Design Concept of Fast Neutron Detectors using a CCD Cameras for Nondestructive Testing

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1. Introduction

Fast neutron radiography (FNR) has promise as a nondestructive inspection technique due to the excellent matter-penetration characteristics of fast neutrons. FNR is especially suitable than conventional thermal neutron radiography when applied object is thick or dense.

FNR system consists of three major components: neutron source, object and neutron detector [1]. The quality of radiographic image is affected by the results of each component. A fast neutron imaging detector system can consist of a scintillator, a mirror, an optical system, a charge-coupled device (CCD) camera and shielding structure. In the real-time FNR system, a silicon intensifier target (SIT) tube camera has been developed and tested [2]. The potential of a cooled CCD-detector system for these purposes depends on both its design and the experimental conditions, and has still to be investigated.

In this study, D-T reaction based sealed tube neutron generator manufactured in SODERN, France was used as fast neutron source, and neutron radiography system was built at Kyung-Hee University (KHU, Korea) [3].

The aim of this work was to investigate the issues concerned with the application of a cooled CCD-detector system for FNR under the condition of a sealed tube neutron generator.

2. Selection and Characterization of the CCD Detector Components

In the following section, the validity of cooled CCD camera was evaluated for FNR system, and the strategy of the selection of the individual components was described. In reality, careful selection of the components and their fine-tuning may gain up to a few orders of magnitude in sensitivity. A cooled CCD camera as neutron radiography detector has been developed [4]. The basic principle of this detector is shown in Fig. 1. The neutron beam reaches the neutron converter screen after penetrating the sample. Since the CCD chip would be damaged by neutron radiation, it is necessary to locate the camera outside of the direct neutron beam. Therefore, the light emitted from the converter screen is reflected to the camera by a mirror and focused on the CCD chip by a lens. These components are located in a light shielded housing together with shielding material to protect the cooled CCD camera from scattered neutron and γ-ray. The cooled CCD camera is connected to a computer to read out the information stored by the CCD chip and to reconstruct and process the digitized image data obtained with this imaging device.

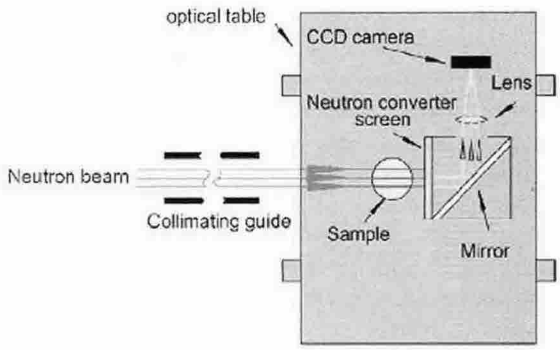

Figure 1. Schematic layout of a fast neutron imaging system with converter screen, mirror, optical system and CCD camera.

2.1 Fast Neutron Sensitive Scintillator Screen

The scintillator of type NAG glass made by the company Applied Scintillation Technologies (AST) was used in this study. [5] AST has developed and manufactures a variety of cerium activated lithium-free glass (NAG) scintillators for a wide range of applications. The NAG glass was specifically designed to have high sensitivity to fast neutrons of 14 MeV and low sensitivity to thermal neutrons and other radiations. Since NAG is provided as glass type and has opaque for its own light, thickness of glass is limited. This scintillator has its peak emission at 400 nm. The detection efficiency with fast neutron energy is in the order of about 1%. The Gamma sensitivity of the scintillator is between 30% and 50%. The effect of the after-glow as a disturbing effect for the following neutron radiographic image can be neglected for most applications.

2.2 Mirror and Lens

The scintillation light is mirrored via an optical quartz plate out of the neutron beam path and is collected by a camera lens. The demands of mirror used in FNR system are high reflectivity (90%) of the light emitted by the NAG scintillator and low generation of γ-ray as possible as from lasting activation of mirror materials. Therefore 1~2 mm thick glass plate coated with Al and with quartz as protecting layer was manufactured at Korea Atomic Energy Research Institute (KAERI). In order to obtain higher reflectivity over 95% for blue region, silver is better suitable than aluminum. Fig. 2 shows the mirror box configuration without scintillator and mirror.

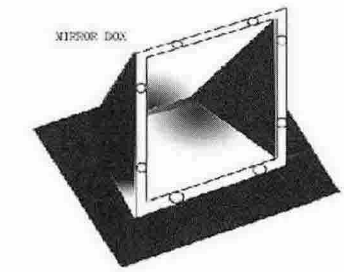

Figure 2. The configuration of mirror box.

Because light transmission should be maximized and imaging distortion has to be avoided, use of high quality lens is extremely important. The desired image size is (26× 26) μm^2. The available space beside facility is about 100 cm. Founded on boundary conditions, standard high quality photo lens of the company Nikon with an F/1.2 and a focal length of 50 mm was applied. In conclusion, even high magnification systems should be installed in lenses with low F-number and shorter focal length, with the camera as close as possible to the scintillator screen. As most camera lenses require a minimum distance of 100 cm for their built-in adjustable range to be effective, the system will require special distance holders with thickness up to several centimeters to vary the width between CCD-matrix and lens.

2.3 LN Cooled Digital CCD Camera

On a CCD chip, potential wells are formed below electrodes on the surface. Photo electrons are collected in these potential wells. On a classical CCD chip, the photons have to traverse these electrodes which usually consist of very thin aluminum layers. These electrodes are very transparent for blue light. On some CCDs, the sensitivity for 400 nm drops down to 4% quantum efficiency, while others reach 16%. So-called back-illuminated CCDs are etched thin down to 20 μm and are illuminated from the back side where no coating exists. They reach up to more than 80% efficiency for blue light. The CCD chip produces a certain amount of thermal noise, which ranges from several thousand electrons per second at room temperature down to less than one electron per hour at -120°C for liquid nitrogen cooled CCD camera made by Roper Scientific Incorporation.

The pixel array format of this chip is (1340× 1300) pixels with a pixel size of (26.8× 26) μm^2. The quantum efficiency of the LN cooled CCD camera is in the range of 84~94% for wavelengths from 350 to 800 nm. The high-precision CCD driver electronics provides 16 bit digitization (65535 gray levels). Figure 3 shows LN cooled CCD camera.

Figure 3. Imaging of Liquid Nitrogen cooled CCD camera

For the application at a sealed tube neutron generator, high speed exposures are necessary if the spectral information coded in the pulse duration is to be used. The scintillation light of the NAG glass typically decays to 10% in 1 ms without an after-glow and decay time of the BC-720 fast neutron detector manufactured by Bicron is 0.2 μs.

A big problem in all images taken with CCD camera is gamma rays that hit the CCD chip itself. Therefore, the CCD chip must be shielded against background gamma rays. The detection efficiency for gamma rays is low, but detected gammas form a local electron cascade which will cause a local overflow of the CCD chip and deliver white spots in the image.

3. Conclusion

The aim of this work was to investigate the issues concerned with the application of a cooled CCD-detector system for FNR under the condition of a sealed tube neutron generator. In the case of a sealed tube neutron generator, a point-like source emits neutrons isotropically. However, this condition increases additional background radiation. Proper shielding structure for detector is needed to eliminate the background and the CCD chip damage. Another problem is caused from scintillator which has very low detection efficiency of only 1~2% for fast neutron. For the future, it is required to study on a Monte Carlo simulation for the optical behavior of scintillation detectors in fast neutron imaging to improve detection efficiency.

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