DESIGN OF AN e-γ CONVERTER FOR A 10MeV ELECTRON BEAM

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Abstract

Non Destructive Testing is a powerful tool to inspect samples for different purposes (quality controls, structural and objects of cultural heritage checks, etc.). For such inspections, which involve thick or heavy samples, high energy x-ray beams are required. To the aim to design such a source, based on a 10MeV electron linac, an e-γ converter has been designed by means of the MCNP4C2 simulation code and optimized for a 10MeV electron beam. A wide investigation has been performed to choose material and thickness for the e-γ converter in order to provide the highest x-ray yield. Then, angular distribution and energy spectrum have been simulated to characterize the produced bremsstrahlung beam. Also the target activation has been investigated. Finally, thermal analysis has been performed using a finite element model code, Deform 2D, to choose the definitive mechanical settings of the e-γ converter.

THE E-γ CONVERTER

When an electron beam interacts with a target, x-rays are produced by the bremsstrahlung effect. Angular distribution and enery of the emitted x-rays can be modulated by changing the target converting electrons to x-rays.
X-ray production by bremsstrahlung effect has been already discussed [1] considering a 5MeV pulsed electron beam to the aim to design an x-ray source based on a compact electron linac [2] for in situ x-ray radiography purposes. In this paper, the design of an e-γ converter for a 10MeV pulsed electron beam will be discussed, to the aim to produce an intense and high energy x-ray beam for very heavy or thick sample radiography purposes.
Many Monte Carlo simulations have been performed to evaluate the x-ray production by using the MCNP4C2 (Monte Carlo N Particle, version 4C2) code [3]. The photon production cross sections evaluated by Berger and Seltzer [4]-[5] are used.
Different materials (Al, Ti, Cu, Ta, W and Au) have been considered as the target candidates. In Fig.1, a comparison among x-ray yields from different target materials is shown as a function of the target thickness. As expected, for each material a thickness value for which the x-ray yield is maximum exists. This value represents a compromise between x-ray production and absorption effects. Moreover, heavier the target is, higher the x-ray yield results.

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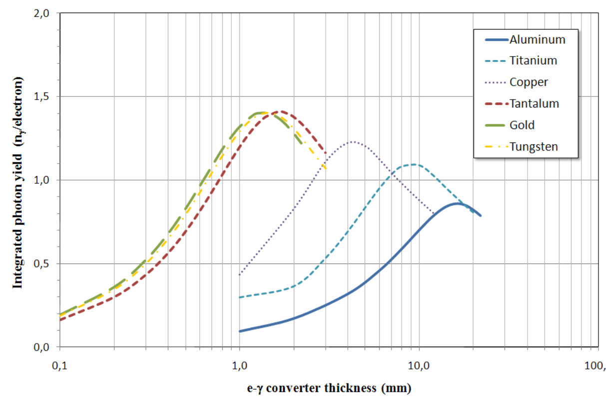

Figure 1: Comparison among x-ray yields from different targets, as a function of the target thickness.

As shown in Fig.1, x-ray yields from Ta, W and Au are similar each other and higher than the yield from Al, Ti and Cu targets. As a consequence, and to the aim to produce an x-ray beam as intense as possible, we have to choose among Ta, W and Au as the target material. Taking into account also manufacturing properties and heat dissipation capacity, 1.7mm-thick Ta target has been chosen as the e-γ converter.
By comparing bremsstrahlung spectra coming from different thicknesses of the Ta target, it results that for small thicknesses the bremsstrahlung beam is enriched of low energy photons while for greater thicknesses the hardening of the bremsstrahlung beam occurs. The integrated photon yield varies from 1.6E-01 to 1.16E+00 photons/electron for 0.10mm and 3.0mm thicknesses, respectively, reaching a maximum value of about 1.41E+00 photons/electron for 1.7mm-thick Ta target. 1.7mm thickness is a good compromise if an intense and hard x-ray beam is required. In Fig.2 a comparison among bremsstrahlung spectra obtained for different Ta target thicknesses is shown.
Regarding the radial distribution of the emitted x-rays, simulations indicate that x-ray emission is forward peaked. Nevertheless, for a 10MeV electron beam energy, a bremsstrahlung emission cone of about 2°55' is expected.
The chosen Ta thickness is not enough to entirely stop primary electrons which exit beyond the target showing a continuous energy spectrum peaked at about 6MeV, Fig.4. If a thin e-γ converter would have been used, the energy spectrum of these 'survivor' primary electrons would have been

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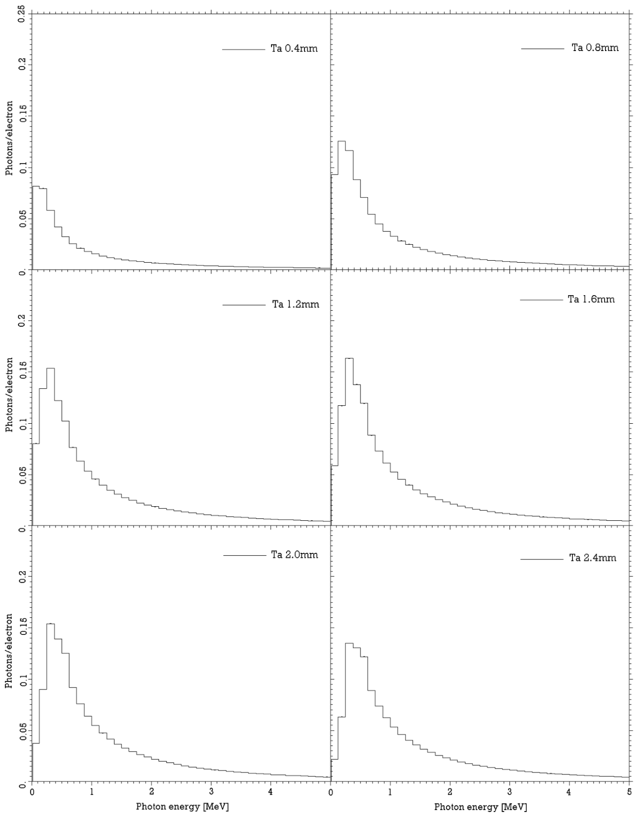

Figure 2: Comparison among energy spectra of x-rays coming from different Ta thicknesses.

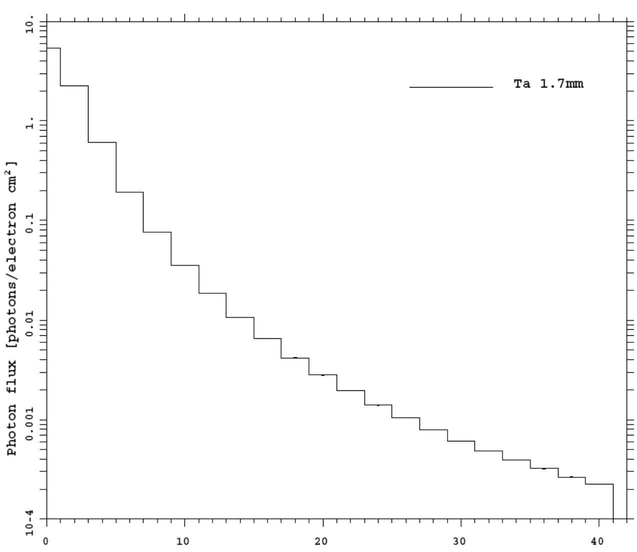

Figure 3: Radial distribution of photons emitted by 1.7mm Ta target.

quasi-monoenergetic. In the last case, and by means of a properly designed magnetic field, they can be directed back into the target or toward further thin targets thus continuing to contribute to the x-ray emission.

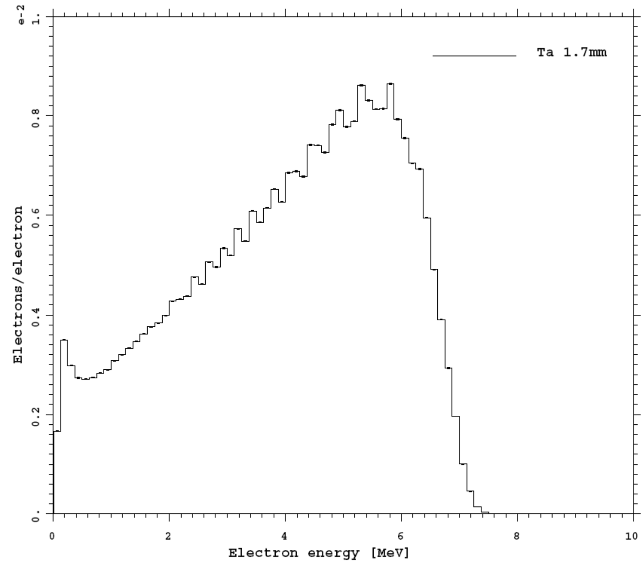

Figure 4: Energy spectrum of primary electrons beyond the Ta target.

NEUTRON PRODUCTION

When electrons interact with a target, the photonuclear (e,γ) reaction can occur, depending on the electron beam energy and on the material constituting the target. The (e,γ) reaction energy thresholds are above 7-8MeV for most materials except that for D and Be for which they are about 2.2 and 1.66 MeV, respectively [6]. For Ta, the (e,γ) reaction energy threshold is 7.58MeV and cross section is up to 50mbarn for γ energy of 10MeV. As a consequence, to characterize the produced x-ray beam, also neutron contamination by neutrons coming from the e-γ converter itself has to be taken into account.

Monte Carlo simulations, basing on IAEA photonuclear data [6], have been performed to evaluate neutron yield and energy spectrum. As shown in Fig.5, neutrons with energy up to 1.5MeV are emitted. Also the radial distribution has been simulated and results indicate an isotropic neutron distribution.

The neutron fluence has to be taken into account mostly for safety reasons. By supposing to operate at 80mA electron peak current, 300Hz frequency and electron pulses of 3μs, then 10^9 neutrons/s would be produced. In this case, an accurately designed neutron shielding would be required.

Nevertheless, by properly designing a thermalization line for neutrons, the resulting thermal neutron fluence could be still enough to make neutron radiography thus having both the possibilities at once: x-ray and neutron radiography.

THERMAL ANALYSIS

During irradiation, the Ta target temperature enhances and a correct heat dissipation has to be assured to avoid it melts. To the aim to evaluate the temperature of Ta target during irradiation, a commercial finite element software,

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DEFORM 2D, has been used.

The energy deposition of electrons in Ta target has been simulated by MCNP4C2 and used as the input for thermal calculations.

To simplify the model, a two-dimensional analysis has been carried out and due to its geometrical symmetry, only one half of the target has been reproduced.

Fig.6 shows the mesh area of the reproduced target. R is the target radius (note that the target is a disc of 5mm radius); r defines the target portion the electron beam flows through (this has not been meshed); the black arrow indicates the electron beam direction. The energy deposition trend is also shown and it has been applied to the red nodes.

The target has been simulated taking into account the heat dissipation due to the surrounding air; two dissipations modes have been considered: irradiation (Ta emissivity is 0.19) and natural convection (Ta convection coefficient is 5 W/m^2K).

Fig.7 shows the temperature reached by the target after 500s irradiation and supposing to operate at 80mA electron peak current, 300Hz frequency and with an electron pulse of 3μs. The temperature of the target portion close to the beam line rises up to 800°C; a correct heat dissipation has to be assured thus avoiding the target melts.

CONCLUSION

Composition and thickness of a 10MeV electron beam target have been optimized to produce a high and intense x-ray beam for radiography purposes. Also neutron contamination has been taken into account and results indicate that neutron shielding is needed if operating at high electron rate. Finally, thermal analysis of the target suggests to couple it to a cooling system thus avoiding its melting.

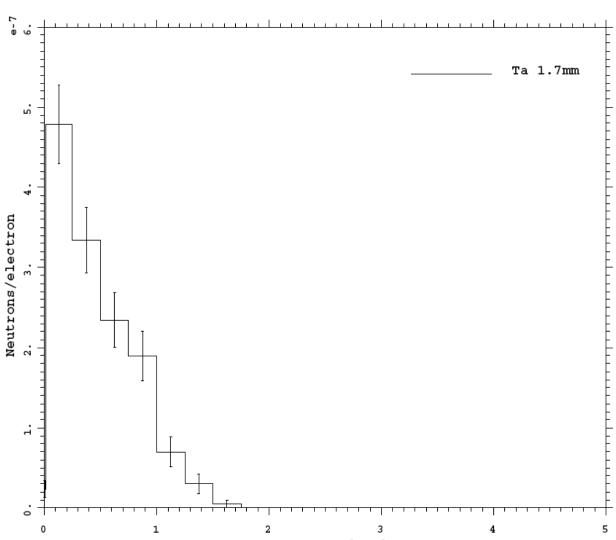

Figure 5: Energy spectrum of neutrons emitted by the Ta target.

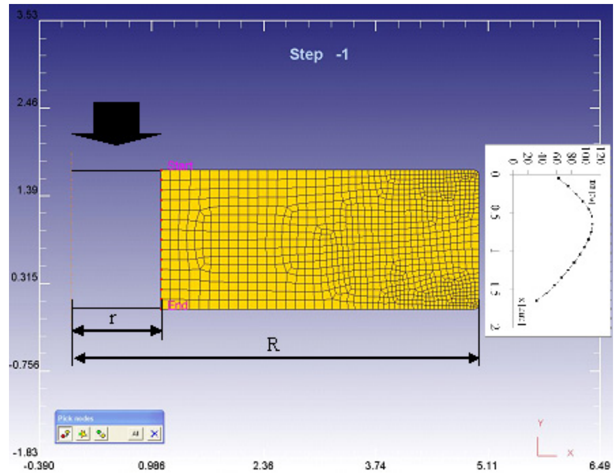

Figure 6: Model, mesh and boundary conditions for thermal calculations.

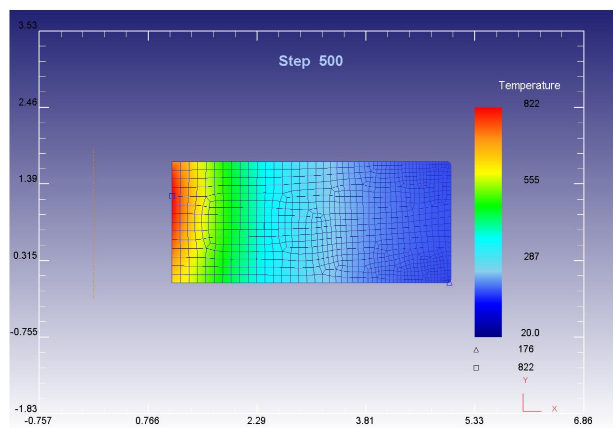

Figure 7: Heat flow through the Ta target after 500s irradiation.

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