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ScienceDirect
Nuclear Instruments and Methods in Physics Research B 266 (2008) 2138–2141
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

X-ray tomography system for industrial applications

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Available online 13 March 2008

Abstract

X-ray radiography and tomography are two of the most used non-destructive testing techniques both in industrial and cultural heritage fields. However, the inspection of heavy materials or thick objects requires X-ray energies larger than the maximum energy provided by commercial X-ray tubes (600 kV). For this reason, and owing to the long experience of the INFN-Gruppo Collegato di Messina in designing and assembling low energy electron linacs, a 5 MeV electron linac based X-ray tomographic system has been developed at the Dipartimento di Fisica, Università di Messina. The X-ray source, properly designed, provides a 16 cm diameter X-ray spot at the sample position, and a beam opening angle of about 3.6 degree. 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 image acquisition system consists of a CCD camera and a scintillator screen. Preliminary radiographies and tomographies showing the high quality performances of the tomographic system have been acquired. Finally, the compactness of the accelerator system is one of the advantages of the discussed tomography device which could be made transportable.

PACS: 41.50.+h; 29.17.+w; 07.85.Fv; 07.05.Tp; 87.59.−e; 87.59.Bf

Keywords: X-ray radiography and tomography; Electron linac

1. Experimental setup

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

This accelerating structure is very compact, thus being a promising starting point for the design of a mobile tomographic system for in situ inspections. In Fig. 1 the design of a compact linac prototype with the same accelerating structure of the existing linac is shown.

Moreover, both electron current and repetition rate can vary within wide ranges, allowing the user to set a variety of different irradiation conditions, thus satisfying the most different experimental requirements. The Bremsstrahlung source [2], entirely designed by means of the MCNP-4C2 (Monte-Carlo-N-Particle, version 4C2) code [3], has been assembled using a W converter, 1 mm thick, coupled to a 9 mm thick Cu layer, which is used for filtering the produced X-ray beam both from primary electrons and low energy X-rays. It has been then coupled to a collimation system, providing an X-ray spot of about 16 cm diameters at the sample position, and a beam aperture of about 3.8°. The image acquisition system consists of a CCD camera and a scintillator screen, as shown in Fig. 2.

Main parameters of the CCD camera (Alta Apogee E1) are: 768×512 pixel resolution; 9×9 square pixels; low dark current (10 pA/cm^2@25 °C); cooling range of 40 °C below the room temperature. In order to preserve the

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doi:10.1016/j.nimb.2008.02.082

Table 1
Main features of the S-band electron linac held in Messina

Energy (MeV)	3.5–5.5
Peak current (mA)	200
Repetition rate (Hz)	1–300
Pulse duration (μs)	3
Peak power (MW)	1
Average power (kW)	1
RF frequency (GHz)	2.997
Structure type	SWOAC
Operating mode	$\pi/2$
No. accelerating cavities	9
Magnetic lenses	NO
Length (cm)	40
Weight (kg)	25
Beam aperture size (mm)	12

CCD camera from radiation damage, it has been set at 90° with respect to the beam direction and 100 cm far from the mirror reflecting the image from the scintillator screen to the camera. An aluminated mirror has been used thus reducing image distortion. A lead glass, 2.5 cm thick, has been inserted between aluminated mirror and CCD camera, to the aim to avoid that spurious X-rays reach the CCD.

2. Tomographic system

An acquisition of the X-ray spot has been performed by coupling the CCD to the GOS (Gd SiO) scintillator screen [4,5], thus to view the whole X-ray spot. In Fig. 3 the experimental X-ray spot profile is shown, together with the MCNP simulation results.

X-ray spot profile gives information both on the photon flux uniformity overall the spot extension, resulting to be

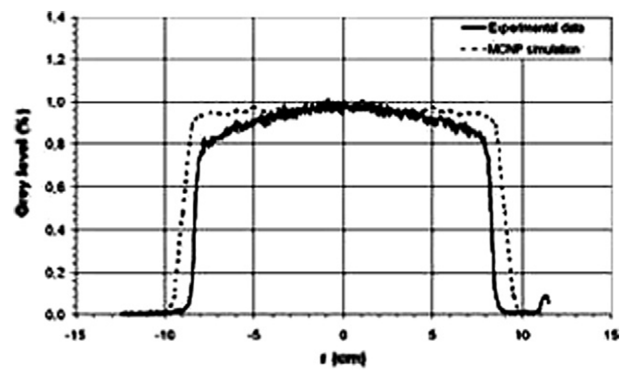

Fig. 3. Comparison between the experimental X-ray spot and the MCNP simulations.

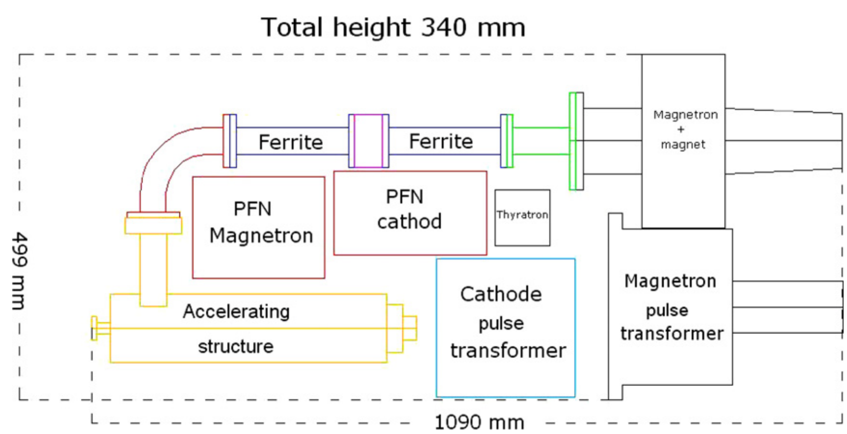

Fig. 1. Design of a compact 5 MeV, S-band, 1 kW, electron linac.

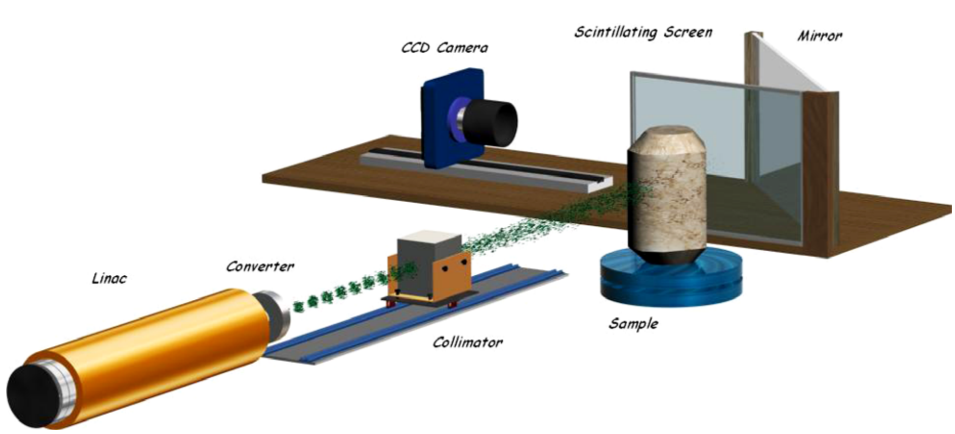

Fig. 2. 3D design of the image acquisition system.