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DEVELOPMENT OF SIDE COUPLED X-BAND MEDICAL LINEAR ACCELERATOR FOR RADIOTHERAPY*

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Abstract

Recently, LINAC-based radiotherapy equipment are being developed by combining with imaging devices such as CT or MRI, so that it is possible to precisely focus high dose radiation on tumor tissues while minimizing the normal tissue damage. In order to place the diagnostic and treatment devices simultaneously in a confined space, constraints related to interference and volume between the subsystems must be considered. To meet these requirements, the size and weight of the LINAC system need to be reduced, which can be achieved by applying X-band technology. For the purpose of use in IMRT based on image guided radiotherapy, we developed a 9.3 GHz X-band medical LINAC using side-coupled structure. The LINAC is designed to have the accelerating field strength of 16.8 MV/m, and the beam current transmission efficiency of 26 % at the end of accelerating cell when the supplied RF power is at 1.7 MW. Therefore, it can accelerate the electron beam up to 6.2 MeV with having about 90 mA beam current. We plan to carry out the performance test using beam diagnostics system and X-ray measurement system, and the details of design and experimental results of LINAC will be described in this paper.

DESIGN OF X-BAND LINAC

RF Cavity Structure

The developed 9.3 GHz X-band LINAC system accelerates electron beam and finally produce high energy X-rays and, the specifications are shown in Table 1. The RF cavity include 4 bunching cells, 20 accelerating cells, coupler port and vacuum port (see Fig. 1). The side coupling method is applied to distribute RF energy supplied from magnetron, which is an external RF source, to each cell inside cavity. The advantage of the side coupling method is higher acceleration efficiency per unit length, so it is possible to make the LINAC length shorter. In addition, since the cavity operate with π/2 mode which has the largest mode spacing comparing with other mode, it has advantage related to the performance and stability [1].

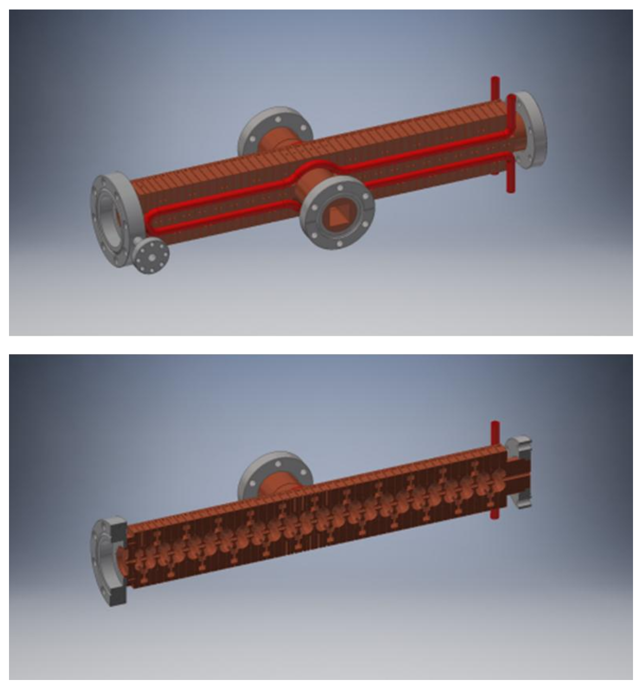

Figure 1: X-band RF cavity.

The total length of the RF cavity is 42 cm, which includes the flange for assembly. When 1.7 MW of RF power is supplied from the magnetron to the LINAC system, the RF loss is occurred in the coupler port and the RF module such as 4-port circulator and directional coupler, so the 1.58 MW of RF power is actually transmitted to the RF cavity. In this RF condition, the LINAC system is designed to generate the 90 mA electron beam 6.2 MeV.

Electron Gun Type

For the radiation therapy, the triode e-gun is mainly used, because it is essential to precisely control the beam current

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generated by LINAC. The triode e-gun has a grid electrode in addition to the cathode and the anode. Therefore, it can regulate the amount of current emitted from the cathode by means of applying current across the heater. This means that the beam current produced from LINAC system is also regulated by grid control. The specification of the e-gun is shown in Table 1.

Table 1: Specifications of X-band LINAC

System	Parameter	Value
Cavity	Frequency	9.3 GHz
	Coupling	Side coupled
	Operating Mode	π/2
	Length	38 cm
	Material	OFHC
	Effective Shunt Impedance	116 MΩ/m
	No. of Cells	24
RF Source	Type	Magnetron
	Power Output (Peak).	1.7 MW
	Pulse Width	4 us
	Duty Cycle	0.0008
E-Gun	Type	Triode e-gun
	Cathode Voltage	18 kV
	Emission Current	350 mA

LINAC SYSTEM DEVELOPMENT

RF Cavity Manufacturing

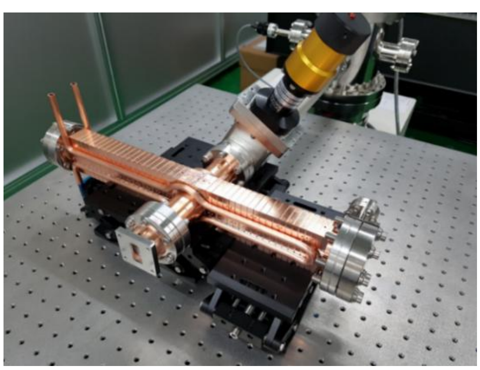

Figure 2: Fabricated RF cavity module.

To improve the accelerating efficiency inside the RF cavity, the shunt impedance should be increased. The shunt impedance is influenced by the cavity material and its geometry. Another important characteristic associated with the RF cavity is the quality factor, which is the ratio between stored energy and dissipated power in the cavity [2]. Because the quality factor also depends on the cavity material, both the choice of material for cavity fabrication and the precision of the machining is important. Therefore, we fabricated RF cavity using Oxygen free High Conductivity copper (OFHC) (see Fig. 2), which has high electrical conductivity, high thermal conductivity and relatively low secondary emission yield [3]. The surface roughness maintain less than 30 nm to reduce the RF loss and the break down inside cavity.

X-ray Target

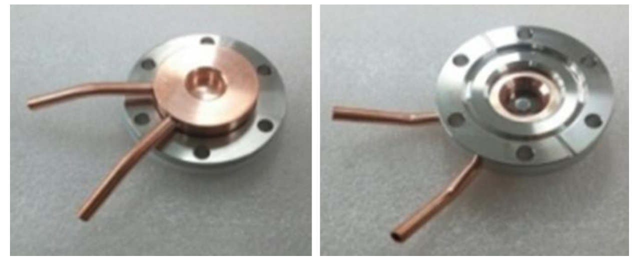

Figure 3: X-ray target for the 6 MV X-ray beam.

When a high energy electron beam bombards a metallic X-ray target, high energy X-ray is produced by the process of bremsstrahlung. The efficiency of the generation of the X-ray is determined by the geometry and the target material. The X-ray target is manufactured by tungsten which has high atomic number, high melting point and good thermal conductivity [3]. The dose rate from X-ray target depends on thickness of both the tungsten and the copper used for electron filtering. The X-ray target with a thickness of 0.87 mm for tungsten and 1.61 mm for copper is fabricated to generate the efficient 6 MV X-ray beam (see Fig. 3). The maximum dose rate that can be achieved using the manufactured X-ray target is measured to be 5 Gy. (Beam energy: 6 MeV, Beam current: 90 mA, PRF: 200 Hz, RF pulse width: 4 us, The distance from target to ion chamber: 100 cm)

Electron Beam Diagnostic System

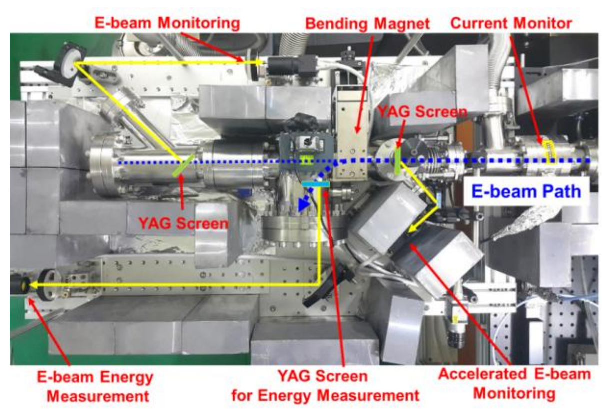

Figure 4: Beam diagnostic system.

Figure 4 shows the configuration of the developed electron beam diagnostic system. The system can measure the electron beam energy by orbit change under externally applied magnetic field from permanent magnet and measure the accelerating electron beam current by using beam current monitor. In addition, the electron beam diameter of the electron beam can be measured using a CCD camera by the visible light generated by the acceleration electron beam colliding with the YAG screen.

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PERFORMANCE TEST

RF Cold Test

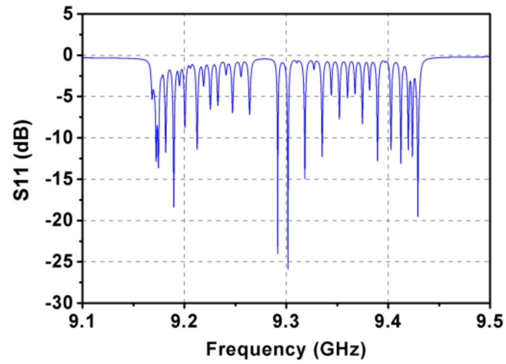

Figure 5: RF spectrum of the cavity.

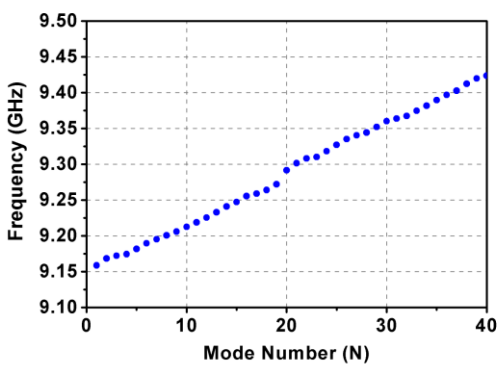

Figure 6: Dispersion curve of the cavity.

As shown in Fig. 5, the S11 parameters were measured to analyze RF resonance characteristics of the fabricated cavity after brazing process. We analyzed the existence of the stop band in the dispersion curve plot and it was confirmed that the fabricated cavity operates with the desired π/2 mode properties (see Fig. 6).

RF High Power Conditioning

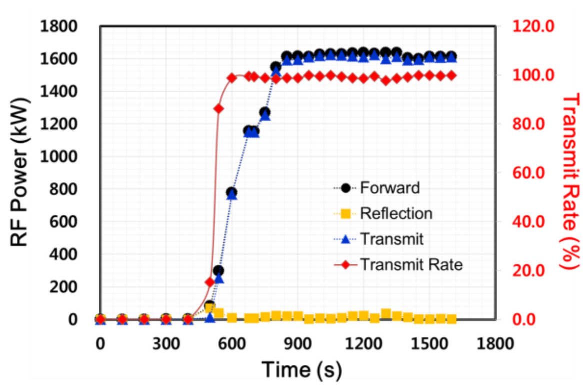

Figure 7: RF power and transmission ratio.

A newly fabricated RF cavity frequently undergoes arcing or breakdown in the high accelerating field due to the scratches or the impurities inside cavity. Therefore, it is necessary to provide RF input strength gradually from low power before supplying full RF power to LINAC. The field strength can be controlled by adjusting the pulse repetition frequency (PRF) and the pulse width. This process allows LINAC to maintain a stable state without arcing even when full RF power required for operating is supplied. The fabricated RF cavity is able to maintain the RF transmission ratio at about 95% or more (see Fig. 7).

Electron Gun Activation

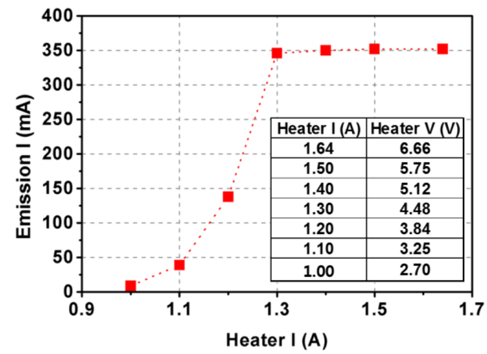

Figure 8: E-gun activation result.

The e-gun activation is the stabilization process for e-gun with emitting a steady electron flow. A fully activated e-gun has a constant emission region as shown in Fig. 8. Operating in this region after activation will allow current emit to be stable even with cathode temperature variation.

FUTURE WORKS

The recent trend related to the development of radiotherapy devices is fusion with imaging devices, so there are needs for miniaturization and weight reduction of LINAC system. Therefore, we developed 9.3 GHz X-band side coupled standing wave LINAC, and have finished the fundamental performance test. We have plan to measure the diameter, energy and beam current of the accelerated electron beam using the electron beam diagnostic system. After this process, we will perform QA processes to measure the X-ray energy, beam profile (flatness, symmetry, and penumbra) and dose rate based on the AAPM TG51, 142 Protocol.

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