Development and Optimization of Backscatter X-ray detection system Based on Pencil Beam Scanning

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1. Introduction

With the increase of trade volume, the demand for fast and accurate non-invasive security screening is increasing. Currently, most of the container and baggage detection systems in the Korea Customs Service are composed of foreign products. Therefore, it is necessary to develop an X-ray detection system based on domestic technology.

The backscatter X-ray detection system makes an image by detecting scattered particles by Compton scattering in opposite directions (130˚ ~ 180 ˚) of an object. This system has the advantage of detecting drugs or explosives composed of organic substances different from the transmission X-ray system. In addition, unlike the transmission X-ray system, there is an advantage in that the surface information of an object can be imaged.

The pencil beam-based backscatter X-ray detection system consists of an X-ray generator, a rotating collimator, and large-area detectors. In this study, we aim to backscatter X-ray detection system by developing a DAQ system, the decision of scintillator and Photo Multiplier Tube (PMT), and housing of the detection system.

2. Methods

2.1 Detection system modeling

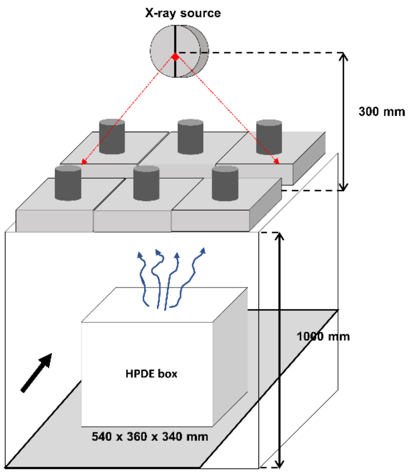

Fig 1. Schematic view of backscatter X-ray detection system.

Figure 1 is a schematic view of backscatter X-ray detection system. With the conventional X-ray tube structure, the target material is tungsten which is 2 mm thickness. The X-ray energy is 160 keV and the angle is 10˚. The scintillator is determined PVT which is long-term stable and low-temperature change dependent widely used in large area detectors.

2.2 Decision of scintillator parameter

To determine the dimension of the PVT, the parameters were decided through Monte Carlo N-Particle (MCNP) version 6. The parameters of scintillator length and distance between scintillators are calculated by absorbing in scintillators among backscattered particles. The parameter of scintillator thickness is calculated by the flux of backscattered particles.

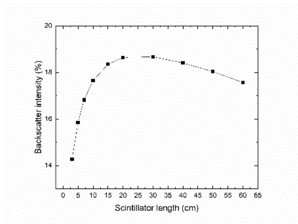

Fig 2. Intensity of backscattered particles according to scintillator length.

In consideration of the tunnel size of the conveyor belt, the x-length of scintillators is fixed to 200 mm. There is no gain after 200 mm of y-length of scintillators.

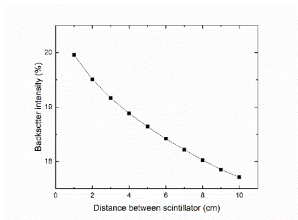

Fig 3. Intensity of backscattered particles according to the distance between scintillators.

We determined that 50 mm is appropriate for the distance between the scintillators, considering the backscatter intensity, housing of the detection system, and whole geometry of the X-ray tube and detection system.

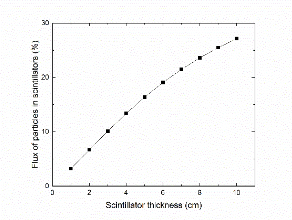

Fig 4. Flux of backscattered particles in scintillators according to scintillator thickness.

As the thickness of the scintillator increases, the number of particles absorbed will increase as shown in Fig 4. However, because the weight of the detection system is also important, the thickness is determined to be 50 mm.

2.3 DAQ system

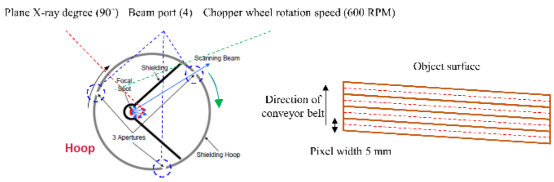

Fig 5. Schematic design of imaging backscatter X-ray system.

Chop per wheel Rotation speed (RPM)	Chop per wheel Rotation speed per second (s)	Beam port	Number of data (parameter)	Number of total data per second	Time to process a data (us)
600	10	4	500	2000	50

Table 1. Condition of the DAQ system for imaging

The system of the X-ray generator is as follows in Fig 5. The plane X-ray is made through a collimator (approximately 5 mm) and the pencil beam is made as the plane X-ray pass through four small port in the chopper wheel. The rotation speed of the chopper wheel is 600 RPM. Assuming that 500 data are obtained per scan of one line, the total data is 20,000, and the time it takes to obtain one data is 50 us. The DAQ system was developed to save data obtained per 50 us.

3. Result

3.1 Schematic design of detection system

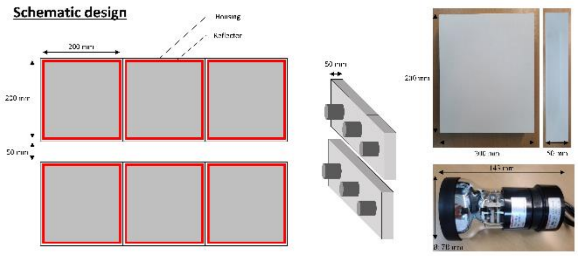

Fig 6. Schematic design of detection system

In Figure 6, the scintillator is determined by EJ-200 200 x 200 x 50 mm^3 from ELJEN. The PMT is determined by 3-inch R6233 from HAMAMATSU.

3.2 Housing of detection system

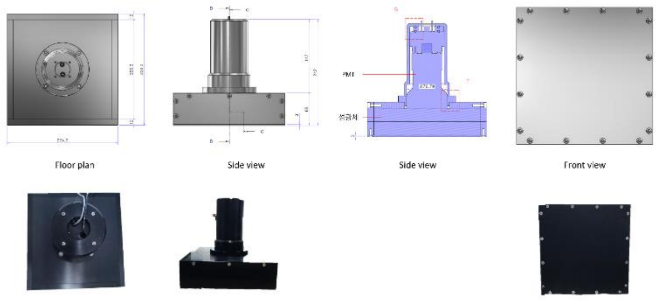

Fig 7. Blueprint of housing

The housing of the detection system and the front of the scintillator are made of 12 mm and 3 mm thick aluminum, respectively.

3.3 DAQ and High voltage power supply board

Fig 8. (a) The DAQ system and (b) the high voltage power supply board

In figure 8, the 6ch DAQ system and the 6ch high voltage power supply board are made. The 6ch DAQ system stores data acquired for 50 us as 8 bytes. The high voltage power supply board can supply power from 0 to 1600 V by adjusting resistance or using Arduino.

4. Conclusion

In this study, we aim to develop a detection system to make backscatter X-ray images. the scintillator is determined by EJ-200 200 x 200 x 50 mm^3 from ELJEN. The PMT is determined by 3-inch R6233 from HAMAMATSU. The DAQ system can store data acquired for 50 us by 8 bytes and also obtain the spectrum. In further works, we evaluate the performance of the detection system using check sources and progress the experiments in an environment where X-ray is irradiated to obtain backscatter X-ray images.

REFERENCES

[1] Siciliano, E. R., Ely, J. H., Kouzes, R. T., Milbrath, B. D., Schweppe, J. E., & Stromswold, D. C. (2005). Comparison of PVT and NaI(Tl) scintillators for vehicle portal monitor applications. *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *550*(3). https://doi.org/10.1016/j.nima.2005.05.056

[2] Akkurt, I., Gunoglu, K., & Arda, S. S. (2014). Detection efficiency of NaI(Tl) detector in 511-1332 keV energy range. *Science and Technology of Nuclear Installations*, *2014*. https://doi.org/10.1155/2014/186798

[3] Verevkin, A., Zhang, J., Sobolewski, R., Lipatov, A., Okunev, O., Chulkova, G., Korneev, A., Smirnov, K., Gol'tsman, G. N., & Semenov, A. (2002). Detection efficiency of large-active-area NbN single-photon superconducting detectors in the ultraviolet to near-infrared range. *Applied Physics Letters*, *80*(25), 4687–4689. https://doi.org/10.1063/1.1487924

[4] Akkurt, I., Tekin, H. O., & Mesbahi, A. (2015). Calculation of Detection Efficiency for the Gamma Detector using MCNPX. *Acta Physica Polonica A*, *128*(2), 332–334. https://doi.org/10.12693/APhysPolA.128.B-332

[5] Jackson, T., Hollenbach, D., & Shedlock, D. (2011). Investigation of backscatter x-ray imaging techniques for uranium dioxide fuel rods. *Research in Nondestructive Evaluation*, *22*(4), 231–247. https://doi.org/10.1080/09349847.2011.623218

[6] Siciliano, E. R., Ely, J. H., Kouzes, R. T., Milbrath, B. D., Schweppe, J. E., & Stromswold, D. C. (2005). Comparison of PVT and NaI(Tl) scintillators for vehicle portal monitor applications. *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *550*(3), 647–674. https://doi.org/10.1016/j.nima.2005.05.056