Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

Design and Fabrication of Rotational Modulation Collimator (RMC) System for Gamma-Ray/Neutron Dual-Particle Imager

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1. Introduction

The demand of dual-particle imager is rapidly increasing, especially in the field of homeland security. As an attempt to develop radiation detection technology for the homeland security application, we plan to develop a fast and economical gamma-ray/neutron dual-particle imager based on the pulse shape discrimination (PSD) capable CLYC (Cs_2LiYCl_6:Ce) scintillation detector combined with the rotational modulation collimator (RMC) technique [1]. A RMC approach has a merit of unnecessariness of position-sensitive detectors. Therefore, it is relatively cheap and simple compared with other imaging techniques. The RMC system is mainly composed of collimator masks and a non-position-sensitive detector. When both collimator masks rotate, the open area made by two masks varies, and the number of particles which can be counted in the detector will change. Therefore, we obtain modulation patterns on the rotational angular domain of collimator masks. Using these modulation patterns, we can estimate information of radiation source distribution. In this study, we designed a CLYC-based RMC system based on Monte Carlo (MC) simulation and fabricated a dual-particle imager based on the RMC system.

2. Methods and Results

2.1 CLYC Scintillation Detector

For the development of dual-particle imager, we adopted a CLYC scintillation detector. CLYC shows excellent performance in the identification of gamma rays and neutrons using PSD. The detection of thermal neutron is based on the ^{6}Li(n,α)T reaction. In our system, the detector consists of a 2”×2” cylindrical CLYC crystal, coupled to a R6233-100 photomultiplier tube and signal processing electronics to perform PSD. The CLYC crystal is enriched to 95% in ^{6}Li, wrapped by Teflon, and enclosed in an aluminum casing. In previous study, we evaluated our CLYC detector using several gamma-ray sources and a ^{252}Cf neutron source. Absolute full-energy peak efficiency values were calculated by Mote Carlo N-Particle Version 6.1 (MCNP6) and the result was validated by measurement experiments [2, 3]. The CLYC detector showed an excellent performance as an effective tool for detecting both neutrons and gamma rays.

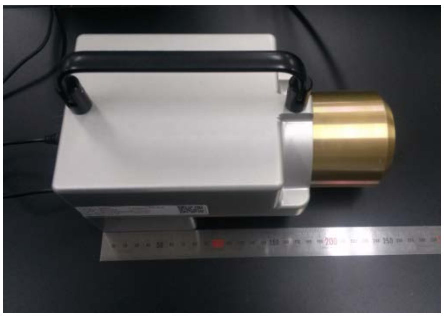

Fig. 1. CLYC scintillation detector.

2.2 Design of CLYC-based RMC System

We created a MC model for the design of CLYC-based RMC system using MCNP6 [4]. As a first step to develop the dual-particle imager, we employed a previously-studied slit design for the collimator masks [5]. Fig. 2 shows a schematic of CLYC-based RMC and slit patterns for the collimator mask.

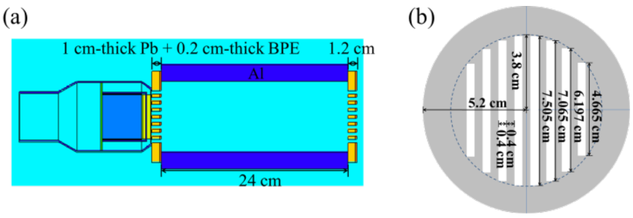

Fig. 2. RMC-based CLYC system: (a) RMC system geometry for MCNP6 and (b) slit pattern for the collimator mask.

In the simulation, we assumed a point source of 356 keV gamma ray and set the source position at (10 cm, 10 cm, 200 cm) from the center of the front mask face (0 cm, 0 cm, 0 cm). We simulated 1×10^8 particle histories at each rotation condition with 1° interval. The gamma response of the detector was calculated by the pulse height tally (F8) in MCNP6.

We obtained modulation patterns using MC model, as shown in Fig. 3. Modulation patterns show numbers of incident radiation particles that was transmitted through the collimator masks and detected in the CLYC at each rotation angle of the masks. The modulation pattern is used to reconstruct the image of radiation source, so that we can estimate the actual position of the radiation source.

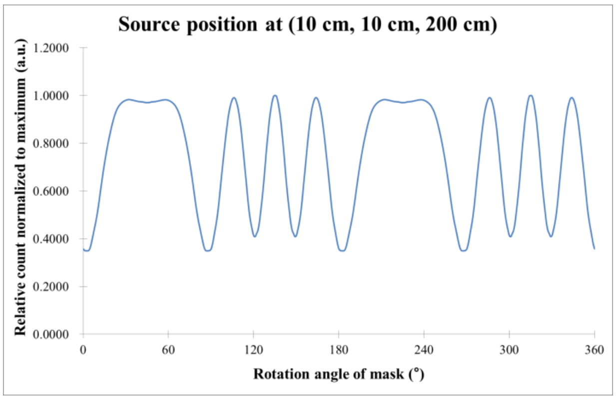

Fig. 3. A modulation pattern of 356 keV gamma rays: source position at (10 cm, 10 cm, 200 cm). (0 cm, 0 cm, 0 cm) is set to be the rotation axis of the front mask face.

2.3 Fabrication of the RMC System

The RMC system fabricated according to our MC studies is shown in Fig. 4. The RMC system consists of an aluminum outer frame, a driver tube, collimator masks, a timing pulley/belt, a stepper motor and a CLYC detector. A timing pulley and belt are mounted onto the driver tube which is used to transfer power from the stepper motor to collimator masks and rotates the RMC. The detector mount was designed to align center of the detector to the center of the collimator mask. For collimator masks, we designed a laminated structure which combines a 1 cm-thick lead mask and a 0.2 cm-thick borated polyethylene (BPE) mask to maximize the shielding efficiency for gamma rays and neutrons. As a result of MCNP6 simulations, the shielding efficiency of the 1 cm-thick Pb mask was estimated to be 95.20% for 356 keV gamma rays, and the shielding efficiency for thermal neutron was estimated to be 100% when 0.2 cm-thick BPE was used.

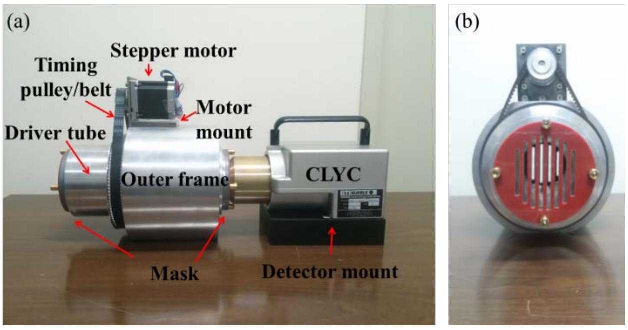

Fig. 4. CLYC-based RMC system: (a) side and (b) front view.

To rotate and control RMC, we used a QSH 6018-86-28-310 stepper motor. We designed a timing pulley with the conversion factor from the motor pulley to the driver tube pulley of 4.5 to 1. That is, the motor pulley rotates 4.5° to rotate the RMC 1°. The stepper motor is controlled by an Arduino board with a DRV8880 motor driver which is capable of micro stepping with the minimum limit of 0.025° per step.

For circuit protection and easy control of RMC, we developed a RMC control console as shown in Fig. 5. Using a toggle switch, we can select a rotation interval of collimator masks. The first mode is used for the alignment of mask slits which has an interval less than 1°, and the second mode is used for the measurement experiment with an interval larger than 1°. We can also select the rotational direction using a tact switch, either to the clockwise or to the counterclockwise directions.

We plan to perform measurement experiments to obtain modulation patterns and implement the maximum-likelihood expectation-maximization (MLEM) method to reconstruct a radiation image from the modulation pattern. Further studies on developing a dual-particle radiation imager will be performed on the basis of the result we obtained in this study.

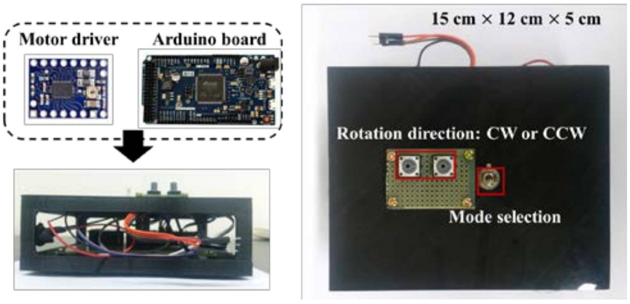

Fig. 5. A console developed for RMC control.

3. Conclusions

We demonstrated the design of CLYC-based RMC system and fabrication process for the dual-particle imager. The CLYC-based RMC system can compensate shortcomings of radiation imagers based on the detection of only-one type of particles. It can be extensively utilized for many applications in the field of radiation safety and homeland security.

REFERENCES

[1] H.S. Kim, H.Y. Choi, G. Lee, S.J. Ye and G. Kim, Monte Carlo Simulation of Rotational Modulation Collimator (RMC) Patterns for the Gamma-Ray/Neutron Dual-Particle Imager, in Conf. Rec. 2015 IEEE NSS/MIC/RTSD, San Diego, USA. 2015.

[2] H.S. Kim, M.B. Smith, M.R. Koslowsky, S.W. Kwak, S.J. Ye and G. Kim, Characterization of a CLYC Detector and Validation of the Monte Carlo Simulation by Measurement Experiments, Journal of Radiation Protection and Research, to be published.

[3] D. B. Pelowitz, MCNP6^{TM} user's manual Version 1.0, Los Alamos National Laboratory, Los Alamos, NM, LA-CP-13-00634, 2013.

[4] H.S. Kim, Y. Shin, G. Lee, S.J. Ye and G. Kim, Radiation imaging with rotational modulation collimator (RMC) coupled to a Cs_2LiYCl_6:Ce (CLYC) detector, Journal of Korean Physics Society, Vol. 69, pp.1644-1650. 2016.

[5] B.R. Kowash and D.K.Wehe, A unified near-and far-field imaging model for rotating modulation collimators, Nuclear Instruments and Methods in Physics Research Section A, Vol. 637, pp. 178-184, 2011.