A COMPACT 5 MeV S-BAND ELECTRON LINAC BASED X-RAY SOURCE FOR INDUSTRIAL RADIOGRAPHY.

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Abstract

A compact and reliable X-ray source, based on a 5 MeV, 1 kW, S-band electron linac, has been set up at the Dipartimento di Fisica, Università di Messina. This source, coupled with a GOS scintillator screen and a CCD camera, represents an innovative transportable system for industrial radiography and X-ray tomography. Optimization of the parameters influencing the e-γ conversion and the X-ray beam characteristics have been studied by means of the MCNP-4C2 (Monte-Carlo-N-Particle, version 4C2) code. The converter choice is the result of the study of the e-γ conversion performances for different materials and material thicknesses. Also the converter position with respect to the linac exit window has been studied. The chosen converter consists in a W-Cu target inserted close to the linac window. In the final source project, a collimation system provides a 14 cm diameter X-ray spot at the sample position, and preliminary radiographic results have been obtained by inspecting different density materials and thicknesses.

THE ACCELERATOR

The availability of an S-band, 1 kW, 5 MeV electron linac at Dipartimento di Fisica, Università di Messina [1], has suggested the idea to design and assemble a bremmstrahlung X-ray source for high energy radiographic purposes [2, 3].

The electron linac provides a very compact and autofocusing structure which could match some industrial requirements. Main features of the electron linac are summarized in Table 1.

Table 1: Main features of the S-band Electron Linac held in Messina.

Energy (MeV)	3.5 - 5.5
Structure type	SWOAC
Peak Current (mA)	200
Operating mode	$\pi/2$
Repetition Rate (Hz)	1-300
N. Accelerating Cavities	9
Pulse duration (μsec)	3
Magnetic Lenses	NO
Peak Power (MW)	1
Lenght(cm)	40
Average Power (kW)	1
Weight (kg)	25
RF Frequency (GHz)	2.997
Beam aperture size (mm)	12

THE BREMMSTRAHLUNG CONVERTER

Many bremmstrahlung target designs can be found in literature (see [2], for example) but a systematic study of the bremmstrahlung production performances of different materials does not exist. To this aim, several MCNP-4C2 [5] simulations have been performed to study the bremmstrahlung production by different target materials and material thicknesses by considering a 5 MeV electron beam. For practical reasons a 1mm thick W target has been chosen as the e-γ converter, coupled to a 9 mm Cu layer acting as a filter both for electrons from the source (which are not stopped in the W target) and for low-energy X-rays. The bremmstrahlung spectrum from the W-Cu target is shown in Fig.1.

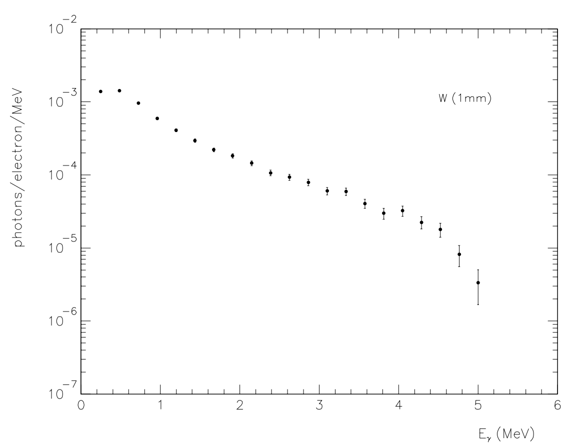

Figure 1: Bremmstrahlung spectrum from 1 mm thick W target coupled to a 9 mm thick Cu layer.

The converter position with respect to the linac exit window has been also studied and the effects of the electron beam spread on the X-rays production have been estimated. As expected, inserting the converter at increasing distances

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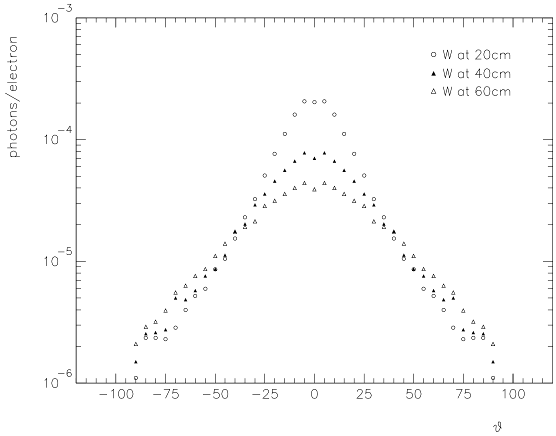

Figure 2: X-ray flux angular distribution as a function of the distance between the linac exit window and the converter.

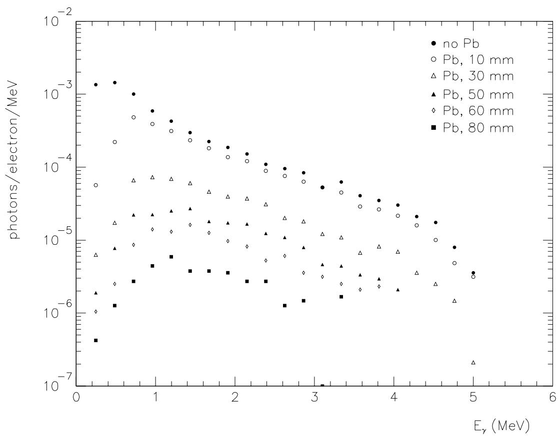

Figure 3: Influence of different thicknesses lead layers on the bremmstrahlung spectrum.

from the linac exit window, the X-ray yield decreases, as shown in Fig.2. This behaviour enables the user to choose the suitable linac-exit-window to γ -converter distance to properly modulate the beam intensity for his purposes.

THE X-RAY FILTER

As anticipated, the X-ray source design was performed to assemble an high energy radiographic system. Depending on the sample to inspect, a suitable energy range have to be selected to improve the image quality. To this aim, several simulations have been performed to estimate the energy range selection obtainable by inserting different filtering materials. Generally light elements, such as copper, are used to filter low energy X-rays or to avoid contamination of the beam by electrons coming from the source. Nevertheless, when a strong energy selection is needed, heavy materials can be used. As shown in Fig.3, the insertion of thick lead layers can act as a selector of the beam energy, provided that an energy range selection and not a single energy selection can be performed. Note that the insertion of an energy selector causes a bunch of low energy X-rays randomly distributed, and that the use of a properly designed collimation system after the selector is needed.

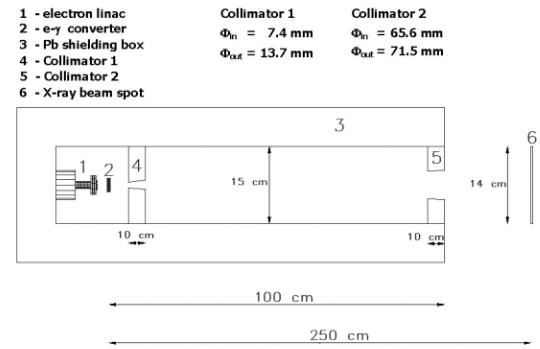

Figure 4: Final X-ray source configuration.

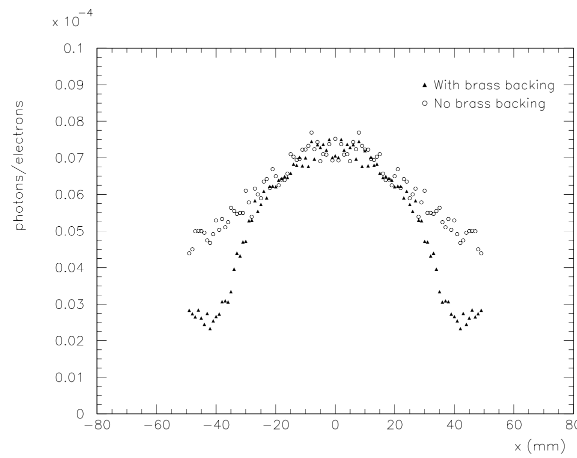

Figure 5: Radial X-ray flux with and without brass backing.

THE COLLIMATION SYSTEM

A collimation system has been designed to obtain a spot of about 14 cm diameter of parallel X-rays at the sample position. This spot dimension has been chosen as the compromise between the limited sizes of the laboratory actually hosting the 5 MeV linac and the requirements of a good radiographic set-up.

The collimation system consists of two collimators, both 100 mm thick, which lateral dimensions have been properly chosen to avoid the affection of the X-ray beam from scattered particles. Each collimator provides a conic-shaped hole which inner and outer diameters are 7.4 mm and 13.7 mm for the first one (inserted next to the source) and 65.6 mm and 71.5 mm for the second one (inserted at 100 cm from the source).

The final configuration of the assembled X-ray source is shown in Fig.4, including the linac shielding.

Moreover, to easily switch from e-beam line to X-ray beam line, a cylindrical brass backing for the converter has been assembled, acting as a filter for low energy X-rays and

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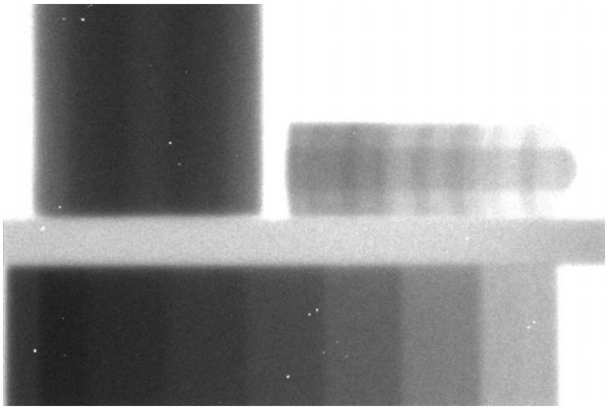

Figure 6: Inspected objects: a lead cylinder providing a central hole; a steel object; a perspex layer; a lead ladder.

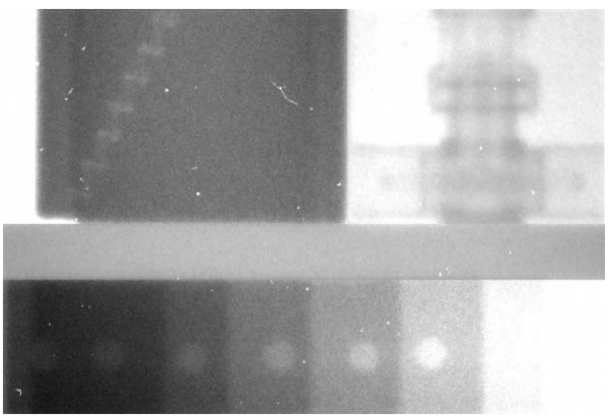

Figure 7: Inspected objects: iron overlapped ladders; a BNC connector; a perspex layer; a brass ladder providing a 5 mm deep hole on each step.

as a preliminary collimator, as shown in Fig.5.

PRELIMINARY RADIOGRAPHIC RESULTS

Preliminary radiographies have been obtained by coupling a cooled CCD camera (Apogee Alta E1) to a GOS screen, type MedeX Portal. These first results, as shown in Fig.6,7, enabled us to schedule some changes to the radiographic system thus to achieve a higher image quality. Moreover, an analytical study has been prompted to evaluate the experimental limits of our system.

In Fig. 8 a radiographic image of four ladders consisting of four different materials is shown. Each ladder provides 3 steps which thicknesses show a logarithmic behaviour. From the left side to the right side of Fig. 8, aluminum, brass, steel and lead ladders are shown. The thickness is mantained constant going from the left side to the right side and decreases going from the bottom to the top of the image. Fig. 8 provides an idea of the density resolution of our system, thus resolving between different materials and thicknesses within a large density range.

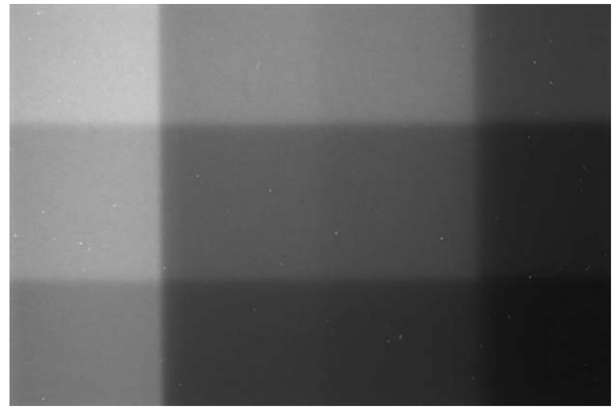

Figure 8: Radiographic image of four ladders consisting of four different materials.

Work is still in progress to achieve better image quality and to reach the goal of the TRALIN experiment, held by the INFN Messina Group, which consists in the assembly of a transportable high energy radiographic system thus to enable the radiography of giant structures such as statues or pillars and requiring high energy X-rays.

CONCLUSION

An X-ray source based on a 5 MeV, S-band, 1 kW, electron linac was designed by means of the MCNP-4C2 code and assembled at Dipartimento di Fisica, Università di Messina, for high energy radiographic purposes. First digital radiographic images have been acquired and work is still in progress to develope the system thus to achieve good image quality.

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