ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPRB056

DOSE MEASUREMENT EXPERIMENTS FOR SINGLE AND COMPOSITE TARGETS IN 6 MeV LINEAR ACCELERATORS *

Zhihui Wang*, Jiaru Shi†, Hao Zha, Jiayang Liu,
Department of Engineering Physics, Tsinghua University, Beijing 100084, China
also Key Laboratory of Particle & Radiation Imaging of Ministry of Education,
Tsinghua University, Beijing 100084, China

Abstract

The target in electron linear accelerator plays an important role in the production of photon. Targets of different materials and thicknesses have different X-ray yields. In this study, experiments were carried out to measure the dose rates of single targets and composite targets of different thicknesses for 6 MeV linear accelerators utilizing ionization chamber. The electron energy spectrum at the outlet of accelerating tube was detected with magnetic analyser. The experimental results show consistent rules with Monte Carlo simulations. Composite material target of 1.2 mm tungsten and 2 mm copper can deliver 1242 rad/min/100 μA dose rate at 1 meter in front of the target. Dose rates of tungsten- rhenium alloy(74%W-26%rhenium) targets were examined too.

INTRODUCTION

Medical linear accelerators are the most commonly used device for external beam radiation treatments for patients with cancer [1]. The X-ray target is a very important component at the end of the accelerating tube to produce high-energy X-ray. The incident electron beam hits the metal target to produce high-energy protons through bremsstrahlung, then the X-ray passes through the collimators and flattening filter to produce uniform and stable X-ray beam [2].

Targets of different materials and different thicknesses have different conversion efficiencies. Monte-Carlo Method is the most popular tool to calculate the yield of the X-ray and to optimize the design of the target [3]. In previous studies, Monte-Carlo simulations were carried out to study dose rates of different thicknesses single material targets and composite material targets [1]. Results show that X-ray dose rate changes with target thickness and that a peak dose rate can be obtained with proper thickness target. Figures 1 and 2 show dose rates of single tungsten targets and tungsten-copper composite targets with different thicknesses, respectively. For single targets, dose rate increases with target thickness and reaches maximum at a certain thickness, then dose rate decreases with target thicknesses. For composite targets, dose rate changes regularly with two targets' thicknesses. The optimized composite target with the greatest X-ray yield is 1.2 mm W+2 mm Cu. Dose measurement experiments need to be done to verify the Monte-Carlo simulation results.

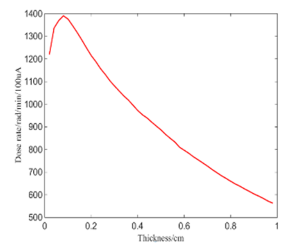

Figure 1: Dose rate of single tungsten target.

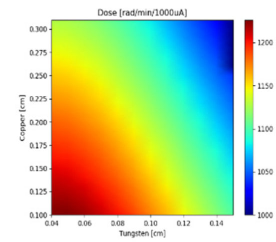

Figure 2: Dose rate of tungsten-copper target.

X-ray targets are exposed to pulsed electron beam. Elevated temperatures can lead to target recrystallization, fatigue, creep and even melting. Tungsten-rhenium alloy W26Re is a promising X-ray target material given its higher recrystallization temperature, better high temperature performance and lower ductile brittle transition temperature (DBTT) compared to tungsten [4-5]. Dose characteristics of W26Re need to be investigated.

EXPERIMENT PLATFORM SETUP

An S-band 6 MeV standing-wave accelerator with 6 pairs of accelerating cells was used. Table 1 shows the operational parameters of the accelerator. Magnetic analyser was designed and adopted to detect the electron energy spectrum at the accelerating tube outlet. The target electron currents were detected by an externally connected resister. X-ray dose rates at 1 meter in front of the target were detected by an ionization chamber. The layout of the experiment is showed in Fig. 3. After collecting the energy spectrum data, the magnetic analyser was moved aside and dose rate values of every target were collected one by one. An aluminium block was set 20 mm in front of the ionization chamber to absorb transmission electrons.

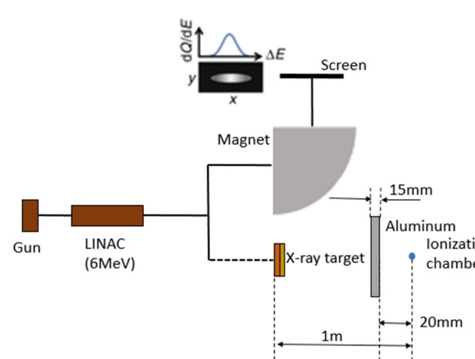

Figure 3: Schematic of dose measurement experiment.

* zhihui-w16@mails.tsinghua.edu.cn
† shij@mail.tsinghua.edu.cn

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPRB056

Table 1: Accelerator Operational Parameters

Parameter	Value
Gun Filament Voltage/Current	6.5V/2.2A
Magnetron Filament Voltage/Current	9.4V/9A
Gun High Voltage/Emission Current	10KV/346mA
Magnetron High Voltage/Current	45.8KV/105A
Repetition Frequency	25Hz
Pulse Width	4.3μs

EXPERIMENT RESULTS

Energy Spectrum and Currents on Targets

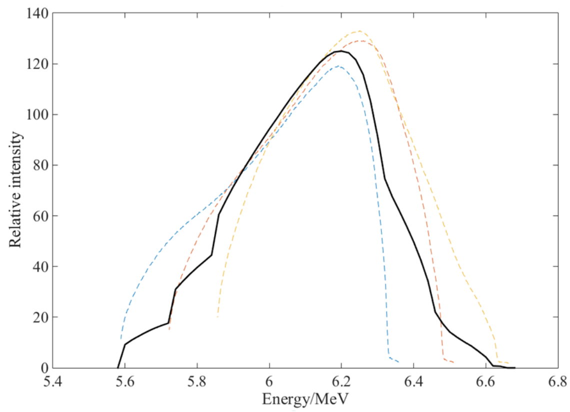

Figure 4: Electron energy spectrum at 10 KV gun voltage.

For electron gun voltage of 10 KV, Figure 4 shows the electron energy beam detected by magnetic analyser. Dash lines are outcomes of different deflection strengths. Black solid line represents synthesized outcome. The FWHM of the energy spectrum is about 8.1%. The peak kinetic energy of the beam is 6.2 MeV.

Electron currents flowing through the targets were detected using an externally connected resister of 50 ohms. The currents can be deduced by detecting the voltage drops across the resistor using an oscilloscope. For different targets, the electron currents varying from 80 mA to 86 mA.

X-ray Dose Rates of Single Material Targets

In order to investigate the effect of target thicknesses on X-ray yields and to examine the reliability of simulation results, we measured the dose rates of single tungsten targets of thicknesses of 0.08 cm, 0.1 cm, 0.12 cm, 0.15 cm, 0.19 cm. Figure 5 shows the comparisons between simulation results and experimental results of W targets.

Compared to pure tungsten, W26Re has higher recrystallization temperature (W: 1300-1500 ℃; W26Re: 1600-1800 ℃) and lower DBTT (W: 70 ℃; W26Re: -100-100 ℃). Besides, DBTT of pure tungsten rises to 250 ℃ after recrystallization. W26Re can be a promising target material for its high temperature strain performance and thermal fatigue resistance. In order to investigate the X-ray dose rate characteristics of W26Re and to compare dose rates of tungsten targets with W26Re targets of the same thicknesses, we also measure dose rates of W26Re targets of thicknesses of 0.08 cm, 0.12 cm, 0.15 cm, 0.19 cm. Figure 6 shows the comparisons between simulation results and experimental results of W26Re targets.

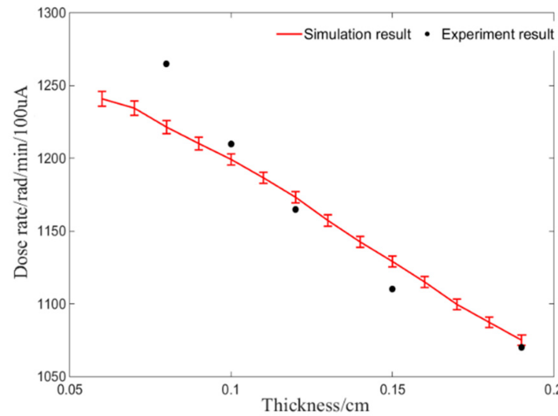

Figure 5: X-ray dose rates of W targets.

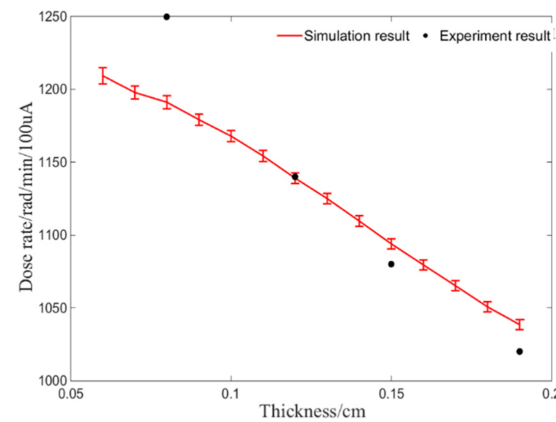

Figure 6: X-ray dose rates of W26Re targets.

For single material targets with thickness over 1 mm, experimental results are basically consistent with simulation results. For 0.6 mm targets, experimental measured dose rates are evidently greater than simulation results. It is because many electrons penetrate the thin targets and the aluminium block, arriving at the ionization chamber, which is unable to distinguish electrons from photons. Electrons' penetration ability is weaker than photons. The energy of electrons deposits in the chamber, causing the rising of measured dose rate. For 1.2 mm W, the dose rate was measured as 1165 rad/min/100 μA.

W26Re's X-ray dose rates are slightly lower than those of tungsten targets of the same thicknesses in both experiments and simulations. The greatest difference is 49.1 rad/min/100 μA with the target thickness of 1.9 mm. For 1.2 mm W26Re, the dose rate was measured as 1140 rad/min/100 μA.

X-ray Dose Rates of Composite Material Targets

For composite material tungsten-copper targets, we chose several targets around the optimized thickness target with similar X-ray yields and measured the dose rates of 0.5 mm W+3.2 mm Cu, 1 mm W+2.1 mm Cu, 1.2 mm W+2

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-THPRB056

mm Cu, 1.5 mm W+0.8 mm Cu. Table 2 shows the results of experiments and simulations under the same conditions.

In order to investigate the dose rate properties of W26Re as part of composite material targets and to compare the dose rates of W26Re-copper composite targets with tungsten-copper targets of the same thicknesses, we also measured the dose rates of W26Re-copper composite targets of the thicknesses of 0.5 mm W26Re+3.2 mm Cu, 1 mm W26Re+2.1 mm Cu, 1.5 mm W26Re+0.8 mm Cu. Table 3 shows the results of experiments and simulations under the same conditions.

Table 2: X-ray Dose Rates of Tungsten-copper Composite Targets

Thicknesses of Composite Targets	Simulation Results (rad/min/100 µA)	Experimental Results (rad/min/100 µA)
0.5 mm W+3.2 mm Cu	1101.85	1088.33
1.0 mm W+2.1 mm Cu	1108.96	1077.76
1.2 mm W+2.0 mm Cu	1250.28	1242.42
1.5 mm W+0.8 mm Cu	1093.79	1067.19

Table 3: X-ray Dose Rates of W26Re-Copper Composite Targets

Thicknesses of Composite Targets	Simulation Results (rad/min/100 µA)	Experimental Results (rad/min/100 µA)
0.5 mm W26Re +3.2 mm Cu	883.70	1058.45
1.0 mm W26Re +2.1 mm Cu	943.97	1040.17
1.5 mm W26Re +0.8 mm Cu	1023.77	1040.16

For all the composite targets we measured, X-ray dose rate experimental results are basically consistent with simulation results. For 1.2 mm W+2 mm Cu, the dose rate was measured as 1242.42 rad/min/100 µA.

W26Re-copper composite targets' X-ray dose rates are slightly lower than tungsten-copper targets of the same thickness in both experiments and simulations. The maximum difference is 37.6 rad/min/100 µA. For 0.5 mm W26Re+3.2 mm Cu, the dose rate was measured as 1058 rad/min/100 µA.

CONCLUSION

The optimized tungsten-copper composite material target 1.2 mm W+2 mm Cu can deliver 1242.42 rad/min/100 µA at 1 meter in front of the target in experiment. For single material targets and composite material targets, experimental X-ray dose rates results show consistence with simulation results. The simulation method proves to be reliable and the simulation results show great accuracy.

W26Re proves to have similar dose rate characteristics with tungsten serving both as single material targets and as part of composite material targets. 0.5 mm W26Re+3.2 mm Cu target can deliver 1058.45 rad/min/100 µA at 1 meter in front of the target in experiment. Thermal and stress behaviours of W26Re as X-ray targets require further studies.

REFERENCE

[1] Qiang Gao and Hao Zha, "Design and optimization of the target om electron linear accelerator", in *Proc. IPAC'13*, Shanghai, China, May 2013, paper THPWA016, pp. 3663-3665.

[2] Ajaj, F. A. A., and N. M. H. Ghassal. "An MCNP-based model of a medical linear accelerator X-ray photon beam", Australasian Physics & Engineering Sciences in Medicine, vol. 26, no. 3, pp. 140-144, 2003.

[3] Shi, Yinghua *et al.*, "Monte Carlo simulation of 6 MV medical electron linear accelerator", Chinese Journal of Radiological Medicine and Protection, vol. 31, no.3, pp. 220-224, 2011.

[4] Chen, Lei *et al.*, "Preliminary study on transient thermal shock behaviour of high purity tungsten", Nuclear Fusion and Plasma Physics, vol. 34, no.1, pp. 53-56, 2014.

[5] Uytdenhouwen I. *et al.*, "Influence of recrystallization on thermal shock resistance of various tungsten grades", Nucl Mater, vol. 363, pp. 1099-1103, 2007.