Nuclear Instruments and Methods in Physics Research A 797 (2015) 1–7

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

# Gamma-ray inspection of rotating object

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ARTICLE INFO

*Article history:*
Received 30 January 2015
Received in revised form
8 May 2015
Accepted 14 June 2015
Available online 20 June 2015

*Keywords:*
Radiotracer
Positron emission tomography
ML-EM algorithm
Image reconstruction
Rotating object

ABSTRACT

We develop a method to diagnose two-dimensional distribution of positron-emitting radioactivity in a rotating object through γ-ray coincidence measurements with two detectors. The principle of this method is same as PET but the measurement system is much simpler. We have constructed a prototype and performed tests with point-like and plate-shaped radioactive sources. The image reconstruction with ML-EM algorithm reproduced the distribution. It can be useful for radiotracer measurements of slow transport processes of materials in a closed system and can find applications in mechanical engineering.



## 1. Introduction

Radioisotopes (RIs) have long been used as tracers in many fields. In biology and medicine, radiotracers are used to study the transport and accumulation of specific elements or chemical compounds in living bodies. Imaging technologies such as positron emission tomography (PET) [1] or single-photon emission computerized tomography (SPECT) have been developed and utilized for non-invasive examination in hospitals. Radiotracers are also used in various fields of industry, which require real-time measurements of distribution of matter in closed systems like machines or plants without stopping the system. In such diagnoses, a radiotracer is added to the object material and the time dependence of the γ-ray intensity is monitored from outside. For example, the flow and mixing of fluids like gas, liquid or powder are measured in petroleum, chemical and mineral-processing industries[2,3], where radiotracers are injected to the fluid and monitored at downstream by radiation detectors. On the other hand, thin-layer activation (TLA) method is employed for diagnosis of wear or corrosion of solid materials of machine parts or piping, where a thin layer of the surface of the object is activated and the removal rate of the surface is determined by the measurement of the radioactivity [4,5].

In most of the industrial applications, the transfer of the radiotracers are monitored through the time dependence of the radiation intensity measured by detectors fixed at proper positions. If the time-dependent spatial distribution of the radioactivity is visualized by tomography methods like gamma camera, SPECT [3] and PET [6], it would be possible to obtain more details of the dynamical processes in the closed system.

We develop a new method to determine two-dimensional spatial distribution of positron-emitting RIs on rotating objects [7]. It is based on the same principle as medical PET systems but is simpler and less expensive. It would be useful in some industrial applications such as wear diagnostics of rotating parts in a machine. In Section 6, we discuss possibility to combine it with a new method of TLA with RI-beam implantation[8].

## 2. Method

A significant part of nuclear $\beta^+$ decay in matter is followed by emissions of two 511-keV γ-ray photons in almost opposite directions. If the positron is annihilated on a line connecting two γ-ray detectors (Line Of Response: LOR), these photons can be detected in coincidence. Collecting coincidence events on various LORs in different orientations, the spatial distribution of the radiotracer can be reconstructed. In conventional PET, the object of diagnosis is at rest, surrounded by hundreds of γ-ray detectors and a pair of detectors which capture 511-keV photons in coincidence determine an LOR.

In our method, two γ-ray detectors that determine an LOR are placed on both sides of the object of diagnosis with radiotracer.

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http://dx.doi.org/10.1016/j.nima.2015.06.023
0168-9002/

The object continuously rotates and the detectors move in parallel relative to the rotation center so that the LOR scans the object in all directions.

Fig. 1 shows the geometrical concept of an example where a point RI source is fixed on a continuously rotating disk. A Cartesian coordinate $(X,Y)$ is fixed to space and $(x,y)$ is fixed to the disk with the origins of both at the center of the rotation. The position of the source is $(r,\theta)$ in the polar coordinate fixed to the disk. A pair of collimated γ-ray detectors on both sides of the disk determine the LOR on a line $X=s$. The detectors move back and forth in one body relative to the disk along the $X$-axis so that the LOR continuously scans the disk. Equivalently, the detectors may be fixed whereas the disk moves back and forth. In this case, the Cartesian coordinate $(X,Y)$ is not fixed but moves back and forth with the rotation center of the disk.

The condition of coincidence detection of the two photons is expressed by an equation

$$s = r\cos(\theta+\phi), \quad (1)$$

where $\phi$, the angle of the $x$-axis from the $X$-axis, shows the orientation of the disk. Therefore $r$ and $\theta$ are fixed whereas $s$ and $\phi$ change with time. When $\phi$ and $s$ are scanned, the coincidence events from a point source fall on a sinusoidal curve in the $\phi$–$s$ plane, as shown in Fig. 2.

The sinusoidal curve represents the position of the source: its amplitude is equal to $r$ and the angle $\phi$ at the maximum $s$ is equal to $-\theta$. The $\phi$–$s$ plot of the coincidence event rate distribution is called sinogram.

For multiple point sources, the sinogram consists of multiple sinusoidal curves and if the source has a two-dimensional distribution on the disk, the corresponding sinogram is a superposition of sinusoidal curves weighted by the radioactivity distribution. Conversely, when a sinogram is given, the two-dimensional spatial distribution of the source can be reconstructed. Therefore, with only two detectors, the RI distribution on a continuously rotating object can be inspected, if $s$ and $\phi$ at the time of coincidence detection are determined.

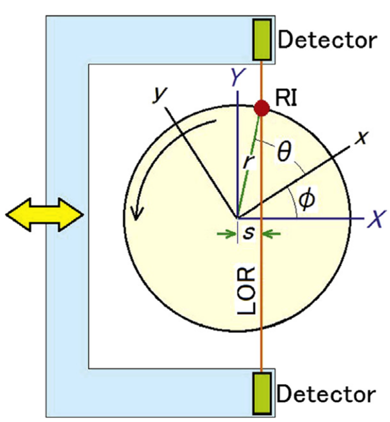


**Fig. 1.** Geometrical concept. The two detectors move as one body in $X$-direction.

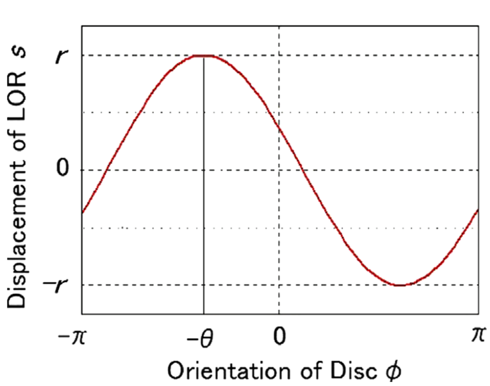


**Fig. 2.** Sinogram for one point source.

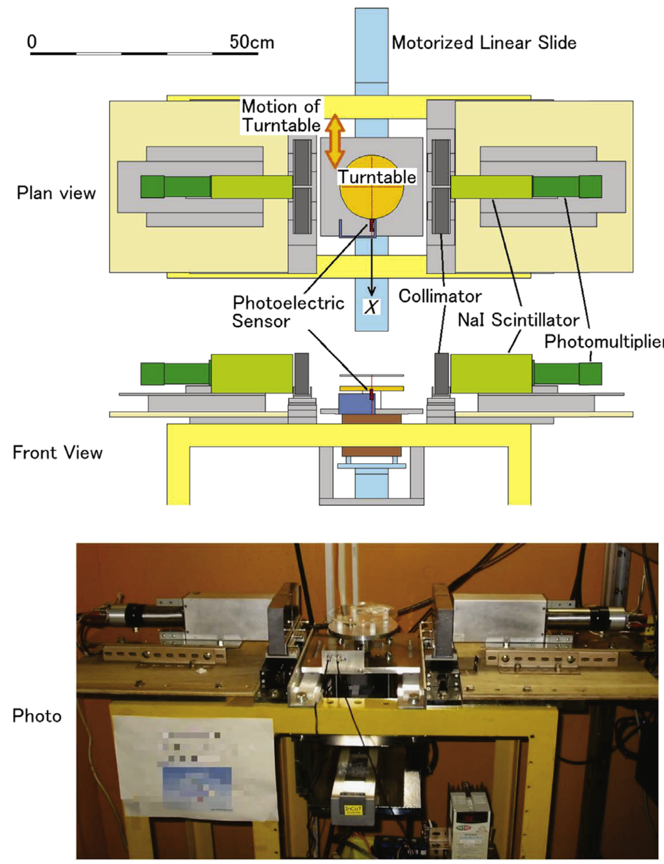


**Fig. 3.** The setup (upper) and photograph (lower) of the prototype.

## 3. Prototype

In order to prove the feasibility of the method, we have constructed a prototype. Fig. 3 shows the setup (upper) and the photograph (lower). A turntable with a diameter of 14 cm holds RI sources. The turntable is a plastic disk supported by plastic pillars so that the attenuation of γ rays is minimized. A pair of rectangular-shaped NaI-scintillator detectors (Saint Gobain Crystals and Detectors, 1.77 × 3.15H6.3/1.5L-X, 45 mm wide, 80 mm high and 160 mm deep) are placed on either side of the turntable opposite to each other. A pair of 3-cm thick Pb blocks are placed in front of each detector to form a vertical aperture for a γ-ray collimation. The center lines of the scintillators and the apertures of the collimators are aligned to a common line which determines the LOR.

In order to scan the turntable with LOR, the rotating turntable is mounted on a motorized linear slide and moves back and forth perpendicular to the LOR between the NaI detectors. The displacement of the LOR relative to the center, $s$, is changed stepwise between −70 mm and 70 mm. For the measurement of the orientation of turntable $\phi$, a timing pin fixed to the turntable passes once per a turn through a photosensor fixed near the edge of the turntable. A timing pulse from the photosensor resets a clock-pulse scaler and the angle $\phi$ at the time of coincidence detection is deduced from the clock-pulse count.