THE OPTIMIZED X-RAY TARGET OF ELECTRON LINEAR ACCELERATOR FOR RADIOTHERAPY

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Abstract

The x-ray target in medical electron linear accelerator is an important part in the production of x-ray photon beam. X-ray dose rate is depended on materials and thickness of the target. For the low cost 6 MeV prototype of medical linac in Thailand, this study gives the optimized x-ray target in which the dose rate can be maximized. MCNP simulations were performed during an optimization for a high x-ray dose rate at 1 meter away from the target. 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 aims to demonstrate the benefit of particle accelerator to the human healthcare. This low cost 6 MeV linac has a fixed x-ray target, which will be fired with a high energy electron beam in order to get x-ray photons from a bremsstrahlung process. Main components of treatment head is shown in Fig. 1. X-ray beam from a bremsstrahlung passes through a primary collimator to become a cone beam. Flattening filter is used to make a flat beam for an entire energy spectrum. Secondary collimators control beam opening size. Water phantom is used to measure an x-ray absorbed dose.

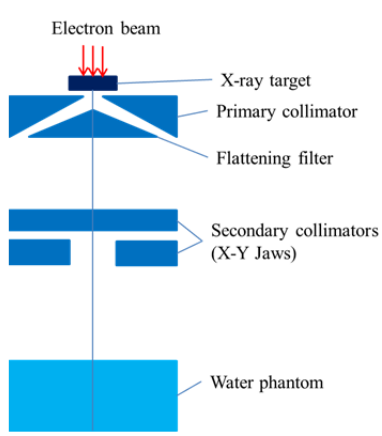

Figure 1: Simulation components of treatment head.

X-ray target with different materials and thickness has different efficiencies of x-ray generation for certain energy of incident electrons. An optimized thickness of target materials can be obtained from a scanning thickness simulation. The Monte Carlo Method in MCNP code [1] was used in simulation to find an optimum x-ray target.

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This paper is organised such that the simulation model is described in the next section. The following section presents the results of the studies. Thereafter the uniformity and misalignment studies are reported. Some concluding remarks are presented in the final section.

SIMULATION MODEL

Components as listed in Fig. 1 were used in MCNP simulation model. A circular disk of target with a radius of 3 mm was used; to correspond with an opening iris diameter of accelerating structure of 5 mm. Gaussian source distribution was used with a sigma of 1.2 mm and source strength of $2.5\text{x}10^{10}$ particle/s-cm^2. A water phantom as a dose detector was placed at 100 cm after a target.

With light particles such as electrons bombarding targets the intensity of bremsstrahlung radiation is proportional to the square of the atomic number of the target (Z). Therefore, the high Z materials such as tungsten (W), tantalum (Ta), and gold (Au) are a flavour material for an x-ray target. An earlier study [2] suggests that W is commonly used as a target with a high dose rate. This study focuses on finding an optimized thickness of W target. In simulation, silver (Ag) target was used to represent a low Z material.

RESULTS

When a high energy electron beam bombards x-ray target fractions of electron energy is converted into photon energy in form of x-ray beam and most of electron energy is absorbed by target result in target temperature increases. Efficient target cooling system is necessary for removing this heat.

The simulation photons tracking results of x-ray generation in a treatment head is shown in Fig. 2. The dose rate of different W target thickness compare with Ag target is illustrated in Fig. 3. It is clearly seen that a high Z material target has a high dose rate than a low Z material. Cancer treatment requires an x-ray beam without electron contamination. So the leakage rate of electron should be considered in a design process. The electron leakage rate illustrated in Fig. 4 suggests that the thicker target has more electron filtering efficiency than the thinner target. A low Z material has to be thicker than a high Z material to get a same filtering efficiency. The optimum between dose rate and leakage rate has to be determined to get an optimized target thickness. The study suggests the optimized thickness of W target to be 2.682 mm.

In [2] also suggests the using of double layer target for a higher dose rate with a configuration of a high Z material placed in front of a low Z material. The combination of W and Ag was chosen to compare with a single layer W target. The comparison percentage depth dose (PDD) curves illustrated in Fig. 5 supports the concept of using double layer target. In this comparison the combination of W and Ag target provides approximately 5% higher dose than a single W layer target.

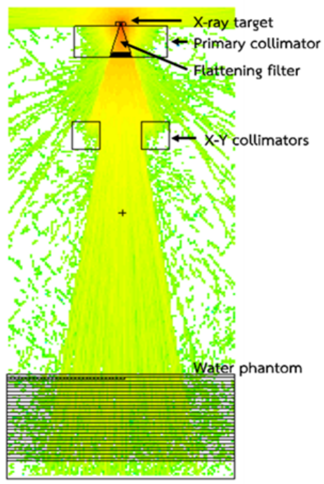

Figure 2: X-ray generation in a treatment head.

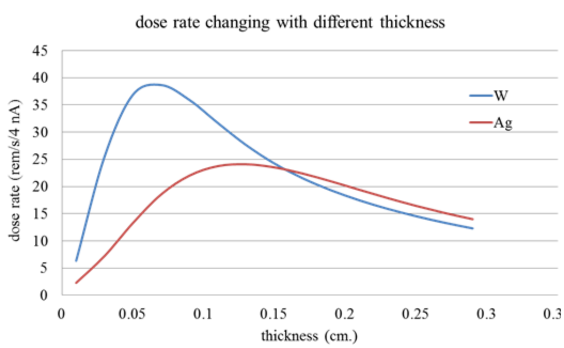

Figure 3: Dose rate changing with various thickness of a high Z material (W) and low Z material (Ag).

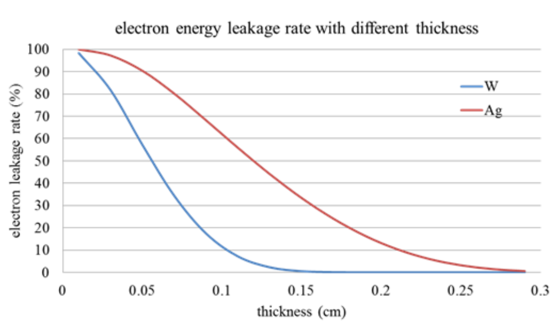

Figure 4: Electron leakage rate changing with various thickness of W and Ag target.

In practice, there is an electron filtering material layer after a target material in treatment head. This helps stopping the leakage electron to contaminate an x-ray beam. Beryllium (Be) with its low density and atomic mass is relatively transparent to x-rays therefore; it is commonly used for window material of x-ray equipment. The high thermal conductivity of Be to benefit target cooling. The design of using Be in target's configuration illustrated in Fig. 6 with a small circular disk of W target attached to a bigger circular disk of Be layer.

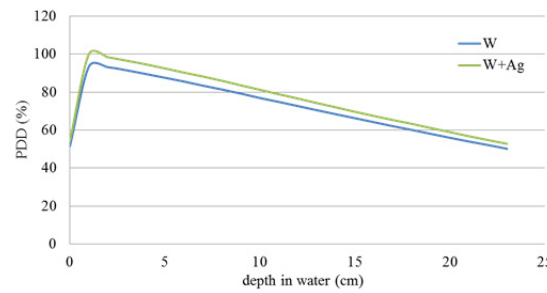

Figure 5: Percentage depth dose comparison of double layer target and a single layer target.

The thickness of Be layer was varied in simulation to compare delivery dose and electron leakage rate with a single layer W target. The delivery doses are shown in Fig. 7 and the electron leakage rates are listed in Table 1. The delivery dose of a thin W target is higher than a thicker target and the electron leakage rate is also high; therefore, it is not suitable for this application. There is a reduction of delivery dose with Be layer attached to target, but the electron filtering efficiency is improved. With Be layer thickness of 3 mm, the delivery dose decreases 4%, but the electron stopping efficiency increases 17%.

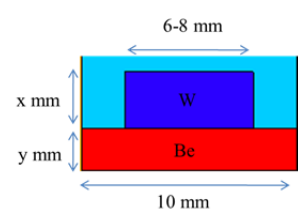

Figure 6: Configuration of W target and Be layer in a target design.

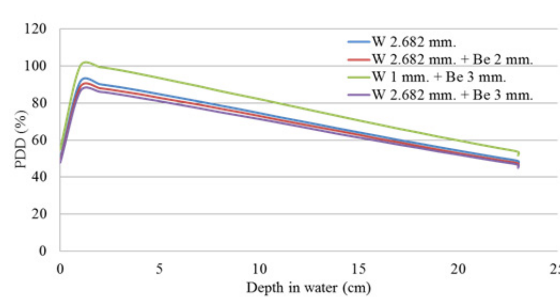

Figure 7: Percentage depth dose of various target configurations.

Table 1: Electron Leakage Rates of Various Target Configurations

Target configuration	Electron leakage rate (%)
W 1 mm + Be 3 mm	4.39
W 2.682 mm	0.30
W 2.682 mm + Be 2 mm	0.10
W 2.682 mm + Be 3 mm	0.05

UNIFORMITY AND MISALIGNEMNT STUDY

The non-uniformity of electron energy was also studied by using a Gaussian distribution of beam energy spectrum with error of +/- 1% instead of constant 6 MeV beam energy. The absorbed dose increases 3% with a Gaussian energy spectrum as the depth dose curve illustrated in Fig. 8.

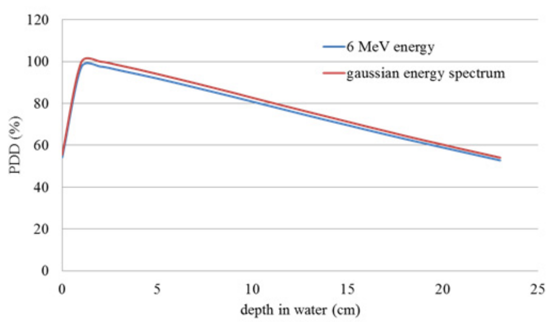

Figure 8: Dose comparison between Gaussian electron energy spectrum and uniform 6 MeV spectrums.

The uniformity of x-ray beam at the detector level was also studied. The shape of flattening filter affects this beam uniformity. By changing flattening filter configurations the flat profile of x-ray beam at the detector can be obtained as shown in Fig. 9.

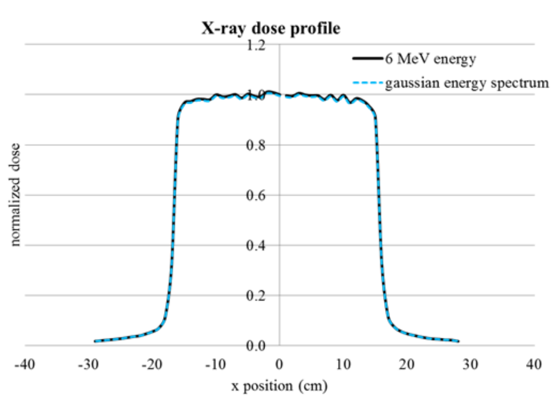

Figure 9: X-ray dose profiles at the detector.

Centre of accelerating structure and x-ray target must be aligned in order to get a uniform x-ray beam. If this alignment is out it will affect the uniformity of x-ray beam at the detector. The studied were carried out by offsetting centre of electron source in x and y direction by +/- 0.5 cm. The results shown in Fig. 10 indicate that the misalignment should be less than 5 mm.

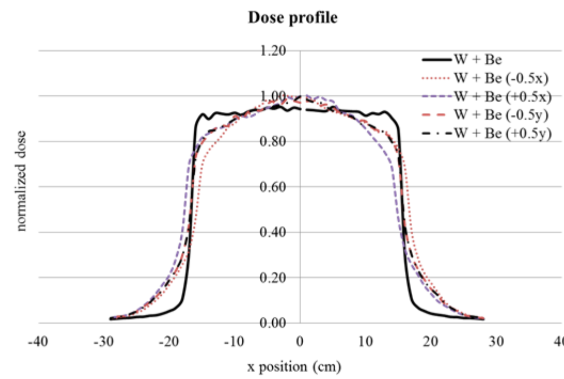

Figure 10: Dose profile comparison between a perfect alignment source and a various source misalignment.

CONCLUSION

The treatment head of prototype medical linac machine has been designed with tungsten as a target material. The optimized thickness of tungsten is 2.682 mm with a 3 mm beryllium as an electron stopping material. This configuration provides an optimized dose rate and a low electron leakage rate of 0.05%. The concept of using double layer target was also validated and the result shows 5% increasing in dose rate. A carefully selection of target combination can generate a higher dose rate and it may become a new target for x-ray generation machine. The effect of a uniformity and misalignment of electron sources were also studied. The Gaussian energy spectrum provides a higher dose than a uniform energy spectrum. The alignment of source and target should be less than 5 mm in order to maintain a flat profile of x-ray dose.

The medical linac project is in a fabrication phase of an x-ray target and accelerating section. The new design of accelerating section [3] and x-ray target will be ready for testing by the end of 2017.

ACKNOWLEDGEMENT

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