ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-THPO021

RESEARCH ON X RAY CHARACTERISTICS PRODUCED BY HIGHENERGY PICOSECOND ELECTRON BEAM SHOOTING*

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Abstract

The X ray sources based on electron linac can produce X-rays with high energy, concentrated directions, and strong penetrating power, which have been widely applied in various fields.An electronic linear accelerator which has been built at present can provide an electron beam with energy of 120 MeV and pulse width of picoseconds. The electron beam shooting at the metal targets can produce ultra-fast pulsed X-rays in the order of picoseconds. In this paper, the pulse X ray characteristics are studied through simulating electron beam shooting at four metal targets with different thickness of Au, Ta, U, W and Pb by Monte Carlo methods. The calculation shows that the X-rays can reach about 10^{10} /pulse and the pulse width can reach about picoseconds level, when the pulsed electron beams with energy of 120 MeV, charge of 0.5 nC and pulse width of picoseconds shooting at Ta targets. The yield and time width of pulsed X-rays are related to the diameter and thickness of the target.

INTRODUCTIONS

Since the discovery of X-rays, various types of X-rays generating devices have been developed, among which the most widely used one is the X-ray source devices used in electron linac, such as industrial irradiation electron linac, medical treatment accelerator and so on. These kinds of accelerators produce high energy electron beams, which can produce X-rays with high energy, concentrated direction and strong penetration. They have been widely used in irradiation processing, nondestructive testing, medical and other fields. The generation rate and time characteristic of X-ray are related to the beam energy, beam length, material and thickness of the target. The X-ray produced by this kind of linear accelerator is either DC or pulse, and the pulse width is mostly more than ns.

The electronic linear accelerator currently being built by Northwest Institute of Nuclear Technology can produce energy of 120 MeV and pulse width of 1ps to 3ps and electron beam with diameter of 15 μm. Using this electron beam to shoot target can produce ultrafast X-ray with high intensity and pulse width of picosecond magnitude, which can provide experimental basis for studying nuclear data and ultrafast ray measurement technology. Therefore, it is of great significance to study the target shooting by picosecond electron beam for designing the parameters of electron linac and target. In this paper, Monte Carlo method is used to calculate the X-ray characteristics produced by electron beam shooting, and the relationship between X-ray characteristics and target parameters, beam parameters.

CONVERSION TARGET SELECTION AND BEAM PARAMETERS

According to classical electrodynamics, charged particles accompany electromagnetic radiation when they are accelerated or decelerated. When a high-speed moving charged particle collides with an atom or a nucleus, under the action of the Coulomb potential, it will be deflected and decelerated while emitting x-rays, which is also called bremsstrahlung. In the electromagnetic theory, the intensity of bremsstrahlung is proportional to the square of the target nuclear charge and inversely proportional to the square of the mass of charged particles. Therefore, high-speed electrons are usually used to bombard the target nuclei to obtain high-intensity X-rays, and electrons are radiated in the target material. The energy loss of the electron can be expressed by the following formula [1]:

$$(-\frac{\mathrm{d}E}{\mathrm{d}x})_r=\frac{z(z+1)e^4NE}{137m_0^2c^4}(4\ln\frac{2E}{m_0c^2}-\frac{4}{3}) \quad (1)$$

Where E is the energy of the incident electron; N is the number density of atoms of the target substance; m_0 is the electron mass; c is the speed of light; and e is the unit charge.

From the electromagnetic theory [2], we can know that bremsstrahlung radiation has the following characteristics: 1) the greater the atomic number, the higher the intensity of X-ray produced by the element; 2) the continuous change of energy; 3) the existence of short-wave limit, short-wave limit $\lambda_{min}=E/(hc)$, in which E is the energy of the incident electron; 4) when the incident electron energy is low, the momentum of the photon is small, the photon is emitted in all directions, and when the incident electron energy is high, the photon tends to emit forward. Therefore, in actual use, an element having a large atomic number and a high energy electron beam are usually selected.

Table 1: Electron Beam Parameters

Parameters	Values	Units
Energy	60～120	MeV
Charges	0.1～0.5	nC
Energy dispersion	0.3%(rms)	
Beam length	1～3(rms)	ps
Beam diameter	~15(rms)	μm
Emittance	<1@0.5nC	mm·mrad

Electron linac is generally used to produce high energy electrons. The electron linac we are currently developing consists of photocathode microwave gun, two acceleration tubes, three microwave power sources, a three-in-one

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quadrupole lens, deflection magnet and beam measuring devices. The parameters of the electron beam produced by the electron linac are shown in Table 1.

X-RAY CHARACTERISTICS SIMULATION CALCULATION

X-ray Calculations for Different Heavy Nuclei

It is shown from Table 1 that the beam emittance, energy dispersion and beam diameter are small, and the beam emittance and energy dispersion need not be considered in the actual simulation calculation. Therefore, in the simulation process, the conditions are as follows: the electron beam is used to vertically strike the cylindricalheavy target from the axial direction (as shown in Fig. 1), the beam is a 120 MeV single-energy electron source with pulse width of 3 ps (rms), beam diameter of 15 μm (rms), charge of cluster of 0.5 nC, electrons are uniformly sampled in position and the incident direction is consistent with the axial direction of the cylindrical heavy target. Six heavy metal targets, Au, Ta, U, W, Pb and Th, are selected.

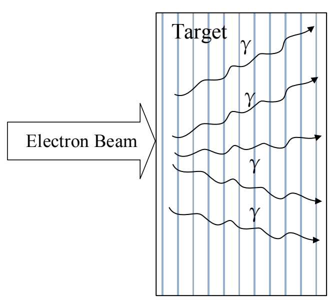

Figure 1: Schematic diagram of response of electron beam to heavy target

Because of the complexity of electron and X-ray motion in target material, it is difficult to calculate X-ray yield, energy spectrum, emission direction and other parameters by formula. Therefore, Monte Carlo method is usually used to simulate and calculate the bremsstrahlung photon characteristics produced by electron beam striking heavy metals. In order to reduce the amount of calculation, the diameter of the target is selected as 1 cm, and the number of X-rays produced by the pulsed electron beam with energy of 120 MeV and charge of 0.5 nC acting on the target with different thickness can be obtained by simulation calculation. The calculation results are shown in Fig. 2. It can be seen from the figure that the X-ray photon number produced in the heavy target can reach 10^{10} /pulse. When the target thickness is less than a certain value, the photon number increases with the increasing of the target thickness. When the target thickness is greater than a certain value, the X-ray photon number remains basically unchanged. That is, it does not change with the thickness of the target.

X-ray Calculation of Ta Target

As can be seen from Fig. 2, the variation of X-ray produced by different nuclides is basically the same. Ta target is the main research object. Monte Carlo method is used to simulate the electron beam vertically incident on Ta targets with different diameters and thickness. The results are shown in Fig. 3. As can be seen from Fig. 3, when the diameter of Ta target is less than 2 cm and the thickness of Ta target is more than 4.5 cm, the number of X-ray photons produced by the electron beam in the target increases with the increase of the target thickness; when the diameter of Ta target is less than 2 cm and the thickness of Ta target is more than 4.5 cm, the number of X-ray photons produced by 120 MeV electron beam in the target is almost constant, and does not increase with the target thickness. Additionally, when the diameter of Ta target is above 2 cm and the thickness is below 1.5 cm, the number of X-ray photons produced by 120 MeV electron beam in the target increases with the increase of the target thickness; when the diameter of Ta target is above 2 cm and the thickness is above 1.5 cm, the number of X-ray photons produced by 120 MeV electron beam in the target decreases with the increase of the target thickness.

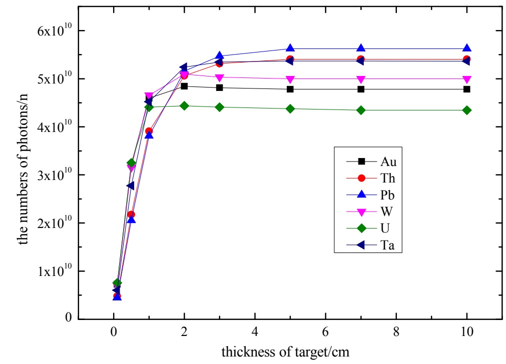

Figure 2: Calculation results of X-ray in heavy targets.

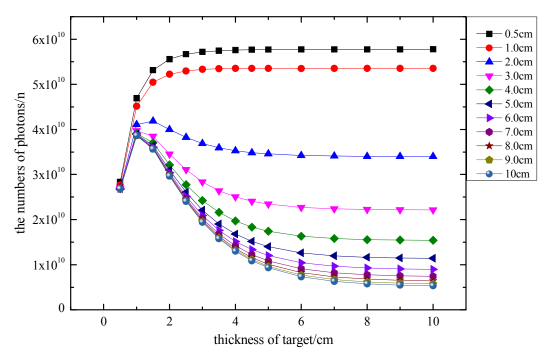

Figure 3: The numbers of X-ray photon produced by electrons in Ta targets.

The energy spectra of X -rayproduced in Ta targets with different diameters and thicknesses is calculated, and the results are shown in Fig. 4. It can be seen that there are four peaks of X-ray photon spectra, which are located near 9 keV, 56 keV, 66 keV and 0.511 MeV respectively. The first three peaks are characteristic X-ray peaks of Ta target, and the last one is positron-negative pair annihilation peak, which is much higher than the first three peaks. The energy spectrum of X ray moves towards low energy with the increase of target thickness and target diameter.

The X-ray time spectrum of Ta targets with different diameters and thicknesses is calculated. The results are

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shown in Fig. 5. It can be seen from the figure that the half-width of X-ray produced by Bremsstrahlung of electron beam with pulse width of 3 ps is several ps to tens of ps, and the pulse width increases with the increase of Ta target thickness and diameter.

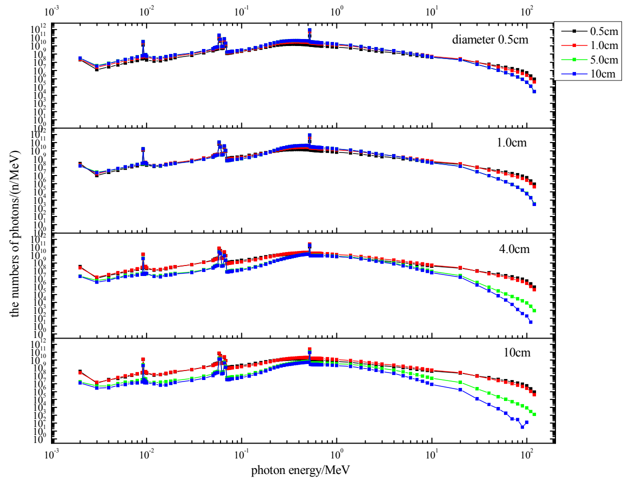

Figure 4: X-ray photon energy spectrum produced by electrons in Ta targets.

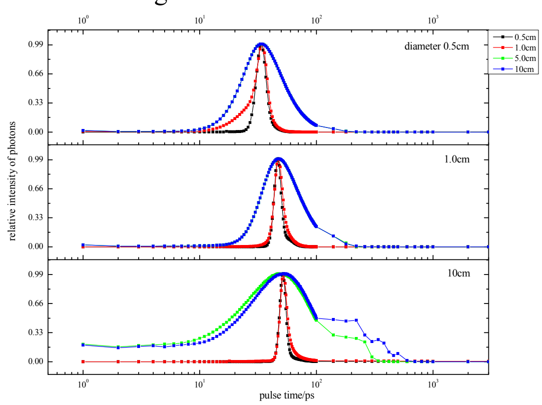

Figure 5: Photon time spectra in Ta targets with different diameters and thicknesses.

The angular distributions of X-ray photons produced by Ta targets with different diameters and thicknesses are calculated. The results are shown in Fig. 6 and Fig. 7. The angles are the angles between the emission direction of photons and neutrons and the incident direction of electron beam. It can be seen from the figure that when the target diameter is below 5 cm, the X-ray emission angle is concentrated in the direction of 0-90 degree; when the target thickness is below 3 cm, the proportion of X-ray photons in the direction of 0-90 degree increases with the increase of the target diameter; when the target thickness is above 3 cm, the proportion of X-ray photons in the direction of 0-90 degree increases with the increase of the target diameter. For the same diameter target, the proportion of X-ray photons in the direction of 0-90 degree decreases with the increase of the target thickness.

CONCLUSION

In this paper, the interaction model of ps electron beam with heavy target is established, and the Monte Carlo

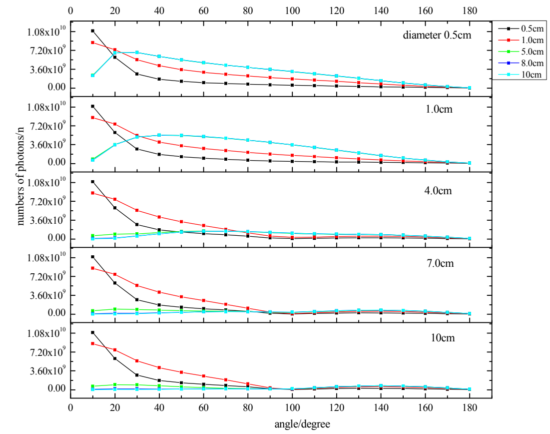

Figure 6: Photon angle spectrum produced in Ta targets with different diameters and thicknesses.

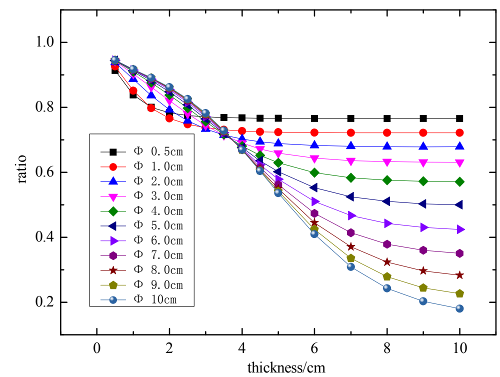

Figure 7: Proportion of photon numbersin the direction of 0-90 degree.

method is used to calculate the interaction between ps electron beam and heavy targets. The results show that the number of X-rays produced by pulsed electron beams with energy of 120 MeV, charge of 0.5 nC and pulse width of 3 ps (rms) in heavy targets with diameter less than 1 cm can reach 10^{10}/pulse. The X-ray characteristics of high-energy electron beam in Ta target are studied. The results show that for 120 MeV electron beam, there are four peaks of X-ray spectrum in Ta target, and the time half-width of X-ray is from several ps to tens of ps. The emission angle distribution of X-ray is related to the diameter and thickness of the target. By studying the X-ray characteristics of ps electron beam incident on heavy target, it can provide important reference value for the ultrafast X-ray application of this type of electron linac.

ACKNOWLEDGEMENTS

Thank you for your help from colleagues from the Northwest Institute of nuclear technology.

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