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High Resolution, Large Area, High Energy X-ray Tomography

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ABSTRACT

An x-ray tomography system is being developed for high resolution inspection of large objects. The goal is to achieve 25 micron resolution over object sizes that are tens of centimeters in extent. Typical objects will be metal in composition and therefore high energy, few MeV x-rays will be required. A proof-of-principle system with a limited field of view has been developed. Preliminary results are presented.

Key words: x-ray tomography, glass scintillator, CCD imaging

INTRODUCTION

As part of the Enhanced Surveillance Program of the U.S. Department of Energy, a high resolution x-ray tomography inspection system for weapons components applications is being developed. The goal for this system is to achieve 25 micron resolution with objects that are tens of centimeters across. This will result in data sets with 10^{12} voxels or more. We report in this paper the first steps toward developing the required system. A limited field of view proof-of-principle system has been constructed and successfully operated. The point spread function has been measured and simple objects have been imaged. The limited field of view system was developed as a means of economically and quickly testing the basic design in terms of achievable resolution. The tested system is scaleable to larger fields of view. Issues relating to the data storage and analysis for large 10^{12} voxel images are not being addressed at this point in the project due to the rapid and continuing revolution in computer capabilities. These will be addressed later in the project although preliminary analyses indicate image reconstruction, display and storage of large data sets will not be a severe limitation.

PROOF-OF-PRINCIPAL SYSTEM

The proof of principal system, shown in Figure 1, consists of an 9 MeV accelerator based bremsstrahlung x-ray source, a rotating platform for the object, a large glass plate scintillator, an imaging lens, and a visible light CCD for ultimate image detection. The x-ray source is a Varian 9 MeV Linatron with a 2 mm source size producing approximately 10^8 x-rays/cm²/sec in the 3-5 MeV band used for the objects of interest. The calculated spectrum is shown in Figure 2. The source size is 2 mm producing a typical source un-sharpness of 25 microns at a distance of 3 meters for typical objects.

The glass scintillator plate is composed of IQI terbium doped glass. X-rays produced by the Linatron propagate through the object and into the scintillator glass where they are converted into visible light fluorescence with a spatially varying intensity which is a function of the local x-ray transmission of the object. Multiple scattering, the generation of Compton electrons, and the generation of secondary x-rays and electrons result in a degradation of the x-ray image as the x-rays propagate through the object and as they are deposited in the glass. The energy deposition process has been modeled using a Monte Carlo simulation. The point spread function (PSF) with a full width half maximum (FWHM) of 33 microns was calculated from the results of the simulation for 6 mm thick glass. No visible light optical effects such as scattering from realistically rough surfaces or refraction were included in the calculations. The calculated PSF is shown in Figure 3. Thicker glass will have a higher x-ray conversion efficiency and a broader PSF. Thinner glass will have a narrower PSF and lower conversion efficiency.

Figure 1. Schematic of the x-ray tomography system showing the x-ray source, the object, the scintillator plate, the turning mirrors, the imaging lens, and the CCD detector.

Figure 2. The calculated x-ray spectrum produced by the x-ray source.

Figure 3. The calculated point spread function for 6 mm scintillator glass. Visible light optical effects as well as limitations resulting from the lens/CCD combination are not included in the calculation.

The visible light fluorescence image in the glass is then relayed by a high quality camera lens onto a CCD detector. Several lenses have been tested including 50, 105, and 200 mm Nikon Macro lenses. The lens and geometry of the system are varied to control the field of view and magnification. An Axiom AX-2 1536 x 1024 CCD detector with 9 micron pixels was used to detect the visible light. The lens/CCD combination was measured to have a 50 micron FWHM PSF when the magnification was adjusted to give a pixel size of 25 microns at the scintillator. This camera was shielded by 6 inches of lead.

The PSF of the entire system was measured using a tungsten edge. This was done for 2 mm thick glass, 6 mm thick glass, and for a 12 mm thick fiber optic face plate with 10 micron pores. The measured PSF for 6 mm glass is shown in Figure 4. The measured FWHM for the 6 mm thick glass detector was .125 microns.

Figure 4. The measured point spread function using 6 mm scintillator glass. The effects resulting from the lens/CCD detector are included in the measurement.

The PSF FWHMs, corrected for source un-sharpness and the optical broadening in the lens/CCD system as well as the data acquisition times, are given in the chart below:

<u>Glass thickness</u>	<u>Exposure time</u>	<u>PSF FWHM</u>
2 mm	360 sec	85 microns
6 mm	120 sec	115 microns
12 mm	40 sec	285 microns

The measured PSF FWHM for the 6 mm glass, when corrected for source broadening and lens/CCD limitations was 115 microns. This differed considerably from the calculated PSF FWHM of 33 microns. This may be due to visible light scattering effects and refractions effects not included in the Monte Carlo model.

SUMMARY

A large field of view, high energy x-ray tomography system has been developed for preliminary testing. Measurements of the system resolution indicate that the achievable system resolution is 125 microns FWHM. Efforts to improve this are underway.

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