treated with beam from different directions, the radiation head mounted on a gantry is required to be rotated around the patient and also the couch rotation is required. Therefore, the sub-systems of radiotherapy machine should be placed with respect to an isocenter [4].

The isocenter of a linac is defined as an intercept between the beam central axis and the gantry rotation axis. It also intersects a vertical axis of the treatment couch rotation (Figure 2). In order to allow treatments to any part of an adult, the longitudinal length between the isocenter and the surface of vertical gantry is determined to be 1250 mm. The distance between the X-ray target and the isocenter is designed to be 1000 mm. There are two goals in our design; the isocenter height and the isocenter tolerance. The isocenter height should be less than 1250 mm. Therefore, it requires to minimize the gantry height, especially reducing the vertical height of bending system. The tolerance of isocenter is aimed to be less than 1 mm in the design and manufacturing. The isocenter clearance presenting the space between isocenter and the treatment head boundary is 595 mm in this design. We prefer the longer isocenter clearance. Though our clearance is longer than that in the commercial radiotherapy machines, this design contains the secondary collimator to provide a rectangular shape of beam (Figure 3) and we do not yet add the multileaf collimators (MLC) which provides more flexible beam shape following the tumor shape and commonly is used in the commercial machines

### *Bending Magnet System*

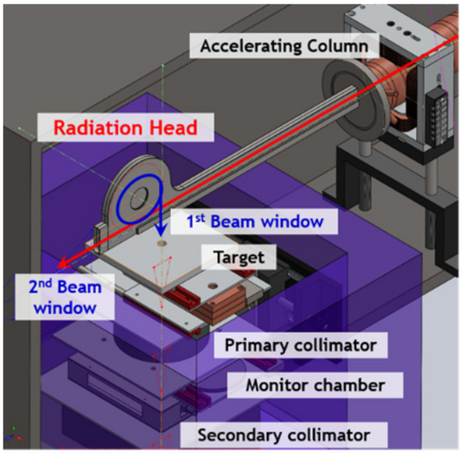

Figure 3: Radiation head before installing the bending magnet. The red-line denotes the electron-beam without the magnetic field. The blue-line denotes the electron-beam which was bended by the magnetic field.

As previously demonstrated, the bending system is required. Since the C-band linac has the shorter length of accelerating column, there is enough space in the horizontal direction. We are designing the bending system based on a double focusing magnet system [5] using three dipoles placed horizontally, reducing the isocenter height. An alternative system is also studied to use a symmetrical 270° single sector that can be installed on the beam pipe shown in Figure 3.

### *Integration of Components*

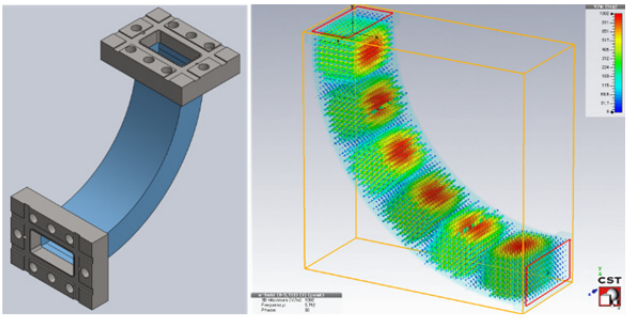

Figure 4: Design and simulation of a 90° waveguide bend (E-bend) with the Riken-DESY vacuum flange.

The gantry is divided into the top part including the gantry arm and the bottom part. The compact integration with the beam transport system and the magnetron requires the modification of some waveguide bends. As shown in Figure 4, a waveguide bend is designed with the Riken-DESY flange [6] for vacuum seal. The simulation verifies this design and we are preparing to fabricate it.

Since the most of linac components are located in the top part, a counter-weight or a beam catcher will be placed in the bottom part to balance the gantry rotation. The heavy components are desirable to be in the support stand. For instance, since the pulse tank is filled with insulation oil and provides the HV pulses to the electron-gun and magnetron via HV cables, it is located in the support stand. The most of components used in the linac are successfully integrated in the gantry, as shown in Figure 2.

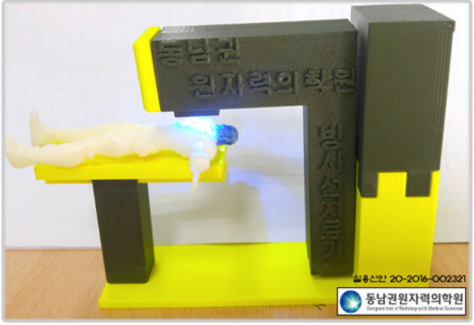

Figure 5: Toy model of radiotherapy machine made by 3D printing.

A toy model of radiotherapy machine was produced by 3D printing for the design validation. It was scaled down in the ratio of 1/30. As shown in Figure 5, it also was developed for the education purpose to understand this kind of medical system. Some of parts were modified to be easily integrated by children. The LED emulates the radiation beam.

## CONCLUSION & FUTURE PLAN

Since the 6 MeV C-band linac was constructed, we are upgrading the sub-systems to improve the beam dose and the stable operation. The 1st design of the radiotherapy machine is done for the integration of the linac components in the gantry with the isocenter height of 1250 mm. It suggests a possibility to build the gantry with basic function.

The next stage is to optimize the bulky components in the beam transport system, to arrange the cables of control, power and HV, and to finalize the design of bending magnet system. Also the shielding of radiation, RF and magnetic field will be studied.

We have the plan to upgrade the radiation head which will generate the high dose of X-ray beam and provide the flexible beam shape with variable types of collimators. In order to improve the positional accuracy and to verify the instantaneous beam interaction with the patient's target tumor, an electronic portal imaging device (EPID) is proposed to be attached on the bottom side of the gantry which intersects the vertical axis of isocenter. The EPID can be designed and constructed using the monitor chamber which we already developed for the real-time dosimetry [7].

## ACKNOWLEDGEMENT

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