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Transmission computerized tomography with a high-energy and quasi-monochromatic photon beam

Hiroyuki Toyokawa*

Research Institute of Instrumentation Frontier, National Institute of Advanced Industrial Science and Technology (AIST), 1-1-1 Umezono, Tsukuba, Ibaraki 3058568, Japan

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Abstract

A high-energy and quasi-monochromatic photon transmission Computerized Tomography system has been developed. The system is used for a nondestructive inspection of industrial products with high-atomic number and high density, and for high-quality inspection of homogeneity/heterogeneity of sintered materials or metal diecasts. Overall system description and some experimental results measured with the prototype CT system are presented.

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1. Introduction

High-energy photon transmission radiography and Computerized Tomography (CT) is one of the simple and conventional methods for nondestructive inspection of industrial products. Some systems use high-energy gamma-rays from radioactive isotopes [1,2], and some use high-energy Bremsstrahlung X-rays from an electron accelerator. The latter one is widely used in many industrial and research facilities for inspections of industrial products with high-atomic numbers or high density, such as composite parts for electronic devices, motor vehicle, aircraft, and power plant. Many of them apply a compact electron accelerator whose electron energy is less than about 10 MeV to suppress neutron production, so that the overall system can be compact.

It is pointed out, however, that the energy spectrum of the Bremsstrahlung X-rays is a continuum and the average photon energy is very low, while the highest photon energy extends to the maximum electron energy. So, there are two major problems associated with this system,

*Tel.: +81 298 61 5687; fax: +81 298 61 5683.
E-mail address: h.toyokawa@aist.go.jp.
URL: http://www.aist.go.jp/index_en.html.

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because the attenuation coefficient [3] for low-energy photons, such as soft X-rays and hard X-rays is many orders larger than that for high-energy photons or gamma-rays of about 0.5 MeV or higher. The first one is that without a proper preprocessing of the data, the beam hardening effect causes an artifact on the reconstructed images because the photons are polychromatic. The second one is that the overall transmission efficiency of the Bremsstrahlung X-ray is very low. So, significant amount of photons have to be incident on the test object to compensate the transmission loss. The widespread use of the radiography system using an electron accelerator owes to the fact that the photon intensity can be made high compared to the conventional radiography system using X-rays and Gamma-rays from radioactive isotopes.

Both problems can be cleared for the CT system using high-energy and quasi-monochromatic photons [4,5]. Because the beam hardening effect stems from the fact that the photon attenuation coefficient is a strong function of the photon energy, the artifact does not appear on the CT image with monochromatic photons, or with polychromatic photons of same attenuation coefficients. The photon transmission efficiency is at its maximum when the attenuation coefficient is at its minimum. For elements of high-atomic numbers, such as iron and lead which are commonly used for many industrial products, the total attenuation coefficient is at its minimum, and shows moderate dependence on the photon energy about a few MeV or higher, where the pair creation interaction is dominant. So, we will be able to enhance the image quality by a reduction of the beam-hardening effect, enhancement of transmission efficiency and linearity of measured attenuation coefficient. In this study, we will briefly describe a prototype CT system for nondestructive industrial inspection with high-energy and quasi-monochromatic photon beam.

2. High-energy and quasi-monochromatic photon beam

High-energy and quasi-monochromatic photons can be produced by the laser-Compton scattering (LCS) of an intense laser beam with relativistic electrons [6]. One of the excellent properties of the LCS photons is that the beam divergence is very small. It is on the same order of the synchrotron radiation. Fig. 1 shows a schematic drawing of the kinematics of the LCS. One can obtain photons with good directionality and with narrow spectrum width by putting a collimator along the photon beam line, because the energy of the scattered photons via the Compton scattering depends on the scattered angle, θ_2. Here is a formula, which describes the scattered photon energy as a function of the collision angles:

$$E_\gamma = \frac{E_L(1-\beta\cos[\theta_1])}{1-\beta\ \cos[\theta_2]+E_L(1-\beta\cos[\theta_2-\theta_1])/E_e} \quad \text{where } \beta=\sqrt{1-\gamma^2},\ \gamma=E_e/0.511 \tag{1}$$

where E_γ, E_L and E_e stand for the energies of a LCS photon, a laser quantum and an electron, respectively, in MeV. θ_1 and θ_2 are the angles of the laser quantum before and after the Compton scattering, measured with respect to the motion of direction of the electron, where θ_1 becomes π in the head-on configuration that we applied in this study.

We have been developing the LCS photon radiography and CT systems using the LCS photon facility of National Institute of Advanced Industrial Science and Technology (AIST) in Japan [7,8]. The photon facility generates 1–40 MeV quasi-monochromatic and energy-tunable photon beams of up to 10^6 photons cm^{-2} s^{-1} using 300–800 MeV electron storage ring

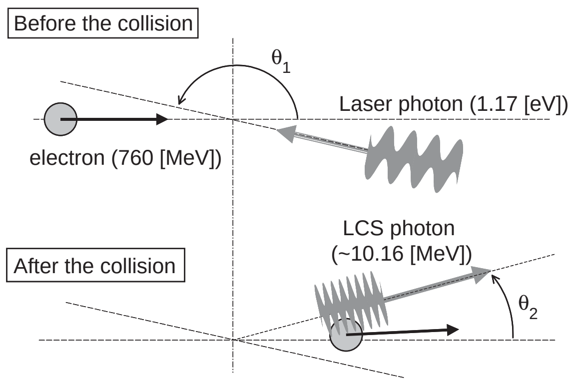

Fig. 1. Reaction kinematics of the laser-Compton scattering.