Annual Report of Iwate Medical University
School of Liberal Arts and Sciences
No. 40 (2005), 9-15.

Measurement of Cerium X-ray Spectra Using a Cerium Oxide Powder Filter and Enhanced K-edge Angiography

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(Received October 31, 2005)

Abstract

The cerium-target x-ray tube is useful in order to perform cone-beam K-edge angiography because K-series characteristic x-rays from the cerium target are absorbed effectively by iodine-based contrast media. The x-ray generator consists of a main controller and a unit with a high-voltage circuit and a fixed anode x-ray tube. The tube is a glass-enclosed diode with a cerium target and a 0.5-mm-thick beryllium window. The maximum tube voltage and current were 70 kV and 0.40 mA, respectively, and the focal-spot sizes were approximately 1×1 mm. Cerium K-series characteristic x-rays were left using a cerium oxide powder filter, and the x-ray intensity was 14.3 μGy/s at 1.0 m from the source with a tube voltage of 60 kV, a current of 0.40 mA, and an exposure time of 1.0 s. Angiography was performed with a computed radiography system using iodine-based microspheres 15 μm in diameter. In angiography of non-living animals, we observed fine blood vessels of approximately 100 μm with high contrasts.

Keywords: x-ray tube, cerium target, cerium oxide filter, powder filter, characteristic x-rays, K-edge angiography

1. Introduction

Flash x-ray generators are useful for performing high-speed radiography,[1] and several different generators with maximum photon energies of 150 keV[2-5] have been applied to biomedical radiography. By forming weakly ionized linear plasma[6-9] using a cold-cathode triode, we have succeeded in producing K-series characteristic x-rays of nickel and copper. Subsequently, we have developed super-fluorescent

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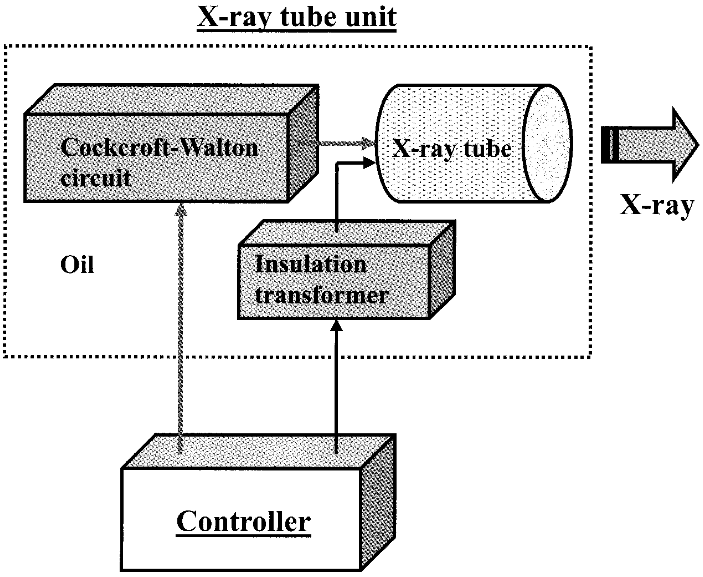

Fig. 1: Block diagram of the compact x-ray generator with a cerium-target radiation tube, which is used specially for K-edge angiography using iodine-based contrast media.

x-ray generator[10-13] to produce comparatively clean high-photon-energy characteristic x-rays of cerium and tungsten.

To produce steady state x-rays, synchrotrons generate high-dose-rate bremsstrahlung x-rays, and monochromatic parallel beams are formed using single crystals. In particular, x-rays of approximately 35 keV have been applied to perform enhanced K-edge angiography[14,15] and phase-contrast radiography,[16,17] including dark-field imaging using an analyzer crystal. Using these imaging, although the spatial resolution has been improved, it is difficult to increase the irradiation field due to the parallelity. Recently, we have developed a steady-state x-ray generator utilizing a cerium-target tube[18-20] and have demonstrated enhanced K-edge angiography utilizing a barium sulfate filter. In this research, $K\alpha$ lines (34.6 keV) were left by absorbing $K\beta$ lines (39.2 keV), and bremsstrahlung x-rays with photon energies lower than the barium K-edge (37.4 keV) were also observed. However, because cerium $K\beta$ lines are also absorbed effectively by iodine, both $K\alpha$ and $K\beta$ lines should be selected to perform angiography.

In the present research, we measured the x-ray spectra from a cerium-target tube using a new cadmium telluride detector, and performed a preliminary study on cone-beam K-edge angiography achieved with cerium characteristic x-rays using a cerium oxide powder filter.

2. Generator

Figure 1 shows the block diagram of the x-ray generator, which consists of a main controller and an x-ray tube unit with a Cockcroft-Walton circuit and a cerium-target tube. The tube voltage, the current, and the exposure time can be controlled by the controller. The main circuit for producing x-rays is illustrated in Fig. 2, and employed the Cockcroft-Walton circuit in order to decrease the dimensions of the tube unit. In the x-ray tube, the negative high-voltage is applied to the cathode electrode, and the anode (target) is connected to the tube unit case (ground potential) to cool the anode and the target effectively. The filament heating current is supplied by an AC power supply in the controller in

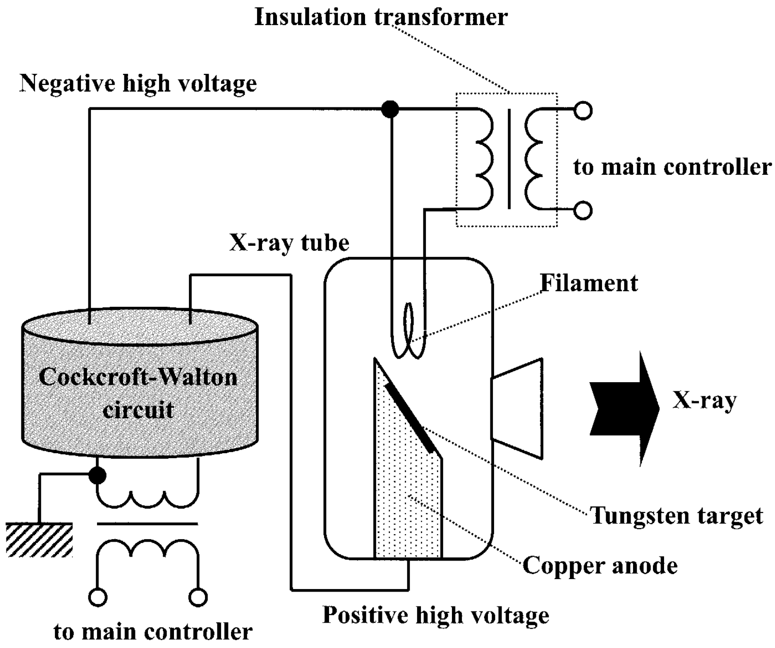

Fig. 2: Main circuit of the x-ray generator.

conjunction with an insulation transformer. In this experiment, the tube voltage applied was from 45 to 70 kV, and the tube current was regulated to within 0.40 mA (maximum current) by the filament temperature. The exposure time is controlled in order to obtain optimum x-ray intensity. Quasi-monochromatic x-rays are produced using a cerium oxide power filter with a surface density of 30 mg/cm^2.

3. Characteristics

3.1 X-ray Intensity

X-ray intensity was measured by a Victoreen 660 ionization chamber at 1.0 m from the x-ray source using the filter with an exposure time of 1.0 s (Fig. 3). At a constant tube current of 0.40 mA, the x-ray intensity increased when the tube voltage was increased. In this measurement, the intensity with a tube voltage of 60 kV and a current of 0.40 mA was 14.3 μGy/s at 1.0 m from the source.

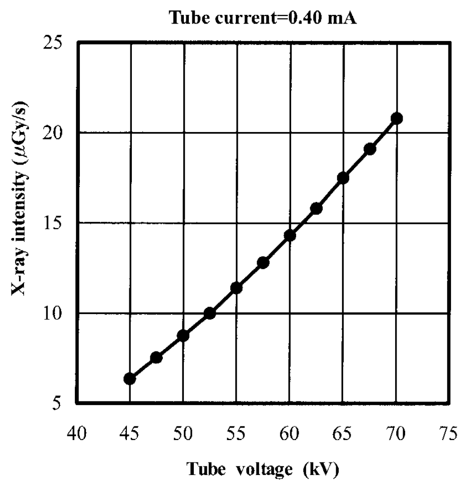

Fig. 3: X-ray intensity measured at 1.0 m from the x-ray source according to changes in the tube voltage.

3.2 Focal spot

In order to measure images of the x-ray source after the filtration, we employed a pinhole camera with a hole diameter of 50 μm (magnification ratio of 1:2) in conjunction with a Computed Radiography (CR)

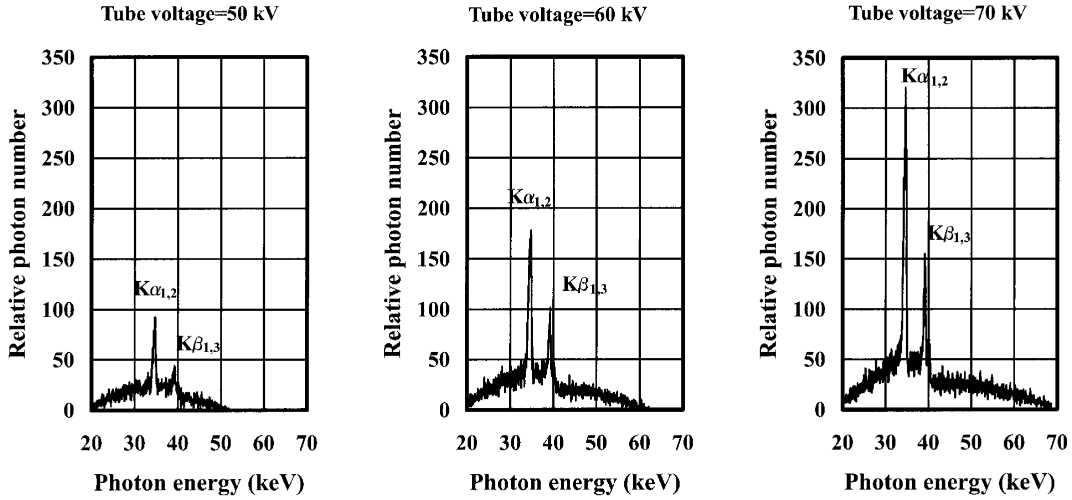

Fig. 4: X-ray spectra measured using a cadmium telluride detector with changes in the tube voltage.

system[21] with a sampling pitch of 87.5 μm. When the tube voltage was increased, spot dimensions increased slightly and had values of approximately 1×1 mm.

3.3 X-ray spectra

In order to measure x-ray spectra, we employed a cadmium telluride detector (XR-100T, Amptek Inc.) (Fig. 4). When the tube voltage was increased, the characteristic x-ray intensities of Kα and Kβ lines substantially increased, and both the maximum photon energy and the intensities of bremsstrahlung x-rays increased.

4. K-edge Angiography

Cerium is a rare earth element and has a high reactivity; however, the average photon energies of Kα and Kβ lines are 34.6 and 39.2 keV, respectively, and iodine contrast media with a K-absorption edge of

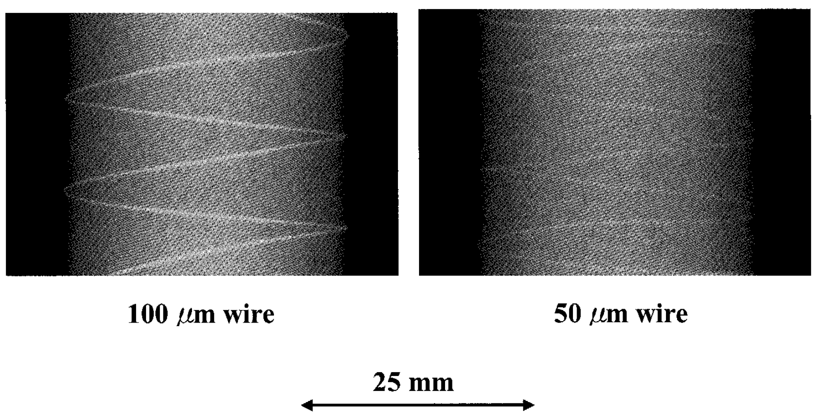

Fig. 5: Radiograms of tungsten wires coiled around PMMA rods.

33.2 keV absorb the lines easily. Therefore, blood vessels were observed with high contrasts.

The angiography was performed by the CR system[21] (Konica Regius 150) using the filter with a tube voltage of 60 kV, and the distance (between the x-ray source and the imaging plate) was 1.5 m. First, rough measurements of spatial resolution were made using wires. Figure 5 shows radiograms of tungsten wires coiled around rods made of polymethyl methacrylate. Although the image contrast decreased somewhat with decreases in the wire diameter, due to blurring of the image caused by the sampling pitch of 87.5 μm, a 50-μm-diameter wire could be observed.

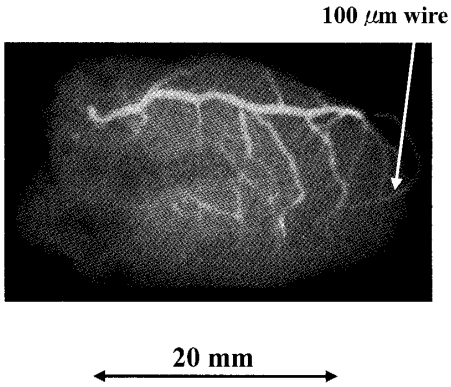

Fig. 6: Angiograms of an extracted rabbit heart using iodine microspheres.

An angiograms of a rabbit heart is shown in Fig. 6. This image was obtained using iodine microspheres of 15 μm in diameter. Fine blood vessels in the coronary arteries in the heart were visible. Figure 7 shows an angiogram of a larger dog heart using iodine spheres, and blood vessels of approximately 100 μm in diameter were visible.

5. Discussion

In summary, we employed an x-ray generator with a cerium-target tube and succeeded in producing cerium K-series characteristic x-rays, which can be absorbed easily by iodine-based contrast media. In the spectrum measurement, high-photon-energy bremsstrahlung x-rays beyond cerium K-edge (40.4 keV) were absorbed effectively.

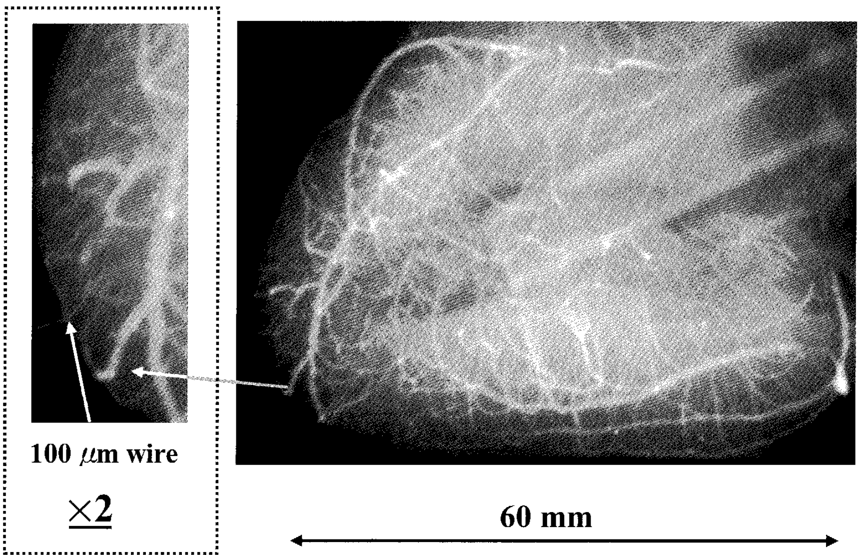

Fig. 7: Angiograms of an extracted dog heart using iodine microspheres.

In angiography, fine blood vessels were observed with high contrast with a spatial resolution of approximately 100 μm; the resolution was almost equal to the sampling pitch (87.5 mm) of the CR system. Therefore, the pith should be minimized, and magnification digital radiography including phase-contrast effect should be employed in order to improve the spatial resolution.

Although the cerium x-ray generator used in this research produces both the characteristic and the bremsstrahlung x-rays, bremsstrahlung intensity can be decreased effectively by considering the angle dependence without using the filter, since bremsstrahlung rays are not emitted in the opposite direction to that of electron trajectory. Subsequently, the generator produced maximum number of estimated characteristic photons was approximately 5×10^7 photons / ($cm^2 \cdot s$) at 1.0 m from the source, and the photon count rate can be increased easily by improving the target.

Acknowledgment

This work was supported by Grants-in-Aid for Scientific Research (13470154, 13877114, 16591181, and 16591222) and Advanced Medical Scientific Research from MECSST, Health and Labor Sciences Research Grants (RAMT-nano-001, RHGTEFB-genome-005 and RHGTEFB-saisei-003), Grants from the Keiryo Research Foundation, The Promotion and Mutual Aid Corporation for Private Schools of Japan, Japan Science and Technology Agency (JST), and The New Energy and Industrial Technology Development Organization (NEDO, Industrial Technology Research Grant Program in '03).

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