STUDY OF AN ELECTRON LINAC DRIVEN X-RAY RADIO-TOMOGRAPHIC SYSTEM RESPONSE AS A FUNCTION OF THE ELECTRON BEAM CURRENT

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Abstract

At the Dipartimento di Fisica, Università di Messina, a high energy x-ray radio-tomographc system driven by a 5 MeV electron linac, has been recently assembled. It has been tested and has already provided good results in inspecting heavy materials.

In order to achieve good radiographic results, especially when inspecting heavy or thick materials, an enhancement of the x-ray dose at the sample position can be required and most of times this is associated to an enhancement of the grey level in the acquired image, according to a linear function.

Nevertheless, in the hypothesis to work at the maximum magnetron power, a variation of the x-ray dose, obtained changing the electron beam current, is associated to a variation of the electron beam energy. As a consequence, the x-ray energy spectrum varies thus influencing the response of the radio-tomographic system. This does not allow a linear correspondence between the x-ray fluence (or the electron beam current) and the image grey level.

By means of MCNP-4C2 simulations, the influence of electron beam energy variations on the produced bremsstrahlung spectrum has been studied and the theoretical results seems to be confirmed by the preliminary experimental ones.

INTRODUCTION

Non Destructive Testing (NDT) is the most used technique in inspecting defects, structure and composition of materials.

As known, commercial x-ray tubes provide bremsstrahlung x-rays up to 600 keV, which attenuation inside materials limits their application to the inspection of light or thin samples.

As a consequence, when a thick sample or a heavy material has to be inspected, higher energy x-rays are needed. A compact, low energy (up to 10 MeV) electron linac, coupled to a suitable bremsstrahlung converter, can be used as a x-ray source for high energy radio-tomography purposes. To the aim to set up a high energy system for x-ray radio-tomography, the 5 MeV, 1kW, S-band electron linac hosted at the Dipartimento di Fisica, Università di Messina [1], has been used to design a x-ray source. A wide study has been performed by means of MCNP4C2 (Monte Carlo N Particle, version 4C2) [2] code thus to optimize all parameters influencing the x-ray production [3]. The radio-tomographic system has been set up and tested [4].

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In order to study the performances of the radio-tomographic device, it is fundamental to test its response as a function of the x-ray flux intensity at the sample position. Such a study also allows the user to choose the suitable electron linac parameters (consequently, energy and intensity of the x-ray beam) when inspecting materials.

In the hypothesis to work at the same magnetron RF generator power (e.g. the maximum one), the response of the radio-tomographic device to a variation of the electron current is not so obvious.

In this paper, a theoretical study of the effects of a variation of the electron current on the produced x-ray beams, then on the response of the radio-tomographic device, at constant magnetron power, is discussed.

THE THEORETICAL STUDY

In the hypothesis to work at fixed magnetron power, a variation of the linac electron current causes a change in the energy of the beam. Once calibrated, the energy of the electron beam can be set up by choosing the electron current.

In this context, if the electron beam is directed on a properly chosen target to produce x-rays, also the x-ray beam energy varies according to the electron current variation, thus allowing the production of bremsstrahlung beams showing different end-point energies.

The effect of the electron beam energy variation as a consequence of the electron beam current variation on the produced x-ray beam has been theoretically studied. The simulated device entirely reproduces the elsewhere discussed radio-tomographic set up [3].

Supposing to work at a fixed magnetron power, the calculated electron beam energies, for electron currents of 10, 20, 30, 40, 60 and 80 mA, are 7.4, 7.29, 7.17, 7.05, 6.81 and 6.58 MeV, respectively.

The energy spectra, as photons/cm$^2\mu$C, of the bremsstrahlung beams obtained simulating the energies above listed, are shown in Fig. 1.

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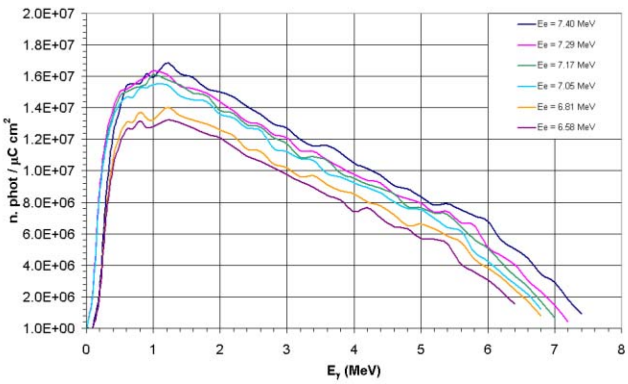

Figure 1: Energy spectra, as photons/cm$^2\mu$C vs MeV, of the bremsstrahlung beams obtained selecting different electron energies.

Due to the little difference among the selected electron energies, the x-ray energy spectra does not differ much each other. Nevertheless, being the energy strictly related to the chosen electron current, i.e. to the μC/s reaching the bremsstrahlung converting target, it has more sense to compare the spectra in terms of photons/cm^2 s rather than in terms of photons/cm$^2\mu$C, as shown in Fig. 2.

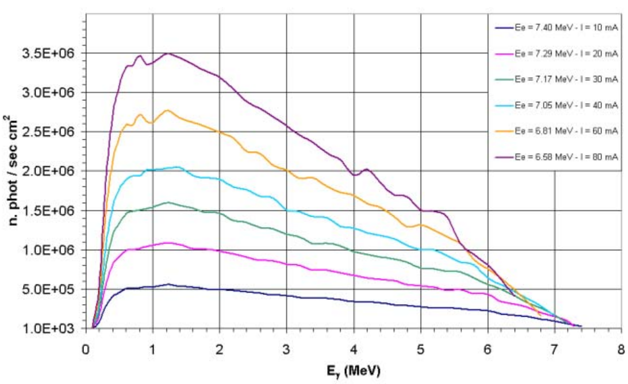

Figure 2: Energy spectra, as photons/cm^2 s vs MeV, of the bremsstrahlung beams obtained selecting different electron energies.

It can be stated that both x-ray fluence and energy are strongly modulated by the selected current, while the end-point of the bremsstrahlung spectra remains more or less the same, being this uniquely affected by the electron beam energy.

The way the energy spectra vary as a function of the electron current (at fixed magnetron power) can be plotted as a quadratic and not as a linear function, as it should be in the case of variable magnetron power and electron current but fixed energy. To underline this behavior, two cases have been considered:

- the magnetron power has been changed according to the electron current thus to maintain the electron energy always constant; an electron beam energy of 7.4 MeV has been considered.
- the magnetron power has been kept constant; a change of the electron beam current causes a variation of the electron beam energy.

The comparison between the energy spectra of the x-ray beams produced in the two cases, is shown in Fig. 3.

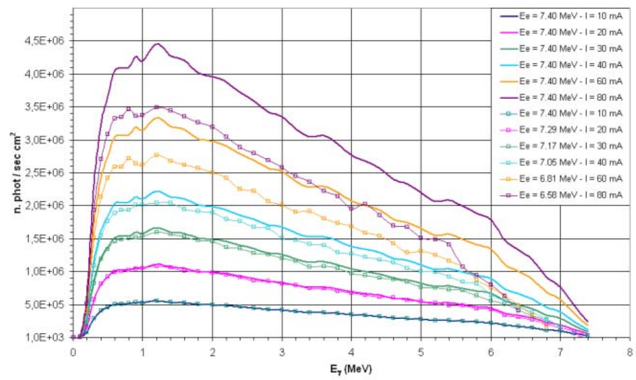

Figure 3: Comparison between energy spectra obtained for fixed and not fixed magnetron power cases.

In the first case, an increase of the electron current causes an enhancement in the number of electrons in the beam, allowing the flux of produced x-rays to also increase, but no modification of the x-ray energy spectrum is observed. The way the x-ray flux varies as a function of the electron current can be expected to be linear.

On the contrary, in the second case, a change of the electron current affects both energy and number of electrons in the beam thus causing a modulation of both number and energy of the produced x-rays. The bremsstrahlung spectrum is entirely modulated.

The way the x-ray flux varies as a function of the electron current is no more linear.

Fig. 4 shows the integrated photon flux as a function of the electron current for both cases, confirming the discussed hypothesis.

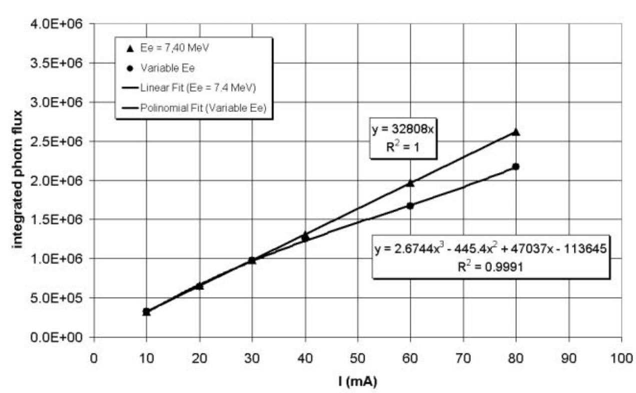

Figure 4: Comparison between integrated x-ray flux as a function of the electron current for fixed and not-fixed magnetron power cases.

PRELIMINARY EXPERIMENTAL RESULTS

A rigorous comparison between theoretical and experimental results would require the acquisition of the different bremsstrahlung spectra provided at different electron current values. However, due to the high x-ray production rate, not endurable by any available detector, a direct measure of the x-ray spectra has not been possible to achieve. For this reason, it has been chosen to have a measure of the intensity of the x-ray source by analyzing the x-ray beam spot images acquired at the sample position.

Without any sample to inspect, a x-ray beam spot image can be acquired by the imaging system coupled to the x-ray source [4] and analyzed in terms of image grey level. For a fixed value of the magnetron power, the electron current has been changed in the 10-80 mA interval and the corresponding x-ray beam spot images have been acquired and analyzed.

In Fig. 5 the mean grey level value of the x-ray beam spot images is plotted as a function of the electron current. As expected, the grey level in images does not show a linear trend as the electron current varies.

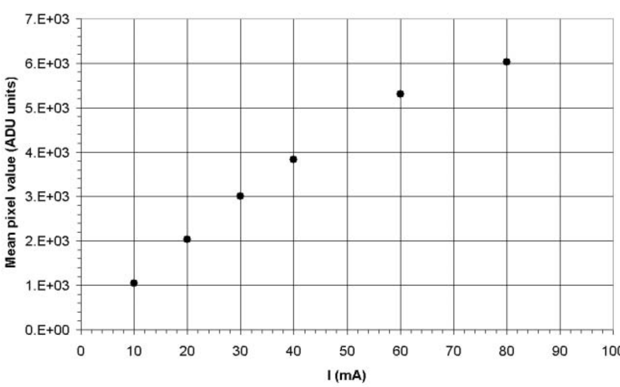

Figure 5: Grey level intensity in the x-ray beam spot acquired imaged as a function of the electron current.

In Fig. 6 the mean grey level value of the x-ray beam spot image and the integrated photon flux (normalized to the area of the x-ray beam spot at the sample position and rescaled by a suitable factor, for a more immediate reading) have been plotted as a function of the electron current, for a qualitative comparison.

A good agreement can be observed between the two plotted trends except for 80 mA current. Nevertheless, up to now no hypothesis have been made on the linearity of the response of the imaging system as the x-ray intensity grows. The eventual non-linearity due to the not-linear response of the scintillating GOS screen, could contribute to stress the non linear trend of the mean grey level value in the x-ray beam spot images.

Work is still in progress to refine the analysis thus taking into account also the intrinsic non-linearity of the imaging system and allowing a direct comparison between grey level value and x-ray intensity.

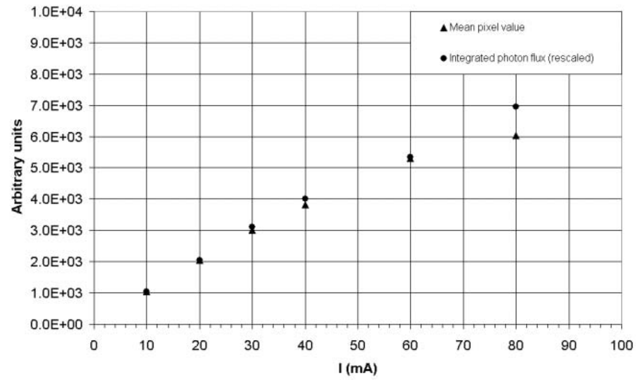

Figure 6: Qualitative comparison between trends of the mean grey level value in x-ray beam spot images and the integrated photon flux (at the sample position and normalized to the area of the x-ray beam spot) as a function of the electron current.

CONCLUSION

By means of MCNP4C2 simulations and preliminary measurements, the response of the radio-tomographic system driven by the 5 MeV electron linac hosted at the Dipartimento di Fisica, Università di Messina, as a function of the electron beam current has been studied.

In the hypothesis to work at constant magnetron RF power, results show that the non-linearity of the response of the device (in terms of mean grey level values in the acquired images) can be partially addressed to the energy change of the electron beam caused by a variation of the electron current.

Further measurements are in progress to refine the experimental evaluation of the percentage of non-linearity to be addressed to the electron current variation and to the imaging system, respectively.

REFERENCES

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[4] L. Auditore, R.C. Barnà, D. De Pasquale, U. Emanuele, A. Italiano, D. Loria, A. Trifirò and M. Trimarchi Proceedings of the 21st Particle Accelerator Conference PAC05, May 16-20, 2005, Knoxville, Tennessee, USA.