ISBN: 978-3-95450-194-6 doi:10.18429/JACoW-LINAC2018-MOPO064

O-ARM MOUNTED X-BAND LINEAR ACCELERATOR SYSTEM FOR RADIOTHERAPY*

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Abstract

Current advances in radiotherapy are based on the precise imaging techniques, and there is a pressing need for the development of techniques capable of visualizing cancer tissues in real time in conjunction with radiotherapy. Indeed, the image-guided radiotherapy systems in which conventional diagnostic tools such as CT and MRI are combined with the linear accelerator (LINAC)-based radiotherapy have been extensively studied. In this work, we mounted 9.3 GHz X-band LINAC system designed by KERI on the 360 degree-rotatable O-arm system, which allows efficient integration of a diagnostic tool with the radiotherapy equipment. After mounting, the X-ray profile and percentage depth dose were measured by following the quality assurance using the AAPM TG-51, 142 protocol. The beam profile symmetry was estimated to be 102.44% with ± 3% tolerance. The X-ray dose was also measured by rotating the O-arm gantry system to confirm the stable operation of the mounted X-band LINAC. As a result, the standard deviation of the X-ray dose was 0.016 while rotating. Therefore, we demonstrate the operational stability of our O-arm mounted X-band LINAC system for use in highly effective radiotherapy combined with simultaneous Computerized Tomography image guidance.

INTRODUCTION

Radiotherapy is preferred as a common choice in the management of patients with cancers as treatment outcomes (i.e. patients' survival or quality of life) are importantly considered. It is moving towards image-guided radiotherapy (or combined radiotherapy) that allows delivering highly precise radiotherapy with periodic image guidance before and/or during each treatment. A core technology in such radiotherapy lies with LINAC devices that generate high energy radiation required for both imaging and treatment. Although the S-band LINAC is widely used, it is not suitable for the compact radiotherapy system. On the other hand the X-band LINAC is fits into small space, thereby reducing the costs of the system [1]. The X-band LINAC system recently developed by Korea Electrotechnology Research Institute (KERI) could reduce the overall device size by about 2/3 compared to the current S-band LINAC system [2]. In this study, we developed a compact X-band LINAC system and integrated into the O-arm computed tomography (CT) diagnostic system for image guided radiotherapy. We confirmed the normal operation of the developed O-arm CT-LINAC by mechanical analysis and ensured its stability and maintainability with the optimized quality assurance (QA) tests.

O-ARM BASED X-BAND LINAC

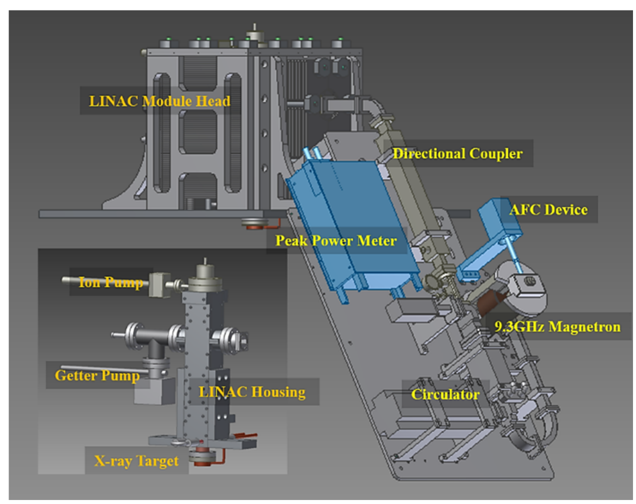

Figure 1: Compact X-band LINAC system.

Miniaturization and reduction in the weight of the LINAC are highly required for combined radiotherapy. In comparison with the 3.0 GHz S-band LINAC system, the 9.3 GHz X-band LINAC produces the same level of X-ray output while reducing the size and weight of the system. Therefore, we designed a compact LINAC system (LINAC module & RF Module) by mounting the X-band LINAC on the O-arm gantry (see Fig. 1). LINAC module consists of a triode type of the electron gun, a side-coupled structure

* Work supported by MSIT/NST (No. 16-11-N0101-06, 18-12-N0101-42)
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ISBN: 978-3-95450-194-6 doi:10.18429/JACoW-LINAC2018-MOPO064

based X-band LINAC with 445 mm long, and a tungsten X-ray target. An ion pump and getter pump were used to maintain a high-degree vacuum when the LINAC is operated. Water cooling was used to maintain the temperature of the LINAC and X-ray target, respectively. The RF module is mainly composed of a 9.3 GHz magnetron with 1.7 MW output for stable RF supply, an AFC device to maximize the RF signal into the LINAC, a 4-port circulator for the protection of the reflected RF power, a directional coupler for the detection of the forward and backward RF signal, and a peak power meter for RF power measurement. Both the waveguide connecting the RF module and the connected components were filled with SF6 gas. Flexible and band waveguides were used to connect LINAC module and RF module in the O-arm gantry structure. All the components mentioned above are mounted in the limited space of the gantry. The LINAC housing, and RF module fixture jigs and frames were designed and fabricated to keep the position of the gantry fixed during a full 360 degree rotation. For radiation shielding, the LINAC head was constructed by filling the outside part of the housing with lead.

O-ARM CT-LINAC SYSTEM

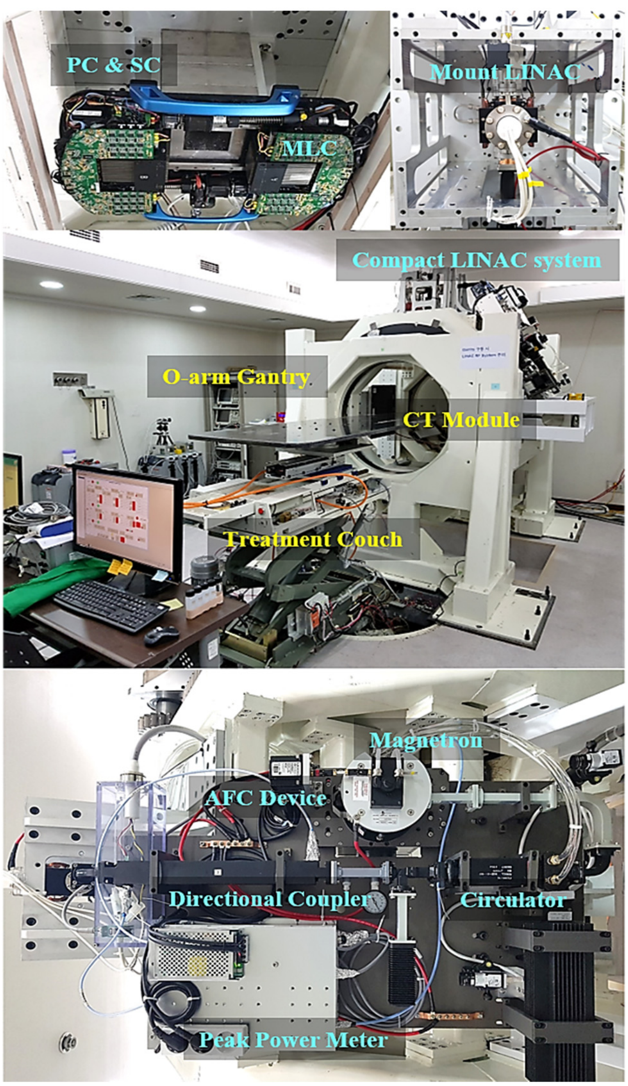


Figure 2: Combined radiotherapy with O-arm CT.

Image guidance in radiotherapy enables real-time tracking of the tumor of interest that may move out of the radiotherapy field, thereby offering potential for accurate and improved radiation treatment of cancers. The new combined radiotherapy machine that integrates compact X-band LINAC system into a medical O-arm CT system are developed [3]. Figure 2 shows the constructed compact O-arm CT-LINAC equipment. The compact LINAC module and CT imaging module are installed in the O-arm structured gantry. It is operated by the therapy integrated control system along with the treatment planning system. The X-band LINAC was mounted onto the gantry, and three collimators, including primary collimator (PC), secondary collimator (SC), and multi-leaf collimator (MLC), were installed under the X-ray target for intensity modulated radiation therapy (IMRT). The X-ray generation and MLC operation were then confirmed by exposing the MLC pattern to a Gafchromic EBT3 dosimetry film under radiation (see Fig. 3).

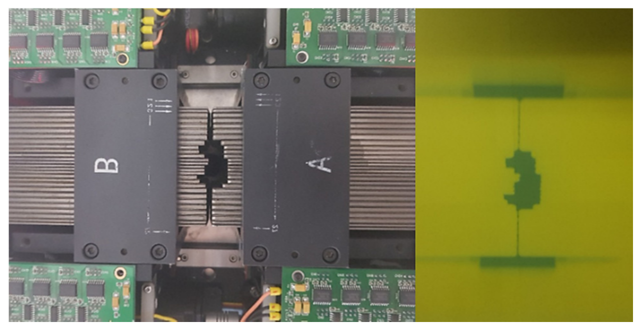


Figure 3: Image of X-ray irradiation controlled by MLC operation in the O-arm CT-LINAC system.

It is important to note that X-ray should be uniformly irradiated onto the selected area along the tumour site of patients over a 360-degree rotation of the gantry. To evaluate this, we measured the generated X-ray dose amounts at different gantry angles. Figure 4 shows relatively constant dose amounts during a full rotation with the standard deviation of the normalized doserate of 0.016.

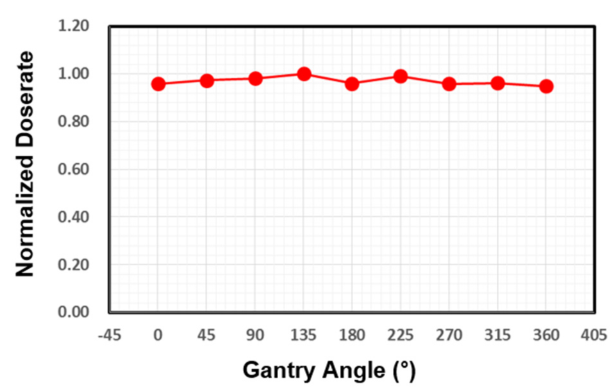
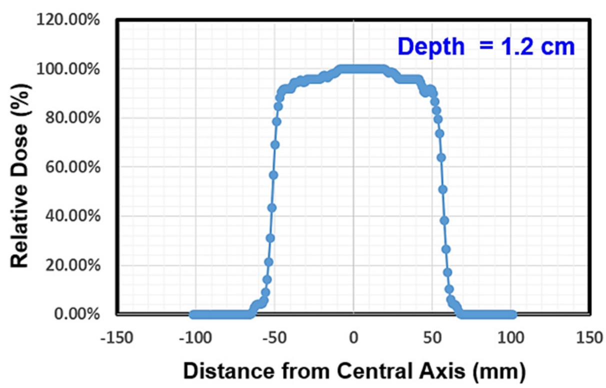


Figure 4: Dose measurement during a full rotation.

QUALITY ASSURANCE TESTS

Medical LINAC as a radiotherapy device should be carefully evaluated based on international standard protocols. In our study, we performed mechanical and dosimetry QA tests of our X-band LINAC using the optimized QA, based on the international standard protocol AAPM TG-51, 142, at Seoul St. Mary's Hospital. For the QA tests, we equipped the gantry with radiation measurement devices, including a 3D water phantom, an electrometer, and an ionization chamber. As shown in Fig. 5, the beam profiles along the x-axis were measured by normalizing the charge amounts at each depth to that in the center when the source-surface distance is 80 cm, and the field size is 10 cm × 10 cm. The results of the beam profile were also reported in Table. 1. We confirmed the beam profile symmetry using the standard protocols and found the tolerance was within ± 3%.



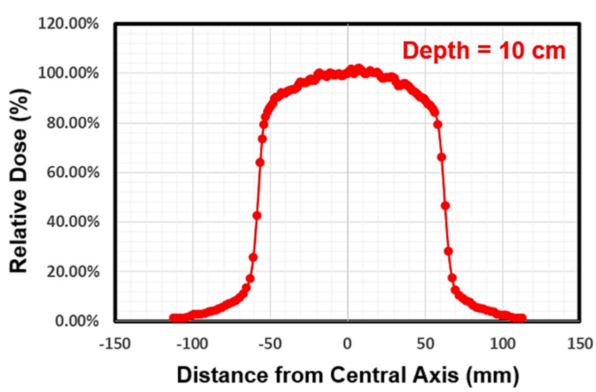


Figure 5: Beam profiles of the O-arm CT-LINAC system at different depths (1.2 and 10 cm).

Table 1: Beam Profile Results

Depth	Penumbra L	Penumbra R	Symmetry
1.2 cm	0.55 cm	0.59 cm	2.4%
10.0 cm	0.89 cm	0.93 cm	3.5%

CONCLUSIONS

O-arm mounted X-band LINAC system has been developed and tested for a compact advanced radiotherapy system. To construct this, we integrated a compact X-band LINAC into the actual O-arm CT system and ensured its stable operation. We further assessed the possible use of our system in medical radiotherapy using the optimized standard QA tests. Thus, our system allows optimal diagnosis with CT imaging and concurrent treatment with X-Band LINAC-based radiotherapy. Therefore, we envisage that this system would be utilized in the development of integrated systems for image-guided radiotherapy such as MR-LINAC, Tomotherapy, and Cyberknife [4, 5].

ACKNOWLEDGEMENTS

This research was supported by Korea Electrotechnology Research Institute (KERI) Primary research program through the National Research Council of Science & Technology (NST) funded by the Ministry of Science and ICT (MSIT) (No. 16-11-N0101-06, 18-12-N0101-42).

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