HIGH-ENERGY GAMMA-RAY CT WITH LASER-COMPTON PHOTON BEAM

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Abstract

A high-energy gamma-ray radiography system for nondestructive inspection of bulk materials and industrial products was developed in AIST. High- and low-contrast resolutions were measured with an aluminium phantom and a set of testing object made of various materials.

1   Introduction

High-energy photon transmission radiography and Computerized Tomography (CT) are the common tools for the nondestructive inspection of industrial products, such as parts of motor vehicles, aircrafts, construction materials and power plants. Several CT systems for the nondestructive inspection of the industrial products apply an electron linear accelerator (linac). The linac produces high-energy bremsstrahlung X-rays which are exposed onto a sample object. The CT system based on the compact linac whose electron energy is typically about 10 MeV or less is preferably used in many industrial facilities for various purposes.

There is a complexity on the reconstruction process, called the spectrum hardening effect, associated with the CT system using polychromatic X-rays, such as the one based on the linac. The spectrum hardening effect causes a cupping effect and some other artifacts on the reconstructed CT image. So, it is necessary to calibrate the CT system using a standard sample or phantom, prior to the inspection for the CT experiments using the polychromatic photons.

Monochromatic photons, or the polychromatic ones with a small energy spread, which are called the quasi-monochromatic photons, do not require the calibration processes, in principle. So, the CT system based on the quasi-monochromatic photons give us qualitative and more accurate information about the linear attenuation coefficient of the sample object. So, an industrial CT system based on the high-energy and quasi-monochromatic photons is ideal for the nondestructive inspection of industrial products such as metal diecasts and sintered materials. There will be no artifact due to the spectrum hardening effect.

2   Description of the CT system

We have been developing a High-Energy and Quasi-monochromatic photon transmission radiography and CT systems (HEQ-CT) [1,2] for the nondestructive inspection of large industrial products using the laser-Compton photons of AIST in Tsukuba [3,4], and

have been tuning the system parameters to give an optimal CT image with an appropriate quality. AIST laser-Compton photon facility provides the high-energy and tunable-spectrum quasi-monochromatic photon beam. The tunable range of the photon energy and the energy spread are from 1 to 40 MeV and a few to few tens of percents, respectively. In this energy range, the dominant interaction process of the photons to the atoms in the materials is the pair creation, whose interaction cross-section shows moderate dependence on the photon
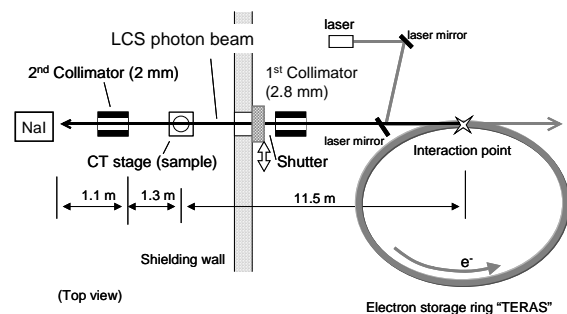

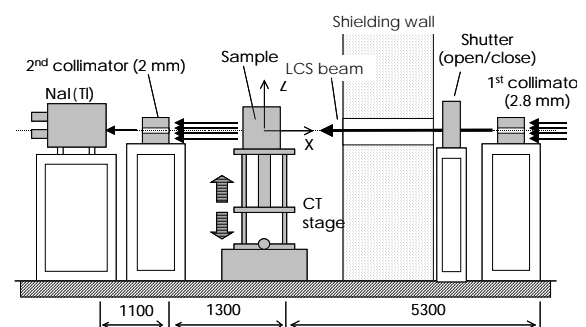Fig. 1 Schematic drawing of the overall laser-Compton photon beamline.

Fig. 2   Side view of the beamline and the setup for CT experiment.

energy.

3   Experiment

Overall beamline and the experimental setup are shown in Fig. 1. The photon beam is transported 11.5 m

in the air from the electron storage ring to the sample object. The experimental setup is designed so that the beamline did not interfere with other beamlines and vacuum components. In this study, we put the CT stage downstream of the radiation shielding wall and the beam shutter, which was located 8 m downstream of the light source, to protect the motors and the sensors of the CT stage from the radiation damage during the electron injection into the storage ring.

A schematic drawing of the CT stage and the experimental components is shown in Fig. 2. We used a large NaI(Tl) single crystal scintillation detector with a diameter and an axial length of 8 inch and 12 inch, respectively, to monitor the energy spectrum and the intensity of the photons.

Because the quasi-monochromatic laser-Compton photon is a pencil-beam whose diameter is about a few mm to 1 cm, we built the 1st generation CT system. The CT stage translate and rotate repeatedly with respect to the photon beam. In this configuration, the smaller the effective beam size at the sample object, the better the spatial resolution. As a compromise among the expected photon intensity, energy spread, required spatial resolution, and time resolution, we put a lead collimator of inner aperture of 2 mm and the length of 100 mm at 1.3 m behind the sample object. The diameter and the divergence of the photon beam were, then, 1.8 mm and 70 μrad at the sample location, assuming the point source geometry.

We used the aluminum and iron for materials of small and large linear attenuation coefficients, respectively. An aluminum phantom of diameter of 80 mm and height of 50 mm with iron rods of diameters of 1, 2, 4, and 8 mm inserted in it, was used as a phantom.

4 Experimental results

Image reconstruction was done with the filtered-back-projection (FBP) method off-line. The logarithms of the projection data normalized to the incident photon intensity were Fourier transformed using the Fast Fourier Transformation (FFT) algorithm, and multiplied by the filtering function. We used a Ramachandran-Lakshminarayanan (Ram-Lak) filter with the cutoff at the Nyquist frequency. The data in the Fourier regime were, then, inversely FFT followed by the coordinate exchange according to the standard tomography method.

Fig. 3a and 3b show a photograph and the reconstructed CT image of the phantom. The white level is proportional to the linear attenuation coefficient of the phantom. Figure 4 shows the measured full width at half maximum (FWHM) of the profiles for iron rods of 1, 2, 4, 8 mm, respectively. The solid line is the least-squared linear fit to the data points for the rods of 4 and 8 mm, while the broken line indicates the least-squared parabolic fit curve to the data points for the rods of 1, 2,

and 4 mm. The zero extrapolation of the parabolic fit was

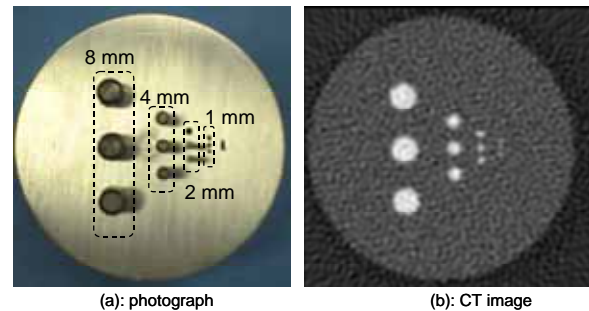(a): photograph   (b): CT image

Fig. 3   Photograph (a) and the CT image (b) of the aluminum phantom.

1.39 mm, which is an intrinsic high-contrast resolution of the CT system.

High-contrast resolution is also evaluated by the sharpness of the edge response function, which is evaluated from the first derivative of the image intensity as a function of position. It was measured to be 1.38±0.19 mm. The high-contrast resolution was, then, evaluated as 1.38±0.17 mm.

Fig. 5 shows a CT image for samples of various densities and attenuation coefficients. The two bottom ones are of water and deuteriated water, respectively, while others are silicon, aluminium, magnesium, copper and other materials. CT value, which corresponds to the linear attenuation coefficients, in this study was plotted as a function of NIST data [5], which showed excellent linearity. The low-contrast resolution was measure to be 5%.

5 Discussion

As we can see clearly in the CT image of Fig. 6b, that the 2 mm rods are well recognized individually but the 1 mm rods are not, the overall high-contrast resolution of the present CT system is estimated between 1 and 2 mm.
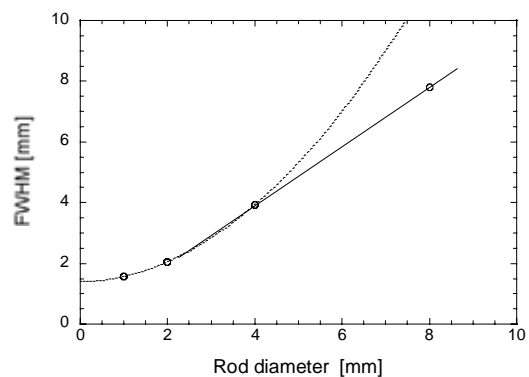

Fig. 4   Measured FWHM for the rods of 1 to 8 mm. The broken line indicates the least-squared parabolic fit to the data points for the rods of 1, 2, and 4 mm. The zero extrapolation of the parabolic fit was 1.39 mm.

So, the evaluated resolution (1.39±0.17 mm) is a reasonable one.

6   Conclusion

High- and low-contrast resolutions of the high-energy and quasi-monochromatic photon transmission CT system were measured. They were 1.39±0.17 mm and 5 %, respectively. To enhance the image quality, noise reduction and the frequency filtering will be optimised. Other improvements are being undergone.

Acknowledgement

References

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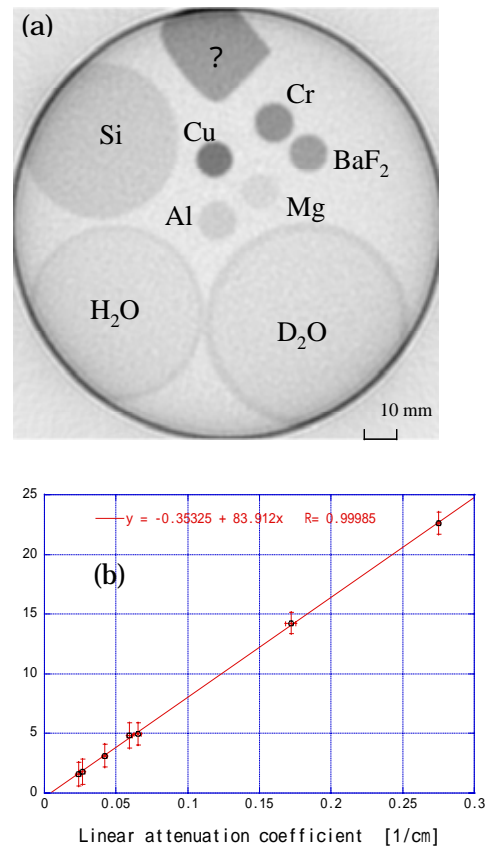
Fig. 5 Transmission CT for various materials (a), and the plot of estimated linear attenuation coefficients plotted along with the original ones (b), evaluated by the data from NIST [5].